Annual Report to the
Tennessee Higher Education Commission
Fiscal Year 2016-2017

October 24, 2017

Submitted by
Vice Chancellor for Research, Dr. Joanne Romagni
(423)425-4478 (ph.) / Joanne-Romagni@utc.edu

CEACSE Chair of Excellence, Dr. Anthony Skjellum
(423) 425-5493 (ph.) / Tony-Skjellum@utc.edu

University of Tennessee at Chattanooga
615 McCallie Avenue, Dept. 5305
Chattanooga, TN 37403-2598
University of Tennessee at Chattanooga

Center of Excellence in Applied Computational Science and Engineering

MISSION STATEMENT

To establish, expand and sustain a cohesive multidisciplinary effort in applied computational sciences leveraged across UTC to produce sustained growth in research funding, excellence in integrated education and research, growing numbers of PhD graduates in these applied areas, and to increase national and international stature and competitiveness in Tennessee.

VISION STATEMENT

UTC’s cohesive multidisciplinary effort in applied computational sciences is recognized for its contributions to the community, the state of Tennessee, the region, and our nation for its solution of problems of importance to society, including the creation of useful inventions based on the applied science and engineering research. Participating UTC’s undergraduate and graduate students graduate to become knowledge workers who contribute routinely through their specialized training to their community, state, region, and nation.
**EXECUTIVE SUMMARY**

UTC's Center of Excellence in Applied Computational Science and Engineering (CEACSE) has embarked on its second decade of invigorating scientific inquiry, bolstering the learning environment, broadening participation, and establishing sustainable research pathways that benefit our institution, faculty and students, and the State of Tennessee. With our previous report for FY2016, CEACSE marked its eleventh year growing UTC's first Center of Excellence into a critically important incubator for inquiry and experimentation across a diverse array of computational science and engineering endeavors. This report for FY2017 follows up our previous report (FY2016) with CEACSE’s focused priority areas, highlights the maturation of its visionary leadership team, and notes greater impacts across a range of stakeholder groups. *CEACSE comprises the indispensible factor that enables UTC to recruit, retain, and engage outstanding professors and equally outstanding students through research experiences for undergraduates up to and including our PhD students.*

CEACSE research and advanced development activities enhance education at all academic levels at UTC including through the Ph.D. program in Computational Science. Graduate and undergraduate students alike participate in various research activities undertaken as a result of current and prior CEACSE funding. Companies in our community and region continue to have growing interest in the educational programs impacted by CEACSE initiatives in large measure because of the applied R&D supported by CEACSE. In the current year, SimCenter and the College of Engineering and Computer Science (CECS) are broadening efforts to partner with companies in the Chattanooga region and beyond. Because of increasing capabilities in high-performance computing and the growing importance of modeling, simulation, and advanced computing in research and education, the efforts and outcomes of our researchers and their students will continue to serve as research anchors attracting students from across the nation and internationally. These students represent a valuable contribution to the future workforce of knowledge workers for the community and the state of Tennessee.

The high-performance computing (HPC) capabilities associated with the new UTC heterogeneous GPU-enabled cluster (a high-end, 33-node, 64-bit Intel-architecture cluster with NVIDIA P100 GP-GPUs) were important differentiators leading to key programmatic accomplishments in FY2017 including:

- Securing extramural support for modeling and simulation of turbomachinery as a result of CEACSE investment –Webster's, Sreenivas', and Tanis' proposal to HPCMP PETTT\(^1\) entitled “Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains” was funded with Engility Corporation at $421,997 over two years, commencing October 2017.
- Securing extramural support for a new joint project of an approximately $900,000 budget for UTC over three years with the University of Dayton Research Institute

\(^1\) **Department of Defense (DoD) HPCMP User Productivity Enhancement, Technology Transfer, and Training**
UDRI, Purdue University, the University of Tennessee Space Institute (UTSI), and the University of Tennessee at Knoxville (UTK) to model and simulate critically important multi-physics processes associated with hypersonic flight with the objective to design reusable hypersonic vehicle structures. This award is pending release of the FY2018 federal budget.

• A successful live demonstration by UTC researchers led by Dr. Sartipi of connected autonomous vehicles during the June US Ignite Application Summit and Smart Cities Connect Conference in Austin, TX, was using the UTC HPC capabilities developed by CEACSE (see https://youtu.be/-cHoB-FYam0).

• A second US Ignite Grant was awarded to Dr. Dalei Wu, as noted in his report: $299,884 over the period of January 2017-December 2019. Dr. Sartipi was the first US Ignite awardee at UTC some months earlier.

Important technical advancements achieved in FY2017 include these highlights:

• The Reising/Sartipi/Loveless project for “Smarter Buildings Through Smarter Models” is now moving to experimental validation using the Building Efficiency Facility at Oak Ridge National Laboratory (ORNL).

• The Tenasi structured code project led by Dr. Arabshahi for hypersonic flow was tested and advanced to support realistic geometries up to higher Mach numbers than previously possible, while achieving good agreement with experiment.

• Refactoring of the FUNSAFE FORTRAN-based CFD application to C++ with the additional capability of using GP-GPU offload (with successful testing and validation on the new cluster).

• As a contribution both to Urban Studies and Health, a prototype of a potential tool for urban planners was created by Heath et al that can be used to maintain/build good/safe road/street networks and urban facilities to support active transportation and physical activities among residents. Their models assessing the impact of increased exposure to dedicated transport/recreation sidewalks/bike paths demonstrated a decrease in physical inactivity among adult residents in Chattanooga by a range of 25% to 50%, with a corresponding decrease in chronic diseases and their associated costs by as much as $1.2M over a project 4-year period, thus providing evidence for a return-on-investment for constructing such sidewalk/pathways.

Additionally, the new cluster is instrumental in the work of faculty recruited during FY2017 and beyond, including High Performance Computing research conducted by the new SimCenter Director, Dr. Tony Skjellum. The cluster is a key local investment that enables leveraged access to remote facilities at much larger scales by supporting proofs-of-principle and key findings ahead of further scale-up and scale-out on leadership class machines available through NSF XSEDE, and through DOE (such as Oak Ridge National Laboratory), among others. It is therefore expected to be of great use during its several years of remaining useful life as an enabling scalable computing platform. And, it has current added benefits for teaching modeling, simulation, and high performance computing apart from its primary research functions.
In collaboration, CECS, SimCenter, and the Office of the Vice Chancellor for Research foster a rapidly expanding and enhancing culture of securing external funding as an outcome of seed research funding provided by CEACSE. We recognize the challenges for faculty to excel in attracting extramural funding while meeting all aspects of meritorious scholarship. We provide support through the Office of Research and Sponsored Programs (ORSP), through focus on opportunities that are designed to lead to larger funding awards, and through development of strategic partnerships. CEACSE is emerging as the nexus of research incubation, high performance computing and data science, as well a key provider of faculty resources that complement and supplement ORSP’s offerings and add to those of faculty home departments.

This document constitutes the Annual Report for Fiscal Year 2017 of CEACSE activities and efforts. On behalf of the University of Tennessee at Chattanooga, the SimCenter, the College of Engineering and Computer Science, our community partners and stakeholders, as well as our CEACSE-funded scientists and students, we express our deep appreciation to THEC for this critically important support of the CEACSE.
<table>
<thead>
<tr>
<th>Table of Contents</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission Statement</td>
<td>i</td>
</tr>
<tr>
<td>Vision Statement</td>
<td>i</td>
</tr>
<tr>
<td>Executive Summary</td>
<td>ii</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>iv</td>
</tr>
<tr>
<td>Faculty &amp; Staff</td>
<td>1</td>
</tr>
<tr>
<td>Students</td>
<td>11</td>
</tr>
<tr>
<td>Program Overview &amp; Accomplishments</td>
<td>16</td>
</tr>
<tr>
<td>Goals &amp; Future Plans</td>
<td>32</td>
</tr>
<tr>
<td>Budget – Schedule 7</td>
<td>38</td>
</tr>
<tr>
<td>Publications</td>
<td>42</td>
</tr>
<tr>
<td>External Funding (Grants &amp; Contracts)</td>
<td>46</td>
</tr>
<tr>
<td>Conclusion</td>
<td>55</td>
</tr>
<tr>
<td>Contact Information</td>
<td>56</td>
</tr>
<tr>
<td>Appendix A – Faculty Biosketches</td>
<td>60</td>
</tr>
<tr>
<td>Appendix B – Project Reports</td>
<td>96</td>
</tr>
</tbody>
</table>
FACULTY & STAFF

The Center for Excellence in Applied Computational Science and Engineering benefits from institutional leadership who are deeply committed to enriching and expanding computational science as a research area and an enabler of innovative research across academic departments. The THEC Chair of Excellence is Dr. Tony Skjellum who joined the campus in August 2017. Please see the Contact Information section for details and biosketches for leadership personnel.

CEACSE FY2017 Awardees
The following faculty and staff were integral to the strategic direction of CEACSE during the 2016-17 competition cycle. As noted below, these individual served as a Lead PI and/or Co-Investigator on projects that advanced the CEACSE mission and vision. Biosketches have been added for all faculty in Appendix A.

Dr. Abi Arabshahi
Lead PI: Computational Simulations of the Aerothermal Environment of Hypersonic Fight Vehicles, Numerical Simulation of Airflow in the Small Human Airways

Dr. Arabshahi is a Research Professor in the Mechanical Engineering Department / SimCenter. He received a B.S. (1982) in Civil Engineering and an M.S. (1985) and a Ph.D. (1989) in Aerospace Engineering from the Mississippi State University. His research interest includes computational fluid dynamics, unsteady viscous flow applications, structured and unstructured grid technologies, autonomous underwater vehicles, internal and external aerodynamics and hydrodynamics and computational bio-fluid dynamics. He has authored papers on these areas in refereed journals, conferences and symposiums. He actively involves students into his research. Dr. Arabshahi’s expertise in aerodynamic simulations has been instrumental for several projects in this award cycle. Please refer to Dr. Arabshahi’s biosketch in Appendix A.
Dr. Trevor Elliott

Lead PI: *Investigation of Resources and Planning for Advanced Manufacturing Applications Center (AMAC) at UT Chattanooga*

Trevor S. Elliott is an Assistant Professor of Mechanical Engineering at the University of Tennessee at Chattanooga (UTC). He is an active member of the American Institute of Aeronautics and Astronautics (AIAA) Hybrid Rocket Technical Committee (HRTC) and is currently serving as Co-Technical Area Organizer (TAO) for the International AIAA Joint Propulsion Conference (JPC). At UTC he serves as Faculty Advisor for the UTC Racing Mocs Baja SAE competition teams, Hardware Counselor for the Chattanooga Student Chapter of IEEE, and Faculty Advisor for the Students for the Exploration and Development of Space (SEDS) competition teams. His research interests include Additive Manufacturing, Alternative Energy, Automotive Design, Combustion Stability, Compressible Flow, Data Analytics, Engineering Design, Fluid Mechanics, Propulsion, Smart Control, Spectral Theory, and Turbomachinery. He actively involves students with his research through design projects, funded research projects, and departmental honors projects. He has authored papers on the above areas in refereed journal and conference proceedings. He is also a reviewer for the International Journal of Energetic Materials and Chemical Propulsion (IJEMCP) and AIAA manuscripts. He holds Lifetime membership with the AIAA, the American Society of Mechanical Engineers (ASME), and the Association for Computing Machinery (ACM). Please see Dr. Elliot’s biosketch in Appendix A.

Dr. Gregory Heath

Lead PI: *Intelligent Urban Planning*

Gregory W. Heath is the Assistant Vice Chancellor for Research, Guerry Professor of Health and Human Performance, and also serves as Director of Research at the University of Tennessee College of Medicine, Chattanooga. Dr. Heath was formerly with the Division of Nutrition, Physical Activity, and Obesity at the U.S. Centers for Disease Control and Prevention (CDC), where he spent over 20 years initially starting as an Epidemic Intelligence Service (EIS) Officer. He has a background in physiology, nutrition, and epidemiology and holds both his masters and doctoral degrees from Loma Linda University School of Public Health in California. Dr. Heath has spent most of his professional career devoted to the understanding and promotion of physical activity and exercise for the enhancement of health as well as the prevention and management of chronic diseases. He is widely published in the preventive medicine and public health literature. Dr. Heath is a fellow in the American College of Sports Medicine (ACSM) and the American Heart Association’s Council on Epidemiology. Please see Dr. Heath’s biosketch in Appendix A.
**Dr. Farah Kandah**

**Lead PI:** Quality of Service Assurance Using GENI, A Robust Network Design in Cognitive Radio Networks

**Co-Investigator:** Multiscale Serviceability Analysis and Assessment of Urban Infrastructure

Dr. Farah Kandah is a UC Foundation Assistant Professor in the Department of Computer Science and Engineering at the University of Tennessee, Chattanooga, TN. He earned his Ph.D. from the Computer Science department at North Dakota State University, Fargo, ND. He received his M.Sc. from the Computer Science Department at the University of Jordan. He has been serving on the technical committee or organization committee of many internationally reputable conferences, such as CHINACOM, IEEE GLOBECOM, and IEEE WCNC. His research interests and experience span a wide range of topics in computer networks from stationary wireless/wired networks to mobile ad-hoc networks, including Security and Privacy as well as performance optimization in Wireless Networks, Software Defined Networks and Cloud Computing. He has multiple publications in multiple internationally reputable journals and conferences including; WILEY Security and Communication Networks (SCN) journal, ACM/Springer Mobile Networks & Applications (MONET) journal, IEEE Global Telecommunications Conference (IEEE GLOBECOM) and IEEE International Conference on Communications (IEEE ICC). Please see Dr. Kandah’s biosketch in Appendix A.

---

**Dr. Joseph Kizza**

**Lead PI:** Trust Propagation and Distrust in Web of Trust and Airborne Networks Authentication

**Co-Investigator:** Multiscale Serviceability Analysis and Assessment of Urban Infrastructure

Dr. Joseph M. Kizza is a Professor and Head of the Department of Computer Science and Engineering at the University of Tennessee at Chattanooga (UTC). He is on editorial boards of half a dozen scholarly journals and Editor-in-Chief of the International Journal of Computing and ICT Research (IJCIR). He is an internationally known speaker on social computing and information security and assurance and has published extensively in journals and conference proceedings including more than ten books on computer ethics, network security and cyber ethics. Some of these books have been translated into several languages including Japanese and Chinese. He is a member of ACM. Please see Dr. Kizza’s biosketch in Appendix A.
Dr. Yu Liang
Co-Investigator: Multiscale Serviceability Analysis and Assessment of Urban Infrastructure

Dr. Yu Liang is an Associate Professor in the Department of Computer Science and Engineering of University of Tennessee at Chattanooga as. His funded research projects cover the following areas: big-data and cloud computing, multiscale modeling and simulation, high-performance scientific and engineering computing, numerical linear algebra, sensor-oriented machine learning, computational mechanics (with focus on structural mechanics and biomechanics), and fault-tolerance techniques. His research work has appeared in various prestigious journals, book or book chapters, and refereed conference, workshop, and symposium proceedings. He owns one technical pattern that is registered at Univ. of Tennessee Research Foundation (UTRF). Dr. Liang is serving in the International Journal of Security Technology for Smart Device (IJSTSD), Journal of Mathematical Research and Applications (JMRA), and Current Advances in Mathematics (CAM) as an editorial board member. Please refer to Dr. Liang’s biosketch in Appendix A.

Dr. Daniel Loveless
Lead PI: Modeling Space and Defense Environmental Effects in Emerging Integrated Circuit Technologies
Co-Investigator: Smart Buildings through Smarter Models

Dr. T. Daniel Loveless is a UC Foundation Assistant Professor of Electrical Engineering at the University of Tennessee at Chattanooga (UTC). He received the B.S. degree in electrical engineering from the Georgia Institute of Technology in 2004 and the M.S. and Ph.D. degrees in electrical engineering from Vanderbilt University in 2007 and 2009, respectively. Prior to joining UTC, he was a Research Assistant Professor at the Vanderbilt University Institute for Space and Defense Electronics where he was involved in the modeling and design of integrated circuits for the evaluation of radiation effects in advanced CMOS technologies. Dr. Loveless has authored over 80 journal articles and conference papers. His honors include three best conference paper awards, the IEEE Nuclear and Plasma Sciences Society (NPSS) Graduate Scholarship Award for recognition of contributions to the fields of nuclear and plasma sciences, and the Georgia Tech Alumni Association Scholarship. He is a Senior Member of the Institute of Electrical and Electronic Engineers (IEEE). His research interests include: embedded systems based on field-programmable gate arrays (FPGAs), microprocessors and microcontrollers, systems-on-chip, CubeSat design, radiation effects and reliability in electronic and photonic integrated circuits, high-performance and radiation-hardened digital, mixed-signal and analog integrated circuit design, sensors, and development of smart cities. Please see Dr. Loveless’s biosketch in Appendix A.
Dr. James Newman
Lead PI: FUNSAFE Framework Development for Enhanced Multidisciplinary and Multiphysics Simulations
Co-Investigator: Intelligent Urban Planning

Dr. James Newman is a Professor in Mechanical Engineering. He has been active in the areas of multidisciplinary analysis, sensitivity analysis, and computational design optimization since 1994. Prior to this, Dr. Newman’s focus area was in the simulation of complex-steady and unsteady moving boundary configurations using both unstructured grid and structured grid domain-decomposition techniques. Dr. Newman has developed software to perform computational fluid-structure, and fluid-thermal, interaction and analysis as well as pioneered new algorithms for evaluating multidisciplinary sensitivity derivatives and for uncertainty analysis. Additionally, he and fellow researchers have created a high-order finite-element based framework enabling multiphysics simulations encompassing fluid dynamics, structural dynamics, electromagnetics, and acoustics. Please see Dr. Newman’s biosketch in Appendix A.

Dr. Donald Reising
Lead PI: Smart Buildings through Smarter Models

Dr. Donald R. Reising is an Assistant Professor of Electrical Engineering at the University of Tennessee at Chattanooga. He received his B.S. degree in Electrical Engineering from the University of Cincinnati in 2006. He received his M.S.E.E. (2009) and Ph.D. (2012) in Electrical Engineering from the Air Force Institute of Technology. His research interests include wireless device discrimination using RF-DNA fingerprints, digital communications, digital signal processing, and compressive sensing. He is a member of Eta Kappa Nu, Tau Beta Pi, and a senior member of IEEE. Please refer to Dr. Reising’s biosketch in Appendix A.
Dr. Mina Sartipi

Lead PI: *Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications, Sensing Communications and Analysis in Smart Grid*

Co-Investigator: *Smart Buildings through Smarter Models and Intelligent Urban Planning*

Dr. Mina Sartipi is a UC Foundation Professor in the Department of Computer Science and Engineering. She is a Program Leader for Urban Science & Technology at University of Tennessee Chattanooga (UTC). She also leads the Smart Communications and Analysis Lab (SCAL). At SCAL, we leverage our expertise on data science (data analytics and data management) and wireless communications in smart city applications such as transportation, health, and energy. More specifically, SCAL focuses on research in Urban Science and Urban Analytics, Data Acquisition and Compressive Sensing, Data Integration, Data Interoperability, Big Data Analytics, Smart Health, Smart Grid, Intelligent Transportation, Information Processing for Wireless Sensor Networks, Cyber-Physical Systems (CPS), Modern Error Control Coding and Information Theory, and Signal Processing and Wavelet Transform. Please see Dr. Sartipi’s biosketch in Appendix A.

Dr. Nur Sisworahardjo

Lead PI: *Near Real-Time Detection of Anomalous Power Consumption in Smart Power Distribution Networks*

Dr. N. Sisworahardjo is an Associate Professor of Electrical Engineering at the University of Tennessee at Chattanooga where he conducts research in the areas of power distribution state estimation, detection of anomalous power consumption in power distribution networks, generating unit asset valuation, load forecasting, distributed generation (fuel cells & microturbine) modeling, distributed generation penetration, and post-disturbance network reconfiguration. His general research interest including smart grid, distributed generation, renewable/alternative energy, power systems operation, optimization, simulation, and planning. Dr. Sisworahardjo has authored 25 journal articles, conferences papers, and book chapters. These papers not only deal with his research interests but also related to engineering education. Please see Dr. Sisworahardjo’s biosketch in Appendix A.
Dr. Kidambi Sreenivas
Lead PI: Towards Simulation of Vertical Axis Wind Turbines in Offshore Settings

Dr. Kidambi Sreenivas is an Associate Professor in Mechanical Engineering. He has been active in the area of unstructured, multi-physics flow solvers since 1996. Prior to this, his focus was in the area of structured flow solver development with applications to acoustics and stability of turbomachinery. Dr. Sreenivas pioneered the capability to enable rotating machinery simulations using unstructured meshes. Additionally, he has developed pre-conditioners that enable simulations of fluids with non-ideal equations of state. Dr. Sreenivas has applied these advanced capabilities to solve real-world problems involving complex geometry and complex physics. The range of applications include maneuvering submarines and surface ships, simulations of wind farms, multi-stage turbomachinery, improvement in aerodynamic efficiency of Class 8 trucks, particle deposition within the human respiratory system, contaminant dispersal through urban environments, and embedded propulsion systems. Dr. Sreenivas has worked closely with researchers from NASA, Navy, Department of Energy and various private companies and has transitioned the latest developments to provide them with advanced flow simulation capabilities. Please see Dr. Sreenivas' biosketch in Appendix A.

Dr. Craig Tanis
Lead PI: Optimizing FUNSAFE for Leadership-class Machines
Co-Investigator: Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications

Dr. Craig Tanis is an Assistant Professor in department of Computer Science and Engineering who researches the use of programming language techniques in high performance computing, helping application scientists develop correct codes without compromising computational efficiency. His expertise lies in high performance computing, programming languages, interactive multimedia. Please see Dr. Tanis' biosketch in Appendix A.
Dr. Robert Webster is an Associate Professor in the Mechanical Engineering Department at the University of Tennessee at Chattanooga (UTC). He has been involved in various areas of aerospace propulsion since the beginning of 1989. For three years, he gained experience as an engineer with NASA by serving as an engine system analyst for the Liquid Propulsion Systems Branch at the Marshall Space Flight Center. This provided an appreciation for understanding that most everything must function as part of a system. Since that time, he has been involved in various aspects of aerospace propulsion applications through the use of computational fluid dynamics. This computational experience consists of simulating flow fields of, for example, helicopter rotors, high-speed internal and external flows related to launch vehicles, turbomachinery flow fields, primarily for fan and compressor aerodynamics of air-breathing engines, and both ideal-gas and equilibrium-chemistry nozzle flows. In short, his underlying interest is in the physics of aero-thermal flow fields. As the general area of aerospace propulsion is a combination of fluid mechanics, thermodynamics, and heat transfer, this field serves as a means for naturally satisfying his professional interests. He is a Member of the American Society of Mechanical Engineers (ASME), a Senior Member of the American Institute of Aeronautics and Astronautics (AIAA), newly elected Member of the AIAA Inlets, Nozzles, and Propulsion Systems Integration Technical Committee, and an Emeritus Member of the AIAA Gas Turbine Engines Technical Committee. Please see Dr. Webster's biosketch in Appendix A.
**Dr. Dalei Wu**  
*Lead PI: Multiscale Serviceability Analysis and Assessment of Urban Infrastructure*

Dr. Dalei Wu is an Assistant Professor with the Department of Computer Science and Engineering at the University of Tennessee at Chattanooga (UTC). Before joining UTC, he worked as a Postdoctoral Researcher with the Mechatronics Research Laboratory at Massachusetts Institute of Technology (MIT). His areas of expertise include intelligent systems, data analytics, sensor networks, and mobile computing. He is particularly interested in using methods of modeling, optimization, and machine learning to solve real-world problems. He has published research papers in the following journals: ACM Transactions on Modeling and Computer Simulation, IEEE Transactions on Industrial Informatics, IEEE Transactions on Automatic Control, IEEE Transactions on Circuits and Systems for Video Technology, IEEE Transactions on Wireless Communications, IEEE Journal on Selected Areas in Communications (JSAC), IEEE Transactions on Multimedia, and IEEE Transactions on Communications. He is the PI of NSF US Ignite project (CNS #1647175) on Focus Area 1: Fiber Network for Mapping, Monitoring and Managing Underground Urban Infrastructure (01/2017 – 12/2019). He is editor-in-chief of the International Journal of Information Security and Privacy, and associate editor of Wiley Security and Communication Networks Journal. Please see Dr. Wu's biosketch in Appendix A.

---

**Dr. Li Yang**  
*Co-Investigator: Multiscale Serviceability Analysis and Assessment of Urban Infrastructure*

Dr. Li Yang is a Guerry Professor and Assistant Dean in the College of Engineering and Computer Science. She is the Director of UTC Information Security (InfoSec) Center, a National Center of Academic Excellence in Information Assurance/Cyber Defense (CAE-IA/CD). Her research interests include network and information security, big data analytics, massive data mining, bioinformatics, and engineering techniques for complex software system design. She actively involves students into her research. She authored papers on these areas in refereed journal, conferences and symposiums. She is editor-in-chief of the International Journal of Information Security and Privacy. She has secured over four million external funding from National Science Foundation (NSF), National Institute of Health (NIH), Department of Defense (DoD), and Oak Ridge National Laboratory (ORNL). Please refer to Dr. Yang’s biosketch in Appendix A.
Awardees with supplemental funding continuing from previous fiscal years

Dr. Neslihan (Nesli) Alp
Co-Investigator: Energy Performance of Residential Building Using Simple-Normalization Based Two-Stage Data Envelopment Analysis

Dr. Neslihan Alp is a Professor and Department Head of the Engineering Management & Technology Department and Associate Dean of the College of Engineering and Computer Science (CECS). She holds the Chattanooga Manufacturers Association (CMA) Chair position in CECS. Dr. Alp earned a Ph.D. in Engineering Management from the University of Missouri-Rolla (Missouri University of Science & Technology) (1996), a master's degree in Industrial Engineering, and a bachelor's degree in Engineering Management from Istanbul Technical University, Turkey. Her teaching and research interests and expertise are in the areas of project management, quality control, facilities management, optimization, lean systems, manufacturing processes, and distance education. She is a member of the American Society for Engineering Management (ASEM), American Society of Engineering Education (ASEE), Industrial and Systems Engineering (ISE), American Society of Quality (ASQ), Project Management Institute (PMI), and Society of Women Engineers (SWE). She currently serves as the SWE Student Chapter’s Faculty Advisor. She strongly advocates for female and other minority students in the STEM field. Please see Dr. Alp’s biosketch in Appendix A.

Dr. Endong Wang
Lead PI: Energy Performance of Residential Building Using Simple-Normalization Based Two-Stage Data Envelopment Analysis

Dr. Endong Wang is an Assistant Professor in the Engineering Management & Technology Department at UTC. He obtained his Ph.D. in Construction Engineering from the University of Nebraska, Lincoln. Before joining UTC, he worked as a Postdoctoral Researcher in Mechanical Engineering. His research interests include sustainable construction, building energy performance evaluation, thermal detection, decision making, and environmental assessment. He has teaching experience at both undergraduate and graduate levels in both U.S. and China. He has been on the review board of multiple journals and the technical committee of several international conferences. Please refer to Dr. Wang’s biosketch in Appendix A.
## Students

**Project Title:** Investigation of Resources and Planning for Advanced Manufacturing Applications Center (AMAC) at UT Chattanooga  
**Lead PI:** Trevor Elliott

<table>
<thead>
<tr>
<th>Students Impacted</th>
</tr>
</thead>
</table>
| Chase Dobbins – Mechanical Engineering Student – Graduated Fall of 2016.  
Expand on his knowledge of dealing with vendors for technical and quote materials. Expanded on 2D/3D modeling experience by completing the last iteration of manufacturing space layout. Learned the detailing of a comprehensive business plan with competitive analysis and asset costing. Currently using experience to search for a position in advanced manufacturing or aerospace.  
All of the current and future ENME 4500 (or equivalent design course) While researching certifications of interest to industrial partners learned of free access to Lean Six Sigma White Belt certification test. Implemented course materials and certification this into the 4500 course for all ME students to graduate with this certification.  

## Students

**Project Title:** Healthy and Intelligent Transportation Planning: Estimating Return on Investment Associated with Improved Infrastructure for Bicycling and Walking and Decreased Physical Inactivity in Chattanooga/Hamilton County  
**Lead PI:** Gregory W. Heath

<table>
<thead>
<tr>
<th>Students Impacted</th>
</tr>
</thead>
</table>
| Graduate Students in Computer Science and Engineering were exposed to the modeling of environmental (air quality) data  

**Project Title:** Modeling Space and Defense Environmental Effects in Emerging Integrated Circuit Technologies  
**Lead PI:** T. Daniel Loveless

<table>
<thead>
<tr>
<th>Students Impacted</th>
</tr>
</thead>
</table>
| Undergraduate Students: Ellis Richards, Ryan Boggs  
Graduate Students: Amee Patel, Matthew Joplin  

Amee Patel: Mrs. Patel was partially funded by the award and facilitated student training on relevant software for the design of the MSM instrument. Mrs. Patel graduated with her M.S. degree in Electrical Engineering and took a position as an embedded systems designer for La-Z-Boy furniture.

Ellis Richards: Mr. Richards was partially funded by the award as an undergraduate student. He utilized the Lumerical software suite for simulation and analysis of photonic structures. After graduation Ellis received a stipend position at Vanderbilt University where is studying radiation effects and reliability.

Matthew Joplin: Mr. Joplin was partially funded by the award and was responsible for the design and layout of the MSM instrument. Matt is a current graduate student.

Ryan Boggs: Mr. Boggs was partially funded by the award as an undergraduate student. He has continued with efforts started by Ellis, and is now a graduate student at UTC. Ryan is also supporting the modeling effort.

Students at the undergraduate and graduate levels were involved in all phases. Further, the work was conducted in collaboration with academic and industrial leaders in the area of high reliability, low power microelectronics.
**Project Title:** Smart Buildings Through Smarter Models  
**Lead PI:** Donald Reising

Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

**Students Impacted**

Graduate Students: Mohammed Fadul, Amee Patel, Jin Cho

Mohammed Fadul: Mr. Fadul is seeking a Master's of Science in Electrical Engineering. Mr. Fadul carried out all of the work related to the construction of the building energy model within the modeling and simulation tool EnergyPlus™. This work pushed Mr. Fadul to work in an area in which he had little to no experience in, and he excelled. This work was invaluable to further developing his critical thinking and problem solving skills as well as transitioning from undergraduate to a graduate level of work. Jin Cho: Jin is finishing his Master's degree in Computer Science this fall. This was a great opportunity for him to expand his data science expertise with a real-world application.

Amee Patel: Mrs. Patel was partially funded with the award and was responsible for the development of the networked sensor array. Her efforts with sensor calibration and network design led to completion of her degree of Masters of Science in Electrical Engineering.

**Project Title:** Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications  
**Lead PI:** Mina Sartipi

Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

**Students Impacted**

Undergraduate Students: Robert Barber, Caleb Campbell  
Graduate Students: Hector Suarez, Austin Harris

Robert Barber: Robert learned more about routing algorithms as well as Python packages. After being involved in this exciting research project, Robert decided to stay for graduate school.

Caleb Campbell: Caleb was able to expand her knowledge on graph theory and data structures.

Hector Suarez and Austin Harris were able to work as a team on several aspects of this project. They also learned how to manage the project as at times the PI asked them to set the goals, justify them, and work with the undergraduate students on the team.
**Project Title:** Near Real-time Detection of Anomalous Power Consumption in Smart Power Distribution Networks,  
**Lead PI:** Nur Sisworahardjo

<table>
<thead>
<tr>
<th>Students Impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.</td>
</tr>
<tr>
<td>Graduate Student: Akram Saad</td>
</tr>
<tr>
<td>One graduate student participated in this project. Through the project, the student gained first-hand experience in research and scholarship activities. The student had the opportunity to write a technical report, which leads to paper(s) publication in a conference/journal.</td>
</tr>
</tbody>
</table>

**Project Title:** Towards simulation of vertical axis wind turbines in offshore settings,  
**Lead PI:** Kidambi Sreenivas

<table>
<thead>
<tr>
<th>Students Impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.</td>
</tr>
<tr>
<td>Graduate Student: David Collao</td>
</tr>
<tr>
<td>David Collao: David was responsible for creating the geometry and generating the meshes for this project. He became comfortable with using the CAD tools within Pointwise to create geometry as a result of this project. He has since graduated with a PhD in Computational Engineering (2017) and is currently employed by a local company that creates software for 3D modeling for dentures and other dental implants.</td>
</tr>
</tbody>
</table>

**Project Title:** Optimizing FUNSAFE for Leadership-Class Machines,  
**Lead PI:** Craig Tanis

<table>
<thead>
<tr>
<th>Students Impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.</td>
</tr>
<tr>
<td>Undergraduate Student: Dominique Pennington</td>
</tr>
<tr>
<td>Dominique Pennington, graduated May 2017, was quite helpful in studying the differences between Xeon Phi and NVIDIA GPU hardware. He was sent to a supercomputing symposium at Oklahoma State in support of this work. This work manifested itself distinctly in Dr. Tanis’ Spring 2017 graduate course offering on Parallel Algorithms, particularly with respect to GPU programming.</td>
</tr>
</tbody>
</table>
**Project Title:** Multiscale Serviceability Analysis and Assessment of Urban Infrastructure  
**Lead PI:** Dalei Wu

<table>
<thead>
<tr>
<th>Students Impacted</th>
<th>Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Undergraduate students pursuing bachelor degree in Computer Science:</strong></td>
<td>Robert Slaughter, Dakila Ledesma, Christopher Davis, Alaykumar Patel, Suhail Arora, Austin Obyrne, Peter Zeglen, Derek Snyder, Morgan Sanborn, Izabella Arredondo.</td>
</tr>
<tr>
<td><strong>Graduate students pursuing Ph.D degree in Computer Science:</strong></td>
<td>Maxwell Omwenga, Mehran Ghafari.</td>
</tr>
<tr>
<td><strong>Graduate students pursuing master degree in Computer Science:</strong></td>
<td>Sharmila Chackrawathy, Stuart Eudaly, Nada Alharbi, Maha Almaimani, Rabhu Bajracharya.</td>
</tr>
</tbody>
</table>

Nada (female) published one conference paper as the first author. Robert Slaughter, Dakila Ledesma, and Christopher Davis submitted one conference paper as co-authors.
PROGRAM OVERVIEW & ACCOMPLISHMENTS

INTRODUCTION
The value proposition for multidisciplinary and inter-disciplinary research, education, and training in the rapidly advancing field of Computational Science and Engineering\(^2\) (CSE) has grown stronger since the start of CEACSE in 2005. Today, modeling, simulation and high-performance computing are considered the third pillar of research, development and scientific inquiry (in addition to theory and experiment) in a broad spectrum of scientific and technical areas. The THEC investment in CEACSE continues to be critically important for UTC to strengthen ongoing interdisciplinary CSE efforts and to continue to improve competitiveness with respect to extramural funding. The primary objectives of CEACSE are as follows:

- Expand CSE capabilities at UTC;
- Support startup of new research and educational work that broadens and expands the CEACSE base of research expertise; and
- Realize appropriate return on investment by attracting new extramural funding.

Fiscal year 2017 has been a year of growth and enhancement for CEACSE. After several retirements and resignations of staff in the SimCenter, the appointment of new leadership has revitalized the environment for CEACSE at UTC. Dr. Reinhold Mann, who was Interim director of the SimCenter for two years, stepped down at the end of FY2017. Dr. Tony Skjellum joined from Auburn University as the new SimCenter, Professor of Computer Science, and Chair of Excellence soon thereafter. Dr. Skjellum’s experience in creating successful multidisciplinary research centers, as well as his strong grounding in High Performance Computing and Simulation bring new leadership to SimCenter. He joins the existing group of established leaders highlighted in last year’s report – Dr. Joanne Romagni, Vice Chancellor for Research, and Dr. Daniel Pack, Dean of the College of Engineering and Computer Science (CECS). In addition, Dr. Mann remains engaged as a consultant to Dr. Romagni and supports her office and SimCenter in their respective engagements with state, local, and federal opportunities nurtured and advanced during his two-year term as Interim Director. Dr. Skjellum will lead the CEACSE efforts moving forward, and plans to grow and support work consonant with the original proposal to THEC for CEACSE. Continued emphasis on modeling and simulation in CSE, high performance computing, and data science will ground the strategy of advancing and diversifying the participation of UTC faculty and students in CEACSE projects in FY2018 and beyond.

The FY2017 portfolio of CEACSE projects accomplished a number of foundational advancements in detailed R&D for computational solvers, for smart cities and urban studies R&D, for work in electric power, and also expanded CSE capabilities in important

new application areas such as modeling and simulation in other ways keyed to the availability of our new computing infrastructure. Importantly, we were able to fund appropriate research projects in all five of the identified research foci (highlighted below), although Aerospace/Defense and Smart Cities remain the largest categories by proposals funded. These areas also have been well represented in new external research awards received by CEACSE-funded professors.

With the rapid march of technology in the era of GP-GPU-enabled computing, it was essential to modernize the locally available high performance computing cluster at UTC. To that end, an approximately $350,000 investment was made in FY2017, including approximately $250,000 of CEACSE funds (with and additional $100,000 from the UC Foundation), in support of a new cluster comprised of Dell-branded, multi-core Intel-architecture servers, each with an NVIDIA GP-GPU Pascal P100, and all connected via an InfiniBand EDR (100Gbit/s) low-latency interconnect. This 33-node cluster provides a revolutionary level of local infrastructure, and matches well with the sorts of clusters our peers and aspirational institutions use routinely. The availability of this system has enabled significant porting of valuable internal codes (e.g., FUNSAFE) to use GP-GPU offload and thereby be able to solve larger and more complex problems. In particular, this system, together with baseline funding for code porting, has enabled our professors and students to solve bigger and harder problem locally while preparing them for access to leadership class machines outside of UTC, such as the forthcoming ORNL Summit system. Overall the combined investment in computing infrastructure and in the core R&D algorithms and code representations with CEACSE funds is designed at the key aim of enabling our scientists to run flow field simulations that will scale out successfully with performance with great performance-portability, and thus be able to target leadership class machines when to solve extremely demanding flow problems, such as hypersonic flows.

Important new collaborative alliances have been made in FY2017, perhaps none more relevant in the computational fluid dynamics area than the cooperation of UTSI, UTDI, UTK, and UTC researchers. As mentioned elsewhere in this report, an approximately $900,000 contract is pending for UTC as part of an overall $10M program to advance hypersonic flow R&D. This consortium of universities and research foundations joins UTC into a new level of massive collaboration with huge potential for solving key programs as part of its statement of work, while also opening the possibility of on-going support for the hypersonic R&D at UTC based on our unique and distinctive know-how, science, and engineering.
CEACSE Strategy and Organization

The scientific, technical and programmatic objectives of CEACSE are aligned with the strategic directions of the research and educational programs at UTC. Figure 1 (below) illustrates the central role CEACSE plays in capability and program development potentially impacting all Colleges at UTC. These strategies intersect with problems of global, national and regional importance in five primary focus areas:

- Aerospace and Defense
- Energy & Environment
- Health & Biological Systems
- Manufacturing
- Urban Science and Technology

These application focus areas were selected based on three important criteria:

- The presence of significant scientific and technical challenges for which there was interest, expertise, and the potential to excel at UTC;
- Clear alignment with educational and workforce development missions of UTC;
- Opportunities to establish extramural R&D funding that can be realized by UTC researchers in strategic partnerships with collaborators at other institutions.

CEACSE proposals that fit one (or more) of these five focus areas are reviewed for technical merit by a panel of outside experts, then undergo a review for strategic alignment which includes scrutiny of a specific plan to develop extramural funding. While these five focus areas span a wide area of science & technology, all excellent ideas that appear outside of these five stated areas are considered so long as they have substantial CSE content.
Figure 1: SimCenter serves as UTC’s intellectual hub and incubator in modeling, simulation and HPC in collaboration with departments across campus. Drivers for the activities include the five focus areas described in this plan. In addition to Computer Science and Engineering, the PhD program will feature concentrations in Mathematics and other Sciences. Notably, progress toward expanding into Mathematics was achieved in the past year, and there is strong SimCenter participation by math faculty as of Fall 2017. The THEC Center of Excellence supports cross-disciplinary innovative efforts that are critically important to continued program development including high-quality faculty recruitment and national competitiveness for follow-on funding.
**Overview of FY2017 Projects**

In FY2017, CEACSE awarded new seed funding to support the research activities of sixteen faculty members for twelve new projects from various disciplines across computational science and engineering. CEACSE continued its efforts to broaden the scope of research through increased participation of additional faculty, graduate students, and undergraduate students.

The funded projects key to the five priority areas: Aerospace and Defense (five projects), Energy & Environment (two projects), Urban Science (three projects), Health & Biosystems (one project), and Manufacturing (one project). Additionally, certain projects have elements that cross-cut multiple areas, such as Urban Science plus Energy & Environment.

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Dr. Abdollah (Abi) Arabshahi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>Dr. Robert S. Webster</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>None</td>
</tr>
<tr>
<td>Project Title</td>
<td>Computational Simulations of the Aerothermal Environment of Hypersonic Flight Vehicles</td>
</tr>
<tr>
<td>Award Start – End Date</td>
<td>July 1, 2016 – June 30, 2017</td>
</tr>
</tbody>
</table>

**Summary**

Continued advances in physics-based simulation technologies in general, and in Computational Fluid Dynamic (CFD) in particular, are essential and required to support almost every aspect of the Hypersonic project. These capabilities will be used to generate accurate numerical predictions to provide and enhance our understanding of the complex flow phenomena that occur at the hypersonic regime (such as aerothermodynamics, aerodynamic, chemical reactions, and high heat transfer) around any flight vehicle. Current effort at the UTC/SimCenter is to develop and validate a physics-based numerical capability for simulating flow around hypersonic aerospace vehicles and components of vehicles, so that performance can be more accurately evaluated and better understood.
<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Trevor S. Elliott</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>(Originally Jan Evans)</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Chase Dobbins – Undergraduate student</td>
</tr>
<tr>
<td>Project Title</td>
<td>Investigation of Resources and Planning for Advanced Manufacturing Applications Center (AMAC) at UT Chattanooga</td>
</tr>
<tr>
<td>Award Start – End Date</td>
<td>August 8, 2016 – June 30, 2017</td>
</tr>
</tbody>
</table>

**Summary**

This work was centered on the development of a resource plan, personnel and infrastructural, related to creating a center for advanced manufacturing. To that end, faculty within the SimCenter, the college of engineering, and other colleges at UTC were linked to topic areas relevant to manufacturing. More specifically they were linked to areas found to be of interest to local manufactures and constituent base of UTC. While the manufacturer needs were assessed the center infrastructural requirements were analyzed. A major finding was that industries are not currently utilizing advanced techniques/technologies in their processes. These industries voiced a desire to test these new techniques and technologies within their current production and a need for integration with conventional processes. The subsequent research on integration yielded results about companies reacting to exactly this need, such as GF+ with a pallet system for moving products from conventional processes to advanced or additive processes in a bulk and automated fashion. This company indicated their process was in need of modeling and simulation similar to what the SimCenter could provide. In addition to the modeling and simulation needs this finding pointed out the possible need for a technology transfer component within the center.

The facility layout produced within this work was a crucial element in space conversations and the space for the center has been secured. While creating the facility layout, equipment was assessed for its merits using a customized weighting scheme and desired equipment was selected for consideration. During the evaluation of potential equipment current faculty interests were considered which leads to a desired outcome of matched faculty interests to center subtopics and possible funding opportunities. The community impacts thus far have been in the area of awareness and soliciting of interested parties in the Chattanooga area. Entrepreneurial players such as CoLab, Branch Technologies,
Collider Technologies, Feetz, and the Enterprise Center have been brought into the planning meetings for center realization. Industrial entities such as Komatsu, Tuftco, TN Rand, and Roper Company have been consulted to ascertain their needs and provide awareness about the center. Resources for certifications were located and resulted in an indirect student impact. These resources have now been implemented in a senior level course. The students in this course, all mechanical engineering students, will have the tools, training, and free access to certification for entry level lean six sigma certification.

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Dr. Gregory W. Heath</th>
</tr>
</thead>
</table>
| Co-PI(s) | Dr. Mina Sartipi  
Dr. James Newman |
| Other Personnel | Mr. Andrew Mindermann – GIS Technician  
Dr. Guijing Wang – Health economist – CDC  
Mr. Eric Asboe – Transportation Planner- City of Chattanooga |
| Project Title | Healthy and Intelligent Transportation Planning: Estimating Return on Investment Associated with Improved Infrastructure for Bicycling and Walking and Decreased Physical Inactivity in Chattanooga/Hamilton County |
| Award Start – End Date | July 1, 2016 – June 30, 2017 |

**Summary**

Based on data related to environment, transportation, and health, we proposed to provide a customized ‘environmental infrastructure and health return-on-investment calculator’ to be used by planners and personal users to guide in planning for pedestrian/bicycle path cost outlays for the former and healthy active wayfinding by the latter. Transport and recreation path/sidewalk costs were assessed in partnership with the city of Chattanooga’s Department of Transportation for both recent and projected transport and recreation construction costs, land costs, projected construction time, and populations reached. Physical inactivity behavior associated impact on heart disease, stroke, type 2 diabetes, colon cancer, and breast cancer prevention outcomes were calculated using: 1) the relative risk (RR) for each of the chronic diseases in association with estimates of physical inactivity; 2) accessing through the Behavioral Risk Factor Surveillance System, the current prevalence of physical inactivity among the adult population 18 years and older residing in Chattanooga/Hamilton County and specifically Census Tracts 16, 18, 19, and 20; 3) using the results from steps 1 and 2 to calculate a Chattanooga/Hamilton County-specific and Census-specific Population Attributable Fraction (PAF) for each of the physical inactivity and chronic disease outcomes; and
4) Adjust the PAF’s for each of the outcomes in accordance with the effect size expected from the sidewalks and paths on behavioral changes in terms of increased levels of physical activity among the adult population; and 5) adjusted cost of chronic disease’s affected by changes in physical activity due to sidewalk/path changes. In addition, we created an application that provides a personalized planning for active transportation in response to vehicular traffic patterns and air quality so as to alert bike and pedestrian active transporters about the potential hazards and/or conditions of travel routes. Hence, in terms of urban planning, the data generated by our applications resulted in a potential tool that urban planners can use to maintain/build good/safe road/street networks and urban facilities to support active transportation and physical activities among residents. Our models assessing the impact of increased exposure to dedicated transport/recreation sidewalks/bike paths demonstrated a decrease in physical inactivity among adult residents in Chattanooga Census Tracts 16, 18, 19, 20 by a range of 25% to 50%, with a corresponding decrease in chronic diseases and their associated costs by as much as $1.2M over a project 4-year period, thus providing evidence for a return-on-investment for constructing such sidewalk/pathways.

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Dr. T. Daniel Loveless</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>None</td>
</tr>
</tbody>
</table>
| Other Personnel | Amee Patel, Matthew Joplin - Graduate Students  
 Ellis Richards, Ryan Boggs - Undergraduate Students |
| Project Title | Modeling Space and Defense Environmental Effects in Emerging Integrated Circuit Technologies |
| Award Start – End Date | July 1, 2016 – June 30, 2017 |
| Summary | Typical electronics reliability modeling tools reside in a proprietary industry setting, employ techniques for a specific need, and are inappropriate for emerging integrated circuit technologies. Further, current methods involve extrapolation of short-term degradation profiles for predicting long-term behavior and lead to inaccurate and over constrained reliability predictions, and significantly limit the use of emerging integrated technologies in large distributed systems. This effort involved development of a stochastic based modeling technique for capturing intrinsic parameter fluctuations that account for time-dependent workload conditions influencing electronics reliability. Further, a novel method for measuring the stochastic behavior of atomic-level defects within electronics |
devices was developed. The hardware was provided to Sandia National Laboratories for measurement of time-dependent reliability in advanced and emerging semiconductor technologies. Future work will involve the collection of data for further improvement of the stochastic models, and the integration of the models into industry-standard simulation tools. This work offers a fundamentally new approach to evaluating system-level reliability vulnerabilities, enabling new approaches for mitigation, and has the potential for transforming the way industry assesses electronic device, component, and system reliability.

The proposed research re-factored a version of the FUNSAFE framework to facilitate, enhance, and extend simulation capabilities. In the Review Summary for this award, reviewers commented that the research “does not strike me as overly creative or transformative”, “This seems more like a support effort that should be funded under the other proposals rather than stand on its own”, and “A clear path to future funding for a follow-on project is needed”. Unfortunately, the reviewers did not recognize that funding opportunities may be pursued proactively through the development of creative and/or transformative research as well as arise based on unique capabilities/expertise possessed by the faculty. The latter falls under the category of reactionary opportunities, and particularly within the DoD, the vast majority of funding is obtained in this manner. The current award, and research conducted, not only enhanced capability, but will make UTC researchers’ proposals more cost competitive. Furthermore, as discussed in a subsequent section, the current THEC award has already successfully attracted extramural funding. Moreover, with
regards to being transformative, NASA within the Transformational Tools and Technologies Program, and in partnership with the United States Air Force, have recently embarked on a re-factoring effort for their simulation software that is similar to this project.

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Dr. Donald R. Reising</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>Dr. Mina Sartipi</td>
</tr>
<tr>
<td></td>
<td>Dr. T. Daniel Loveless</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Mohammed Fadul, Amee Patel, Jin Cho - Graduate Students</td>
</tr>
<tr>
<td>Project Title</td>
<td>Smart Buildings Through Smarter Models</td>
</tr>
<tr>
<td>Date Submitted</td>
<td></td>
</tr>
<tr>
<td>Award Start – End Date</td>
<td>July 1, 2016 – June 30, 2017</td>
</tr>
</tbody>
</table>

Summary

The effort assessed current building energy models and investigated methods by which to improve them using integrated sensor data. The goal was to improve upon the existing model to facilitate real-time, high-fidelity energy usage and efficiency analysis. The existing modeling software, used in this work, requires extensive knowledge of the building’s construction (e.g., materials, dimensions), occupancy, and systems (e.g., HVAC, lighting). The program then returns a projected energy usage and efficiency based upon this model; thus, the accuracy of these projections rely heavily upon the accuracy of the model. However, the sensor data facilitates direct energy usage and efficiency based upon measured values without any knowledge of the building’s construction, occupancy, and systems. This project advanced the SimCenter’s work within the area of Urban Systems in which energy efficiency is a key focus. This work serves as a key preliminary step in the development of a process by which to facilitate real-time, high-fidelity energy usage and efficiency analysis with the goal of improving energy usage across the community.
<table>
<thead>
<tr>
<th><strong>Lead PI</strong></th>
<th>Dr. Mina Sartipi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Co-PI(s)</strong></td>
<td>Dr. Craig Tanis</td>
</tr>
</tbody>
</table>
| **Other Personnel** | Hector Suarez, Austin Harris - Graduate Students  
Robert Barber, Caleb Campbell - Undergraduate Students |
| **Project Title** | Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications |
| **Award Start – End Date** | July 1, 2016 – June 30, 2017 |
| **Summary** | In order to confront unprecedented challenges due to the rapid urbanization, we started a fundamental research on smart urban connectivity. We investigated the methodologies, feasibilities, and potentials of two essential connectivity paradigms for urban futures, i.e., cooperative mobility and citywide wireless communications. We developed a real-time graph for the streets of the city of Chattanooga that can be updated by crowdsourcing, designed personalized routing algorithms that consider features such as health, air quality, and elevation, and investigated a small testbed for advanced wireless communications. The proposed research involved computationally intensive data analytics, graph analytics, simulation and modeling, optimization, operations research, and urban planning. This project advanced the SimCenter’s work within the area of Urban Systems in which transportation and wireless communications are key focuses. |

<table>
<thead>
<tr>
<th><strong>Lead PI</strong></th>
<th>Dr. Nur Sisworahardjo</th>
</tr>
</thead>
</table>
| **Co-PI(s)** | Dr. Abi Arabshahi  
Dr. Kidambi Sreenivas |
| **Other Personnel** | Akram Saad - Graduate student |
| **Project Title** | Near Real-time Detection of Anomalous Power Consumption in Smart Power Distribution Networks |
| **Award Start – End Date** | July 1, 2016 – June 30, 2017 |
| **Summary** | Through this project, our team members (PI and co-PIs) gained tremendous experience in big data and data analytics and understand the possible utilization that not only limited to power industries but also in other disciplines. Strategic relationship with local industry was strengthened with extensive collaboration with EPB and provide us opportunity to further this collaboration in scholarship activities. From this grant one graduate student received full support for one year to pursue his master degree. Through the project, student gained first-hand experience in research and scholarship activities. Student had opportunity to |
write technical report which leads to paper(s) publication in conference/journal. One paper was submitted and accepted for 2017 International Conference on High Voltage and Power System. Another paper is in preparation for possible publication in conference/journal. This research project also enable researchers at UTC to gain knowledge and experience in anomaly detection in distribution network and gain valuable lessons that can be disseminated to other public power utilities in the region and beyond.

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Dr. Kidambi Sreenivas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>Dr. Abi Arabshahi Dr. Robert Webster</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>None</td>
</tr>
<tr>
<td>Project Title</td>
<td>Towards simulation of vertical axis wind turbines in offshore settings</td>
</tr>
<tr>
<td>Award Start – End Date</td>
<td>July 1, 2016 – June 30, 2017</td>
</tr>
</tbody>
</table>

The objectives of this project were to take first steps towards the numerical simulation of the flow field surrounding vertical axis wind turbines (VAWT) in offshore settings. This work was carried out in collaboration with Sandia National Laboratory, with Dr. Todd Griffith as the POC. The idea behind the project was to carry out initial validation using data from a VAWT that Sandia had tested in the 70s and 80s. These experiments were carried out onshore and once this validation was completed, a future project (potentially funded through Sandia National Lab/DOE) would have involved transitioning the VAWT to an offshore setting.

Almost all commercial wind turbines are three-bladed and of the horizontal axis variety. Consequently, there isn't a large body of research supporting VAWTs. This became abundantly clear as we looked for detailed geometry for the Sandia VAWT. The first roadblock we ran into was that proprietary airfoil sections were used in the Sandia VAWT. After significant back and forth between the PIs and Dr. Griffith, we were able to obtain the geometry of these airfoil sections. The second roadblock was that these wind turbines were built and tested in the era of “pencil and paper,” i.e., there were no solid models (CAD) available that defined this geometry. Based on various reports we found (some were provided by Dr. Griffith), we reconstructed the geometry as best as we could. Even with this effort, these were significant doubts about the geometry definition and there was no way to verify the same as the test article does not exist anymore. Simulations were carried out based on the geometry.
we had created, but the results were not satisfactory. Consequently, attempts to get some of these results published were unsuccessful.

Given that the simulations of the Sandia VAWT provided less than satisfactory results, we began the search for relatively recent experimental data, which had the added advantage of having well defined geometry. This search clearly showed us the paucity of experimental data for VAWTs. The only experimental dataset that could be found was completely fortuitous as the PI happened to be at a talk at the AIAA Aviation Conference in Denver (June 2017) where they discussed some of the results. The results were focused on details of the flow field as opposed to the power produced by the VAWT. Additional searches after the conference turned up one more dataset that could be of use. After returning from the conference, the geometry was created and simulations have been carried out. However, there was not enough time between the end of the conference and the end date of the project in order to carry out a thorough validation of the flow field. The PIs will continue these simulations over the course of the fall and spring semesters (as time permits) to see if good agreement with experimental data can be obtained. This project, while not very successful, initiated collaboration between the SimCenter and Sandia National Lab. Additionally, it supported the SimCenter’s swimming lane related to “Energy & Environment”. The future for this kind of alternate energy research is uncertain because of the changes in the political climate at the federal level.

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Dr. Craig Tanis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>Dr. Kidambi Sreenivas</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>None</td>
</tr>
<tr>
<td>Project Title</td>
<td>Optimizing FUNSAFE for Leadership-Class Machines</td>
</tr>
<tr>
<td>Award Start – End Date</td>
<td>July 1, 2016 – July 31 2017</td>
</tr>
<tr>
<td>Summary</td>
<td>The goal of this project was to update the SimCenter-developed finite element code, FUNSAFE, optimizing it for GPU-enabled supercomputing systems, and getting a large case to run on the Titan system at Oak Ridge National Lab. Over the course of the project, we switched to focusing on the SimCenter’s new GPU-based system. Impressive performance results for parts of FUNSAFE were achieved, but the full port is incomplete. We (Dr. Tanis as Co-PI) have been awarded external funding to continue this work, including an update of the code to use the Kokkos framework for performance portability.</td>
</tr>
<tr>
<td>Lead PI</td>
<td>Dr. Robert Webster</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Co-PI(s)</td>
<td>None</td>
</tr>
<tr>
<td>Other Personnel</td>
<td></td>
</tr>
<tr>
<td>Dr. Kidambi Sreenivas</td>
<td></td>
</tr>
<tr>
<td>Dr. Ethan Hereth</td>
<td></td>
</tr>
<tr>
<td>Mr. David Collao</td>
<td></td>
</tr>
<tr>
<td>Project Title</td>
<td>Numerical Simulations of Axial Compressor Flow Fields Employing Higher-order Accuracy</td>
</tr>
<tr>
<td>Award Start – End Date</td>
<td>July 1, 2016 – June 30, 2017</td>
</tr>
</tbody>
</table>

**Summary**

The major objective was to make use of higher-order spatial accuracy in the simulations of an axial compressor, for which there was a reasonable experience base using standard (i.e., 2nd order) spatial accuracy. Thus, one-to-one comparisons could be made, especially with regard to comparison of the numerical results with experimental results in terms of overall performance parameters. The original plan was to use both finite-volume and finite-element methodologies with higher-order spatial accuracy and make comparisons between the two methodologies, as well as with experiment. In the end, only the finite-volume methodology was tested, since it was “ready to use,” at least as applied to rotating machinery. Even so, this was a useful experience as it provided clear evidence that the use of higher-order spatial accuracy improved the agreement with experiment.

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Dr. Dalei Wu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td></td>
</tr>
<tr>
<td>Dr. Yu Liang</td>
<td></td>
</tr>
<tr>
<td>Dr. Li Yang</td>
<td></td>
</tr>
<tr>
<td>Dr. Farah Kandah</td>
<td></td>
</tr>
<tr>
<td>Dr. Joseph M. Kizza</td>
<td></td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Identify by type - senior personnel, technicians, graduate students, undergraduate students</td>
</tr>
<tr>
<td></td>
<td>Mehran Ghafari, Maxwell Omwenga, Stuart Eudaly, Nada Alharbi, Sharmila chackrawathy, Maha Almainani, Rabhu Bajracharya - Graduate students</td>
</tr>
<tr>
<td></td>
<td>Robert Slaughter, Dakila Ledesma, Christopher Davis, Alaykumar Patel, Suhail Arora, Austin Obyrne, Peter Zeglen, Derek Snyder, Morgan Sanborn, Izabella Arredondo - Undergraduate students</td>
</tr>
<tr>
<td>Project Title</td>
<td>Multiscale Serviceability Analysis and Assessment of Urban Infrastructure</td>
</tr>
<tr>
<td>Award Start – End Date</td>
<td>July 1, 2016 – June 30, 2017</td>
</tr>
</tbody>
</table>
The project was primarily targeted at developing a new multi-scale structural health monitoring system over Big-Data platform (MS-SHM-BD) to monitor and evaluate the serviceability of large-scale civil structures. Under the sponsorship of CEACSE funding, the team has been able to complete the major research goals and tasks of the project. The impacts are as follows:

- Two research seminars on the project were given in SimCenter seminar series by the team faculty in early 2017. Research findings were also presented during UTC Research Dialogues 2017.
- A total of 7 graduate students (3 females) and 10 undergraduate students (2 females) have been involved in the project.
- Four research papers have been published, including one book chapter, two journal papers, and one conference paper. A female graduate student is the first author of the conference paper. In addition, two conference papers have been submitted and two journal papers are under preparation by the team.
- The team has submitted four research proposals to NSF, NIST, and NIHS, with one proposal being funded by NSF (#1647175, $299,884).
- Collaborations have been established with researchers from inside and outside UTC. The team submitted research proposals by collaborating with professors and researchers from University of Vermont, University of Cincinnati, University of Tennessee at Knoxville, Old Dominion University, Oak Ridge National Laboratory, and UTC Math Department.
- With the help of The Enterprise Center, The team also held meetings with officials and engineers from local organizations, including Tennessee American Water, EPB, Chattanooga Department of Transportation, and Chattanooga Public Works, for experiment planning and demonstration.
2017 Project Accomplishments, Outcomes, and Impacts

As noted above, in FY2017 CEACSE awarded new seed funding to support the research activities of sixteen faculty members for twelve new projects from various disciplines across computational science and engineering. CEACSE continued its efforts to broaden the scope of research through increased participation of additional faculty, graduate students, and undergraduate students.

The funded projects key to the five priority areas: Aerospace and Defense (five projects), Energy & Environment (two projects), Urban Science (three projects), Health & Biosystems (one project), and Manufacturing (one project). Additionally, certain projects have elements that cross-cut multiple areas, such as Urban Science plus Energy & Environment.

We have highlighted many aspects of those successes in the foregoing, including highlights of new funding, and student impacts. Appendix B provides the full reporting on each of the grants, including detailed final reports articulating the accomplishments, outcomes, and impacts for each award.

In addition, the second part of Appendix B provides the final reports of six projects that CEACSE supported prior to FY2017, but which were completed by June 30, 2017.
GOALS & FUTURE PLANS

FY2017 Awardee Goals & Future Plans
In their final reports, awardees were asked to address their goals and future plans for their research. Information from each awardee is included in Appendix B.

CEACSE Goals & Future Plans
The Center of Excellence in Applied Computational Science and Engineering (CEACSE) catalyzes innovative research across disciplines, supporting scientific inquiry and enabling discovery through computation. The mission of CEACSE is to establish expand, and sustain a cohesive multidisciplinary effort in applied computational science and engineering that is leveraged across UTC to produce sustained growth in research funding, excellence in integrated education and research, and to increase national and international stature and competitiveness in Tennessee.

Grounded in this mission, CEACSE’s goals are being met by a combination of funding of peer-reviewed research, and by strategic investment in advanced computational facilities. In FY2017, $250,000 of CEACSE funds and $100,000 of UC Foundation support funding was jointly invested in a new computational cluster, described elsewhere in this report. That investment has already been leveraged by new funding in Aerospace/Defense, as well as pending funding in Aerospace/Defense.

Consonant with these goals and UTC’s vision for the SimCenter, the 2017-2018 CEACSE grant competition cycle included a strong focus on research in the fields of Urban Science, Energy & Environment, Defense & Aerospace, and Biomedical research. Funds were awarded to proposals that will result in high-impact peer reviewed publications and “seed” larger, long-term extramural funding. For FY 2018 a total of $684,342 was awarded to nine lead principal investigators and twelve collaborating investigators across eight different departments.

The remaining CEACSE funds for FY2017-18 will be devoted to strategic investments in two areas: a new high performance storage system (approximately 1 PB of usable storage) to support the recently acquired HPC cluster and to replace a seven-year old HPC storage system, at a cost of approximately $475,000 ($375,000 of CEACSE funds, and $100,000 of UC Foundation support dollars), and approximately $250,000 on added computational power in the form of new IBM Power9 servers with NVIDIA GP-GPU nodes capable of supporting much higher sustained performance for high performance flow solvers, machine learning, and analytics. These systems also mirror the exact architecture being installed as “Summit” at ORNL in their 200+ Petaflop machine this fall; others such as SpaceX use Power architecture cluster nodes for their high-end simulations. Availability of this superior and distinct architecture, with multiple V100 GP-GPUs per node, will allow UTC scientists further to advance their studies of performance-portable solvers for hypersonic and turbomachinery systems, and better prepare their solvers for the next generation of pre-Exascale leadership class machines at ORNL, LLNL, DOD labs, and elsewhere. (Notably, the Power architecture is not available through NSF XSEDE.)
The following awardees and projects will support CEACSE’s strategic goals and future plans in the 2017-18 fiscal year:

Dr. Feng Bao, Lead PI, in collaboration with Dr. Kidambi Sreenivas and Dr. Jin Wang. “Computational Modeling and Uncertainty Quantification for Wave Energy” Award Amount: $84,771.00

Ocean waves, generated by wind blowing over the water surface, have tremendous energy which can be captured and converted into electricity. With the rising demand for energy, growing consumption of oil and gas, and increasing global warming, waves offer an attractive green energy source and have generated considerable interest in research, development and testing in recent years. The research carried out in this work focuses on deriving mathematical and computational methods which describe structure motions that occur between ocean wave, wind wave and solid energy converters. The research activities conducted in this project will establish interdisciplinary collaborations between the Department of Mathematics and the SimCenter at UTC, and will also build a research direction for future students in the Ph.D. program in Computational Science with a concentration in Computational Mathematics within Department of Mathematics.

Dr. Bradley Harris, Lead PI, in collaboration with Dr. David Giles and Dr. Ethan Hereth. “A Computational Study of the Impact of Exogenous Fatty Acid Substitutions on the Vibrio cholerae Outer and Inner Membranes” Award Amount: $27,481

Food and waterborne enteric pathogens kill approximately 2 million people each year, and the ways in which these organisms uptake and utilize fatty acids are critical to their ability to spread disease. One of the most extensively studied of these pathogens is Vibrio cholerae, the Gram-negative bacterium responsible for the acute intestinal infection known as cholera. The ability of this pathogen to uptake fatty acids from its environment may contribute to its ability to survive as it passes through the human gastrointestinal tract. The objective of this project is to build computational models to further our understanding of the structure and function of bacterial membranes and provide new insights relevant to the prevention and treatment of this disease. This project fosters collaboration among researchers in biology, chemical engineering, and computational science. The combined results of this study will serve to establish this research team as investigators in the field, and

3 All funded projects were subject to an initial internal review and down select based on internal assessments, followed by a second round of evaluation through external peer review, and concluded by internal panel selection in which the external peer reviews were the driving factor determining final selection of the awardees.
will be used to support the pursuit of external funding through agencies such as the National Institutes of Health and the National Science Foundation.

**Dr. Hope Klug, Lead PI, in collaboration with Dr. Jennifer Boyd and Dr. Hong Qin.**

“The Development and Application of Computational Tools to Address Fundamental Questions in Ecology and Evolution”

Award Amount: $88,998

In recent years, funding agencies and journals have required researchers to place data in depositories, which has led to large datasets that can potentially be used to answer fundamental biological questions about the astounding diversity of life in relation to interactions among organisms and their environment (i.e., ecology) and changes across generations in the genetic and phenotypic makeup of populations (i.e., evolution) on a broad scale. We will develop and utilize novel computational tools that allow us to effectively analyze large datasets extracted from biological databases to investigate the link between biological traits and species’ rarity, as well as climate change vulnerability. We will also investigate how life-history traits, ecological conditions, and sociality interact to influence mating and parental dynamics. The proposed research will allow us to utilize high performance computing resources to address pressing questions in ecology and evolution, expand the research programs in two departments and colleges and allow non-computer scientists to collaborate with a computer scientist. This work will lead to high-impact publications and grant submissions, and facilitate the research training of numerous undergraduate and graduate students.

**Dr. Soubantika Palchoudhury, Lead PI, in collaboration with Dr. Abdollah (Abi) Arabshahi.**

“Computational Fluid Dynamic Approach to Predict Transport and Distribution of Nanodrugs”

Award Amount: $89,221

Nanodrugs are seen as a next-generation solution in the field of biomedicine, particularly for their use as chemotherapeutic and drug delivery agents. The key advantage of nanodrugs is their ability to selectively reach the diseased site without affecting healthy tissues. In nanomedicine, a computational approach is used to predict the transport and distribution profile of nanodrugs inside the body, but the method is still in its developmental stages. Transport of nanodrugs is a complex process due to the combined involvement of hydrodynamic forces, chemical interaction of the surface, magnetic attraction, adhesion to the cell wall, and Brownian forces. The goal of this project is to develop a robust computational fluid dynamics model for predicting the transport of a new Pt-iron oxide nanodrug synthesized at CECS, and to determine the factors dominating the drug’s transport. The project will put the SimCenter at the forefront of emerging innovation in the field of Health and Biological Systems. In addition, the project has tremendous potential for publication in high-impact journals like Nano Letters, Chemical
Communications, and ACS Nano due to its novelty. This research will also serve to provide preliminary data for extramural funding opportunities.

**Dr. Hong Qin, Lead PI, in collaboration with Dr. Craig Tanis.**
“Connecting the Control Theory of Engineering to a Network Theory of Cellular Aging in Biology”
Award Amount: $91,906

In Engineering, control theory studies how a system can be tuned to desirable behavior with given input through feedback. Applying control theory to gene networks is a promising new direction in systems biology and precision medicine because it can improve targeted gene therapies. We recently developed a network model for cellular aging which uses the same graph models with network control studies. We propose to apply network control theory in our gene network model of cellular aging, thereby identifying critical genes and gene interactions required for longevity. Methods developed through this pilot project will establish UTC in an important new research direction on complex networks and will enhance research across disciplines on campus.

**Dr. Donald Reising, Lead PI, in collaboration with Dr. Daniel Loveless.**
“Unlocking the Secrets of RF-DNA Fingerprinting”
Award Amount: $91,978

Wireless communication networks are seamlessly used not only by individuals to conduct personal communication, but also by businesses to carry out daily operations that are essential to their success. Therefore, it is imperative that these networks employ sufficient security measures essential to providing a trusted exchange of information while simultaneously protecting and safeguarding both users and associated information. Digital techniques such as encryption and authentication are commonly attacked and compromised and they fail to leverage the naturally occurring discriminatory information contained within the wireless waveforms themselves. Radio Frequency (RF) fingerprinting is one technique that has been developed to leverage such discriminatory information as a means of enhancing wireless network security. However, the relationship between the RF hardware components and the exploited distinct and native attributes remains unexplored, because researchers traditionally treat this collection of components as a “black box” with little to no thought as to how they contribute and/or possibly hinder RF fingerprinting. The proposed effort looks to open the “black box” and investigate the connection between the waveform distinct and native attributes exploited by the RF fingerprinting process, and the hardware components that are used in the construction of the wireless device. This work is integral to the development of secure wireless communication networks that will be deployed throughout the smart and connected communities of the future.
Dr. Mina Sartipi, Lead PI, in collaboration with Dr. Farah Kandah and Dr. Zhen Hu.  
“Enabling Wireless 3C Technologies for Smart and Connected Cities”  
Award Amount: $92,000

There is an unstoppable trend sweeping the globe for smart and connected cities (S&CCs) that are increasingly revolutionizing our lives, with enormous benefits. In order to achieve S&CCs, we need a powerful infrastructure/backbone to facilitate high-performance data transmission, data analysis, and data storage in the Age of Big Data. Due to the prevalence of mobile/Internet-of-Things devices and emerging applications, wireless technologies and mobile communications plays an irreplaceable role. Thus, by combining data with mobility, we propose to design a fundamental wireless infrastructure and to promote novel wireless 3C (Communication, Computing, and Caching) technologies to support the whole data ecosystem in S&CCs. The proposed infrastructure will enable multiple heterogeneous radio access technologies and hierarchical computing/caching modalities. Our proposed research will exploit the state-of-the-art mathematical programming and big data analytics and leverage the theoretical/applied computational science and engineering in the S&CCs design, development, and optimization. Our achievements can contribute to the advancement of 5G technologies and foster the further study on future wireless. Meanwhile, our research can attract the extensive collaborations among academic scholars, industrial partners, and community stakeholders, and have a great potential to transform Chattanooga, TN from Gig City to Wireless Gig City, and eventually to a truly smart and connected city by taking advantage of EPB’s gigabit fiber optics in Chattanooga.

Dr. Kidambi Sreenivas, Lead PI, in collaboration with Dr. Abdollah (Abi) Arabshahi.  
“Development of Computational Aeroacoustics Capability for Aerospace/Defense Applications”  
Award Amount: $68,085

Noise from various sources is a part of everyday life. The ability to simulate the generation and propagation of noise is a significant challenge. This is primarily because acoustic waves are a perturbation (very small changes) of the ambient pressure. Consequently, significant computational resources are needed in order to resolve these waves accurately. A recent advance in high-order algorithms enables one to increase the order of accuracy (instead of or in addition to increasing spatial resolution) locally. This could have significant implications for acoustic wave propagation as it could drive down the cost of these simulations. The proposed research will focus on applying high-order techniques to canonical and practical problems in aeroacoustics.

Dr. Endong Wang, Lead PI, in collaboration with Dr. Neslihan Alp.  
“Robust Multifactor Framework for Large-scale Fault Detection and Diagnosis in Energy Systems of the U.S. Commercial Buildings”  
Award Amount: $49,902
In the U.S., existing commercial buildings, such as shopping centers, office buildings, and warehouses account for around 38% of the total energy consumed. Reducing energy usage through various renovation measures in commercial buildings is an important opportunity to substantially reduce energy use and thereby mitigate possible environmental deterioration. Accurately identifying the sources contributing to energy loss and waste of building energy systems is the first step to reduce energy consumption. Fault detection and diagnosis remains a significant challenge in the domain due to the complexity of building energy systems. Energy benchmarking, which essentially contrasts a target building against referential peers to locate deficiencies, has been frequently adopted in both academia and industry to identify energy system faults that can be addressed through building renovation. Existing multi-criteria benchmarking procedures tend to ignore the inherent interactions between factors or subsystems, e.g. occupants and building structures, which could lead to serious decision errors. We have performed some work to improve this issue for residential buildings. Combining information theory, this proposed project intends to further expand our model to a generalized framework by overcoming algorithm deficiencies to become more functional. It aims at developing an efficient energy decision analysis instrument which we expect will facilitate retrofitting both locally and nationally to lower energy use in commercial buildings.
<table>
<thead>
<tr>
<th>Investigators</th>
<th>Project Title</th>
<th>CEACSE Priority Area</th>
<th>Amount Awarded</th>
<th>Amount Expended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Nur Sisworahardjo, Dr. Abi Arabshahi, Dr. Kidambi Sreenivas</td>
<td>Near Real-Time Detection of Anomalous Power Consumption in Smart Power Distribution Networks</td>
<td>Energy / Environment</td>
<td>$96,477</td>
<td>$88,469</td>
</tr>
<tr>
<td>Dr. Kidambi Sreenivas, Dr. Robert Webster, Dr. Abi Arabshahi</td>
<td>Towards Simulation of Vertical Axis Wind Turbines in Offshore Settings</td>
<td>Energy / Environment</td>
<td>$96,573.00</td>
<td>$92,095</td>
</tr>
<tr>
<td>Dr. Don Reising, Dr. Mina Sartipi, Dr. Daniel Loveless</td>
<td>Smart Buildings through Smarter Models</td>
<td>Energy / Environment</td>
<td>$99,753.00</td>
<td>$85,506</td>
</tr>
<tr>
<td>Dr. James Newman, Dr. Kidambi Sreenivas, Dr. Robert Webster, Dr. Abi Arabshahi</td>
<td>FUNSAFE Framework Development for Enhanced Multidisciplinary and Multiphysics Simulations</td>
<td>Aerospace / Defense / Crosscutting</td>
<td>$94,087.00</td>
<td>$87,971</td>
</tr>
<tr>
<td>Dr. Craig Tanis, Dr. Kidambi Sreenivas</td>
<td>Optimizing FUNSAFE for Leadership-class Machines</td>
<td>Aerospace / Defense / Crosscutting</td>
<td>$86,741.00</td>
<td>$69,936</td>
</tr>
<tr>
<td>Dr. Abdollah Arabshahi, Dr. Robert Webster, Dr. Kidambi Sreenivas</td>
<td>Computational Simulations of the Aerothermal Environment of Hypersonic Fight Vehicles</td>
<td>Aerospace / Defense / Crosscutting</td>
<td>$97,859.00</td>
<td>$92,465</td>
</tr>
<tr>
<td>Dr. Daniel Loveless, Dr. Kidambi Sreenivas</td>
<td>Modeling Space and Defense Environmental Effects in Emerging</td>
<td>Aerospace / Defense</td>
<td>$25,213.00</td>
<td>$21,632</td>
</tr>
<tr>
<td>Name</td>
<td>Project Description</td>
<td>Department</td>
<td>Amount</td>
<td>Gold Award</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-------------------------------------------------------------------------------------</td>
<td>------------------------</td>
<td>----------</td>
<td>-------------</td>
</tr>
<tr>
<td><strong>Dr. Robert Webster</strong></td>
<td>Numerical Simulations of Axial Compressor Flow Fields Employing Higher-Order Accuracy</td>
<td>Aerospace / Defense</td>
<td>$24,140.00</td>
<td>$23,916</td>
</tr>
<tr>
<td><strong>Dr. Greg Heath</strong></td>
<td>Intelligent Urban Planning</td>
<td>Urban Science</td>
<td>$97,942.00</td>
<td>$85,343</td>
</tr>
<tr>
<td><strong>Dr. Mina Sartipi</strong></td>
<td>Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications</td>
<td>Urban Science</td>
<td>$95,503.00</td>
<td>$95,503</td>
</tr>
<tr>
<td><strong>Dr. Dalei Wu</strong></td>
<td>Multiscale Serviceability Analysis and Assessment of Urban Infrastructure</td>
<td>Urban Science</td>
<td>$95,610.00</td>
<td>$84,580</td>
</tr>
<tr>
<td><strong>Dr. Trevor Elliott</strong></td>
<td>Investigation of Resources and Planning for an Advanced Manufacturing Applications Center at UTC</td>
<td>Manufacturing</td>
<td>$24,300</td>
<td>$17,414</td>
</tr>
<tr>
<td>Investigators</td>
<td>Project Title</td>
<td>CEACSE Priority Area</td>
<td>Amount Awarded</td>
<td>Amount Expended</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>------------------------------</td>
<td>----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Dr. Robert Webster</td>
<td>Computational Simulation of a Blow-Down Tunnel for Turbine Testing at Purdue</td>
<td>Aerospace / Defense</td>
<td>$80,591</td>
<td>$79,849</td>
</tr>
<tr>
<td>Dr. Abi Arabshahi</td>
<td>Numerical Simulation of Airflow in the Small Human Airways</td>
<td>Biomedical</td>
<td>$100,577</td>
<td>$97,301</td>
</tr>
<tr>
<td>Dr. Mina Sartipi</td>
<td>Sensing Communications and Analysis in Smart Grid</td>
<td>Urban Science</td>
<td>$59,500</td>
<td>$59,500</td>
</tr>
<tr>
<td>Dr. Nesli Alp &amp; Dr. Endong Wang</td>
<td>Energy Performance of Residential Building Using Simple-Normalization Based Two-Stage Data Envelopment Analysis</td>
<td>Urban Science</td>
<td>$91,000</td>
<td>$88,105</td>
</tr>
<tr>
<td>Dr. Farah Kandah</td>
<td>Quality of Service Assurance Using GENI</td>
<td>Computational Science</td>
<td>$65,000</td>
<td>$64,953</td>
</tr>
<tr>
<td>Dr. Farah Kandah</td>
<td>A Robust Network Design in Cognitive Radio Networks</td>
<td>Computational Science</td>
<td>$45,000</td>
<td>$44,035</td>
</tr>
<tr>
<td>Dr. Joseph Kizza</td>
<td>Trust Propagation and Distrust in Web of Trust and Airborne Networks Authentication</td>
<td>Computational Science</td>
<td>$50,000</td>
<td>$49,291</td>
</tr>
<tr>
<td>Institution</td>
<td>UT Chattanooga</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>---------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Revenues</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New State Appropriation</td>
<td>$1,769,376</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matching Funds</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carryover State Appropriation</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scholarships</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Supplies</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Books &amp; Journals</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-Personnel</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fringe Benefits</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assistantships</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clerical/Supporting Faculty</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faculty Salaries</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special Commercial Services</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group Arranged Events</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Personal Services</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient Care</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplies &amp; Services</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Books &amp; Journals</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Textbooks</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matching</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appropriation</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$1,749,045</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FY 2017 PUBLICATIONS AND PRESENTATIONS OF CEACSE SEED FUNDED RESEARCH

National and International Conference Proceedings

1. Sisworahardjo: One paper was submitted and accepted for 2017 International Conference on High Voltage and Power System. Another paper is in preparation for possible publication in conference/journal.

Publications


**Other External Academic Activities**

1. Heath et al. Physical Activity and Public Health Workshop – May 5, 2017 – PI assisted by other UTC faculty presented a workshop for professional staff of the Tennessee Department of Health Southeast Regional Office. Results from the current project were presented as examples on how public health data can be used to support the promotion of health and concept of a health community.


4. The participated in the Global City Team Challenge (GCTC) 2016 SuperCluster Kickoff, Washington DC, October 25-26, 2016, networking with other GCTC Action Cluster team leads.

5. Dr. Wu attended the IEEE INFOCOM, Atlanta, May 1-4 2017, meeting with NSF CNS program officers.


**Submissions for Additional External Funding**

1. Arabshahi, Webster, Sreenivas: Member of a joint proposal (Team members are; the University of Dayton Research Institute, University of Tennessee, and Purdue University) entitled “Reusable Hypersonic Vehicle Structures,” to the Air Force Research Laboratory (AFRL). Enabling Technologies for High-speed Operable System (ETHOS) federal project BAA No. FA8650-17-S-2002. $10,000,000 / 3 years. August 2017.


5. NIST, “Building Fire Resilient Communities with Emerging Computing Technologies,” $1,508,098, submitted in 03/2017, PI: Li Yang, Co-PIs: Dalei Wu,
Liang Yu.


7. Title of Project: IUSE/PFE:RED: Institutional Transformation of the Computer Science Education System for the 21st Student; Source of Support: IUSE/PFE:RED; Total Award Amount: $1,387,626 (PI: Kizza)

8. Title of Project: Strengthening the National Cyber Security Workforce: SFS program at University of Tennessee at Chattanooga; Source of Support: NSF CyberCorps; Total Award Amount: $1,897,076 (Co-PI; PI: Li Yang). EAGER: Curbing Crimes in Urban Areas Using Emerging Computing Technologies $280,832 (Co-PI) (PI: Dr. Li Yang).


10. NRT-DESE: Data in the GigCity: A Unified and Comprehensive Platform for Education and Research on Data Science and Engineering to Push Revolutionary Urbanization - $2,770,752 (Co-PI), (PI: Dr. Mina Sartipi).


12. E. Wong. NSF PROPOSAL PREPARATION INITIATIVE--- Integrated Efficient Environmental Sustainability Modeling of Built Environments

13. E. Wong. Alfred P. Sloan Foundation---Building Energy Efficiency Analysis

14. E. Wong. CRISP--- 3D Printing Technology for Sustainable Construction

15. E. Wong. ORAU travel grant

16. E. Wong. TDOT research ideas

17. E. Wong. NSF-China---Open-Block Oriented Designing Methods and Strategy


22. NSF Advanced Technological Education (ATE) PROPOSAL - 2+2 MET: Developing an Industry-Responsive Mechatronics AAS to BAS Pipeline for Engineering Technicians Requested Budget: $586,997 PI: Nesli Alp
Student Activities


# **EXTERNAL FUNDING**

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Dr. Abdollah (Abi) Arabshahi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>Dr. Robert S. Webster</td>
</tr>
<tr>
<td>Project Title</td>
<td>Computational Simulations of the Aerothermal Environment of Hypersonic Flight Vehicles</td>
</tr>
<tr>
<td>Proposal Submissions</td>
<td>None</td>
</tr>
<tr>
<td>Contracts / Awards Received</td>
<td>None</td>
</tr>
<tr>
<td>Sponsored Program Capacity Building Activities</td>
<td>None</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Dr. Trevor S. Elliott</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>(Originally Jan Evans)</td>
</tr>
<tr>
<td>Project Title</td>
<td>Investigation of Resources and Planning for Advanced Manufacturing Applications Center (AMAC) at UT Chattanooga</td>
</tr>
<tr>
<td>Proposal Submissions</td>
<td>None</td>
</tr>
<tr>
<td>Contracts / Awards Received</td>
<td>Space within the Mapp Building on UTCs campus was provided for the establishment of this center. Currently approximate square footage is 6500 sq ft. Used funding in current/pending funding reports for grants submitted during this period. One funded grant as Key personnel from THEC for workshop on improving teacher quality during this period. One grant pending review with this grant listed a current funding.</td>
</tr>
<tr>
<td>Sponsored Program Capacity Building Activities</td>
<td>Did not request enough funds for hosted workshop attendance. Located workshop materials from different national funding agencies and reviewed them for potential funding applications, such as NSF MME and Cyber Manufacturing. Also located and reviewed many workshop reports (MME, Materials Innovation, Advanced Manufacturing for Smart Goods, Nano Heat and Mass Transfer, Carbon Nano Materials, etc...)</td>
</tr>
<tr>
<td>Lead PI</td>
<td>Dr. Gregory W. Heath</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Co-PI(s)</td>
<td>Dr. Mina Sartipi</td>
</tr>
<tr>
<td></td>
<td>Dr. James Newman</td>
</tr>
<tr>
<td>Project Title</td>
<td>Healthy and Intelligent Transportation Planning: Estimating Return on Investment Associated with Improved Infrastructure for Bicycling and Walking and Decreased Physical Inactivity in Chattanooga/Hamilton County</td>
</tr>
<tr>
<td>Proposal Submissions</td>
<td>None</td>
</tr>
<tr>
<td>Contracts / Awards</td>
<td>None</td>
</tr>
<tr>
<td>Received</td>
<td></td>
</tr>
<tr>
<td>Sponsored Program</td>
<td>Submission of a symposium proposal for the Annual Meeting of the Southeast Chapter of the American College of Sports Medicine “Potential Impact of the Built Environment on Physical Activity and Chronic Disease Prevent in Communities”</td>
</tr>
<tr>
<td>Capacity Building</td>
<td></td>
</tr>
<tr>
<td>Activities</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Dr. T. Daniel Loveless</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Title</td>
<td>Modeling Space and Defense Environmental Effects in Emerging Integrated Circuit Technologies</td>
</tr>
<tr>
<td>Contracts / Awards</td>
<td>None</td>
</tr>
<tr>
<td>Received</td>
<td></td>
</tr>
<tr>
<td>Sponsored Program</td>
<td>Interactions with program officers from: Defense Threat Reduction Agency (DTRA), Pauline Paki National Science Foundation (NSF), Dimitri Pavlidis, Mary Poats</td>
</tr>
<tr>
<td>Capacity Building</td>
<td></td>
</tr>
<tr>
<td>Activities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Participant in the Grant Writers Workshop, Grant Central Review</td>
</tr>
<tr>
<td></td>
<td>Participant in CAREER development with the Implementation Group (TIG)</td>
</tr>
<tr>
<td>Lead PI</td>
<td>Dr. James C. Newman III</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Co-PI(s)</td>
<td></td>
</tr>
<tr>
<td>Dr. Kidambi Sreenivas</td>
<td></td>
</tr>
<tr>
<td>Dr. Robert Webster</td>
<td></td>
</tr>
<tr>
<td>Dr. Abdollah Arabshahi</td>
<td></td>
</tr>
<tr>
<td>Project Title</td>
<td>FUNSAFE Framework Development for Enhanced Multidisciplinary and Multiphysics Simulations</td>
</tr>
</tbody>
</table>
| Proposal Submissions        | University of Dayton Research Institute, “Reusable Hypersonic Vehicle Structures.” Investigators: Drs. James Newman, Abdollah Arabshahi, Robert Webster, and Ethan Hereth. [$893,239]  
NASA Langley Research Center, “Revolutionary Computational Aerosciences (RCA) Institute Support: Visitors and Faculty Engagement.” Investigator: Dr. James Newman. [$14,948] |
| Contracts / Awards Received | Awards during this period of performance (from Proposal Submissions list above): University of Dayton Research Institute, “Reusable Hypersonic Vehicle Structures.” Proposal funding is in place via the AFRL Enabling Technologies for High-speed Operable Systems (ETHOS) Program. Award is forthcoming.  
Engility Corporation (DoD HPC Modernization Program: PETTT), “Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains.” Proposal has been selected for funding.  
Pointwise, Inc., “High Fidelity Mesh and Geometry Tools.” Proposal was funded, contract is being put in place to receive award.  
NASA Langley Research Center, “Revolutionary Computational Aerosciences (RCA) Institute Support: Visitors and Faculty Engagement.” Proposal was funded. Award has been received.  
<table>
<thead>
<tr>
<th>Sponsored Program Capacity Building Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>$120,000</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Co-PI(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Donald R. Reising</td>
<td>Dr. Mina Sartipi</td>
</tr>
<tr>
<td></td>
<td>Dr. T. Daniel Loveless</td>
</tr>
</tbody>
</table>

| Project Title | Smart Buildings Through Smarter Models |


| Contracts / Awards Received | None |

<table>
<thead>
<tr>
<th>Sponsored Program Capacity Building Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Sartipi and Reising participated in “Chattanooga’s Smart City Testbed” workshop on April 4, 2017. This workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding “smart” city. It focused heavily on brainstorming sessions within the areas of: Transportation, Energy, and Public Health. Dr. Sartipi and Loveless participated in a “Smart Cities” workshop in May of 2017 in Cadiz, Spain. The workshop was intended to facilitate collaboration between researchers at UCA and UTC. Additionally, local government officials were present.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Co-PI(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Mina Sartipi</td>
<td>Dr. Craig Tanis</td>
</tr>
<tr>
<td><strong>Project Title</strong></td>
<td>Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
NSF Big Data Regional Innovation Hubs: Establishing Spokes to Advance Big Data Applications (BD Spokes), Solicitation 17-546  
In Collaboration with GA Tech and VA Tech (to be submitted Sept. 2017)  
NSF Critical Techniques, Technologies and Methodologies for Advancing Foundations and Applications of Big Data Sciences and Engineering (BIGDATA), Solicitation 17-534  
Anticipated submission data, spring 2018. |
| **Contracts / Awards Received** | None |
| **Sponsored Program Capacity Building Activities** | Dr. Sartipi participated in “Chattanooga’s Smart City Testbed” workshop on April 4, 2017. This workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding “smart” city. It focused heavily on brainstorming sessions within the areas of: Transportation, Energy, and Public Health. Through this workshop we met several faculty from GaTech, Vanderbilt, UTK, VA Tech. We have started collaborating with some of these faculties/researchers. We are identifying more collaboration opportunities.  
Dr. Sartipi participated in a “Smart Cities” workshop in May of 2017 in Cadiz, Spain. The workshop was intended to facilitate collaboration between researchers at UCA and UTC. Additionally, local government officials were present.  
Dr. Sartipi also met with Chattanooga DOT, TN DOT, ORNL Transportation for potential collaborations.  
Dr. Sartipi has traveled to several NSF workshops, smart city expos and has talked with several NSF program officers regarding these opportunities. She has also talked with Planning Division director of TDOT. |
<table>
<thead>
<tr>
<th><strong>Lead PI</strong></th>
<th>Dr. Nur Sisworahardjo</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Co-PI(s)</strong></td>
<td>Dr. Abi Arabshahi</td>
</tr>
<tr>
<td></td>
<td>Dr. Kidambi Sreenivas</td>
</tr>
<tr>
<td><strong>Project Title</strong></td>
<td>Near Real-time Detection of Anomalous Power Consumption in Smart Power Distribution Networks</td>
</tr>
</tbody>
</table>
| **Proposal Submissions** | • National Science Foundation, REU Site: An Interdisciplinary CubeSat Research and STEM Education Platform at the University of Tennessee at Chattanooga (UTChattSat)  
• National Science Foundation, EXCEL: EXploring Clean Energy through hands-on Learning  
• Tennessee Department of Transportation (TDOT), Road Health Monitoring System |
| **Contracts / Awards Received** | Non-Disclosure Agreement between UTC and EPB |
| **Sponsored Program Capacity Building Activities** | Attending workshop/conference:  
• NSF Workshop, June 16-17, 2017, University of Minnesota, Minneapolis, Minnesota.  
• 8th Indonesia Focus Conference, University of Kentucky, Lexington, Kentucky, September 30 - October 1, 2016 |

<table>
<thead>
<tr>
<th><strong>Lead PI</strong></th>
<th>Dr. Kidambi Sreenivas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Co-PI(s)</strong></td>
<td>Dr. Abi Arabshahi</td>
</tr>
<tr>
<td></td>
<td>Dr. Robert Webster</td>
</tr>
<tr>
<td><strong>Project Title</strong></td>
<td>Towards simulation of vertical axis wind turbines in offshore settings</td>
</tr>
<tr>
<td>Proposal Submissions</td>
<td>None related to this project. Related to other CEACSE awards: Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains, HPCMP, $400K</td>
</tr>
<tr>
<td>----------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Contracts / Awards Received</td>
<td>Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains, HPCMP, $400K</td>
</tr>
<tr>
<td>Sponsored Program Capacity Building Activities</td>
<td>Met with Dr. Mike List and colleagues at AFRL, Wright Patterson AFB, Dayton, OH. Met with Drs. Hua Shan, Chandra Kannepalli, and Matthew Jemison at NSWC-Carderock Division, Washington, DC. Met with researchers from SmartTruck (at the SimCenter). SmartTruck is a company that designs and produces after-market drag reduction devices for Class 8 trailers. Talked to Jared Luebe of Kewit Engineering Group. They were interested in us carrying out some simulations for an LNG project they were looking to work on, though the LNG project fell through.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Dr. Craig Tanis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>Dr. Kidambi Sreenivas</td>
</tr>
<tr>
<td>Project Title</td>
<td>Optimizing FUNSAFE for Leadership-Class Machines</td>
</tr>
<tr>
<td>Proposal Submissions</td>
<td>CEACSE 2017-18 “Expanding FUNSAFE capability” (not awarded) PETTT “Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains” (Drs. Tanis and Sreenivas as Co-PI)</td>
</tr>
<tr>
<td><strong>Contracts / Awards Received</strong></td>
<td>PETTT “Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains” (Drs. Tanis and Sreenivas as Co-PI); Engility Corp. Funded for approximately $422,000 over two years.</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Sponsored Program Capacity Building Activities</strong></td>
<td>Tanis conference attendances: Supercomputing 2016 (Workshop on heterogeneous computing) PEARC 2017 (part of Regional Campus Champion leadership).</td>
</tr>
<tr>
<td><strong>Lead PI</strong></td>
<td>Dr. Robert Webster</td>
</tr>
<tr>
<td><strong>Project Title</strong></td>
<td>Numerical Simulations of Axial Compressor Flow Fields Employing Higher-order Accuracy</td>
</tr>
<tr>
<td><strong>Proposal Submissions</strong></td>
<td>“Heterogeneous HPC for High-order Stabilized Finite-elements on Moving and Deforming Domains.” The proposal was for $422,001 (over two years) from the Engility Corporation.</td>
</tr>
<tr>
<td><strong>Contracts / Awards Received</strong></td>
<td>See above.</td>
</tr>
<tr>
<td><strong>Sponsored Program Capacity Building Activities</strong></td>
<td>The PI and colleague (Dr. Kidambi Sreenivas) met with Dr. Michael List, director of the compressor research facility at Wright-Patterson Air Force Base. This occurred in September, 2016. A portion of that meeting was related to this project and was likely helpful in being considered for the grant that was awarded. Also, the presentation of the conference paper listed above has sparked a renewed interest from personnel at the NASA Glenn Research Center.</td>
</tr>
<tr>
<td><strong>Lead PI</strong></td>
<td>Dr. Dalei Wu</td>
</tr>
<tr>
<td><strong>Co-PI(s)</strong></td>
<td>Dr. Yu Liang</td>
</tr>
<tr>
<td></td>
<td>Dr. Li Yang</td>
</tr>
<tr>
<td></td>
<td>Dr. Farah Kandah</td>
</tr>
<tr>
<td></td>
<td>Dr. Joseph M. Kizza</td>
</tr>
<tr>
<td><strong>Project Title</strong></td>
<td>Multiscale Serviceability Analysis and Assessment of Urban Infrastructure</td>
</tr>
<tr>
<td>Proposal Submissions</td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------------------------------------------------</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Contracts / Awards Received</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Sponsored Program Capacity Building Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The participated in the Global City Team Challenge (GCTC) 2016 SuperCluster Kickoff, Washington DC, October 25-26, 2016, networking with other GCTC Action Cluster team leads.</td>
</tr>
<tr>
<td>• Dr. Wu attended the IEEE INFOCOM, Atlanta, May 1-4 2017, meeting with NSF CNS program officers.</td>
</tr>
<tr>
<td>• Dr. Wu participated in the Grant Writing Workshop cohort, 2017.</td>
</tr>
</tbody>
</table>
CONCLUSION

CEACSE continues to contribute greatly to the enhancement and expansion of significant and innovative research in computational simulation and applied computational science and engineering. Through THEC’s support, CEACSE researchers effectively recognize the special opportunity afforded to UTC to provide leadership in computational applications-driven research and education needed for future competitiveness in the high-technology sector of the global economy. That factor is crucial in their recruitment, and retention, as well as professional growth toward tenure and promotion. Significantly, this funding provides a fertile ground to create nationally competitive scholars and research proposals through a peer-reviewed selection process of proposals that are significant enablers of follow-on efforts with extramural funding from NSF, DOD, NASA, NIH, among others, as well as the potential for industrial sponsorship in certain situations. Those non-federal opportunities appear to be growing with the faculty’s growing intellectual property, respective regional/national reputations, and know-how.

Through this seed funding for research activities, undergraduate and graduate students are being engaged in a diverse range of topics at the cutting edge of R&D, and experience a high level of interaction and involvement with faculty. In addition, we will strengthen CEACSE outreach to pre-college students and their teachers.

CEACSE-supported initiatives have already formed the basis for several collaborations and partnerships with other institutions of higher education and with business and industry partners. A number of meaningful Memoranda of Understanding and Non-Disclosure Agreements have been executed between UTC and a variety of partners and potential sponsors to explore how CEACSE can support engineering enhancements, address regional and state priority areas, and bolster robust economic growth. Our strategic partnerships with organizations in Chattanooga and the region, such as the Enterprise Center, the CoLab, and the Chamber of Commerce have already resulted in increased NSF funds at UTC for CSE-related projects leveraging the Smart-connected GigCity status of Chattanooga.

In conclusion, advancing computational science and engineering to strengthen the education, workforce development, and R&D missions at UTC continues to be a high-value investment for the State of Tennessee and the US. The CEACSE multidisciplinary team of faculty and graduate students in collaboration with their strategic partners in Chattanooga, the region, and elsewhere has been focused on the three primary objectives for the Center listed in the introductory segment of this report, namely:

- Expand CSE capabilities at UTC;
- Support startup of new research and educational work that broadens and expands the CEACSE base of research expertise; and
- Realize appropriate return on investment by attracting new extramural funding.

We are convinced that the work accomplished in Fiscal Year 2017 and the strategic vision we laid out for the future has positioned UTC and CEACSE to continue to positively impact, enhance, and accelerate the growth and advancement of Tennessee’s scientific and engineering capabilities and resources.
CONTACT INFORMATION

DR. JOANNE ROMAGNI
Vice Chancellor for Research & Dean of the Graduate School

DR. TONY SKJELLUM
Director of the UTC SimCenter
Chair of Excellence in Applied Computational Science & Engineering

DR. REINHOLD MANN
UTC SimCenter Director Emeritus
Dr. Joanne Romagni is the Vice Chancellor for Research and Dean of the Graduate School at The University of Tennessee in Chattanooga (UTC). Before joining UTC, she was the Associate Vice President for Research at DePaul University in Chicago, where she also served as a research fellow in the biology department. Previously, she held a variety of faculty and leadership positions in research and administration at Bucknell, St. Edwards, and St. Thomas Universities. She received her Ph.D. in plant biology from Arizona State University and conducted research as a post-doctoral plant physiologist and biochemist at the USDA-ARS in Oxford, Mississippi.

In her current role, Dr. Romagni is leading efforts at UTC to establish external and interdisciplinary research partnerships to advance the University’s strategic plan. Her work is focused on developing the structures and support mechanisms to enhance and expand research across graduate and undergraduate disciplines at UTC. Under her leadership, proposal dollars requested have increased by 20% while external awards are up by nearly 10% compared to FY15, including an NSF CAREER award - a major milestone for UTC. She has worked to initiate and administer more than $1,035,000 in internal grant awards in FY16.

Dr. Romagni approaches her work with a dedication to synergistic collaboration and strives to provide opportunities to underrepresented individuals. She personally mentored over 75 students in her previous lab, 80% of which were either women and/or Hispanic students. She has developed strong relationships and has extensive experience working with major grant making agencies, having served on numerous federal review panels. She was awarded funds for her own research from the National Science Foundation for her work as a PI developing an international research program for undergraduates. She has been invited by the Association of American Colleges and Universities and the International Conference of Education, Research and Innovation to speak about her expertise and success integrating undergraduate research into curricula.
Dr. Anthony (Tony) Skjellum received his BS, MS, and PhD Degrees from Caltech. His PhD work emphasized portable, parallel algorithms and software for simulation, with a specific emphasis on message-passing systems. After graduating in 1990, he worked at the Department of Energy Lawrence Livermore National Laboratory (LLNL) for 2.5 years as a computer scientist emphasizing performance-portable message passing and portable parallel math libraries. From 1993-2003, he was on faculty at Mississippi State University, where he and his students co-developed MPICH with Argonne National Laboratory, the first implementation of the now-pervasive Message Passing Interface (MPI-1) standard. Skjellum was a leading participant in MPI-1 and MPI-2 standards as well, with specific contributions to the concepts of "groups contexts, and communicators," which stemmed from his PhD research. His work on MPI has made broad impact on all High Performance Computing (HPC) worldwide through the MPICH implementation and further R&D on MPI over the past 25 years.

From 2003-2013, he was professor and chair at the university of Alabama at Birmingham (UAB), Dept. of Computer and Information Sciences, where he continued work on high performance computing and cyber. During his tenure at UAB, he co-founded the university-wide center – Center for Information Assurance and Joint Forensic Sciences (CIA-JFR), together with Justice Science and Business leaders. This highly funded center was able to attract world-class cyber-security and forensics researchers, and spin-off a startup company, Malcovery, which was later acquired by PhishMe and still has a growing presence in Birmingham as of Fall 2017. In July 2014, he was appointed the Lead Cyber Scientist for Auburn University and Cyber Center director. He led the R&D in HPC and cyber at Auburn University in the college of engineering for just over three years prior to joining the University of Tennessee at Chattanooga in August, 2017 as a Professor of Computer Science, Chair of Excellence, and as the new SimCenter Director.

Skjellum's current research group is a split between cyber/Internet of Things, and High Performance Computing and Exascale Storage. FA-MPI is Skjellum's second implementation of a resilient MPI; he and students and his company, MPI Software Technology, previously designed and published MPI/FT, a fault-aware MPI based on MPI/Pro, a commercial MPI licensed from the mid-1990's through mid-2000’s. He has current funding from DOE/NNSA and NSF. He is a senior member of ACM and IEEE, and Associate Member of the American Academy of Forensic Science (AAFS), Digital & Multimedia Sciences Division. Skjellum remains active in the MPI Forum (in multiple working groups), and is the former chair of the Object Management Group (OMG) High Performance Embedded Working Group as well, in which he remains actively involved as a standards designer and standardizer for high performance embedded signal and image processing libraries and related application programmer interfaces.
DR. REINHOLD C. MANN

Dr. Reinhold Mann is the Interim Director Emeritus of the SimCenter at The University of Tennessee in Chattanooga (UTC), a center of excellence in applied computational science and engineering. His work includes engaging faculty across UTC in the strategy development for the SimCenter as a core capability in modeling, simulation and high-performance computing, and ensuring that the strategy is executed and remains relevant.

Dr. Mann has a part-time appointment as Senior Scientist at StrataG LLC, a small business in Knoxville, TN, that provides services to help solve complex energy and environmental challenges. Dr. Mann retired on June 30, 2014 from his position as Associate Laboratory Director for Environmental, Biological and Computational Sciences at the Brookhaven National Laboratory (BNL), where he was responsible for R&D programs in biology, biotechnology, climate science, and computational science and related efforts.

Before joining BNL, Dr. Mann was the Senior Vice President for Research and Development at Battelle Science and Technology Malaysia Sdn. Bhd. in Kuala Lumpur, Malaysia. He moved to this position in November 2008 after leading the Biological and Environmental Sciences Directorate and Program at the Oak Ridge National Laboratory through a five-year period of transformational change with respect to research programs, infrastructure and capability renewal.

Dr. Mann’s research has been at the intersection of the physical and computational sciences with the life and environmental sciences. He has been leading multi-disciplinary R&D teams since 1986 and developed several R&D efforts in intelligent robotics, human-machine interactions, advanced information processing, computational biology, bioinformatics, systems biology and bioenergy. Dr. Mann served as Chairman of the Board of Directors for the US Department of Energy Bioenergy Science Center in 2007 and 2008, and was a Senior Consultant to the Director of the Oak Ridge National Laboratory from November 2008 through June 2010. Dr. Mann was a member of the Board of Directors for the NASA National Space Biomedical Research Institute, and a member of the Board of Directors for the Laufer Center for Physical and Quantitative Biology at SUNY Stony Brook, from 2011 to 2014. Since June 2015, he has been a member of the Board of Directors for Genera Energy Inc., Vonore TN, a company delivering integrated biomass supply chain solutions. He is a Senior Member of the IEEE, and member of the APS and the AAAS.
APPENDIX A

Faculty Biosketches
Abdollah (Abi) Arabshahi, Ph.D.

Research Professor
Department of Mechanical Engineering and SimCenter
University of Tennessee at Chattanooga
Chattanooga, TN 37403
Abi-Arabshahi@utc.edu
http://www.utc.edu

tel: (423) 425-5485
fax: (423) 425-5229

Professional Preparation:

Mississippi State University Starkville, MS Civil Engineering B.S. 1982
Mississippi State University Starkville, MS Aerospace Engineering M.S. 1985
Mississippi State University Starkville, MS Aerospace Engineering Ph.D. 1989

Appointments:

2005 – Present Research Professor
University of Tennessee at Chattanooga
2002 – 2005 Associate Research Professor
University of Tennessee at Chattanooga
1998 – 2002 Senior Research Associate
Applied Research Laboratory, The Pennsylvania State University
1996 – 1998 Research Engineer II, Computational Fluid Dynamics Laboratory, NSF/ERC for Computational Field Simulation, Mississippi State University
1991 - 1996 Research Engineer I, Computational Fluid Dynamics Laboratory, NSF/ERC for Computational Field Simulation, Mississippi State University
1989 – 1991 Post-doctoral Fellow, Computational Fluid Dynamics Laboratory, NSF/ERC for Computational Field Simulation, Mississippi State University

Book:


Five Products Most Relevant to Proposal:


**Five Other Significant Products:**


**Synergistic Activities:**

4. SimCenter leadership role in unsteady viscous flow engineering applications, scientific computing, and structured grid technologies, including software development, integration, and management, and also facilitating teamwork to solve complex real-world engineering problems (University of Tennessee at Chattanooga)
5. SimCenter leadership role in instruct/mentor qualified and motivated undergraduate and graduate students in the UT SimCenter research program. Maintain research based interactions with students in order to facilitate their process of gaining knowledge, skills, and other aspects of professional growth in the engineering and research field. Mentor for over 65 Undergraduate Student Researchers (University of Tennessee at Chattanooga).
Neslihan Alp, Ph.D., P.E.

(a) Professional Preparation

Istanbul Technical University
Istanbul, Turkey
Engineering Management
B.S., 1989

Istanbul Technical University
Istanbul, Turkey
Industrial Engineering
M.S., 1994

University of Missouri-Rolla
Rolla, MO
Engineering Management
Ph.D., 1996

(b) Appointments

2016-Present
Associate Dean, Graduate Programs and Research, Department Head of Engineering Management & Technology, UC Foundation Professor, & Chattanooga Manufacturers Association Professor, University of Tennessee at Chattanooga

2014-2016
Interim Dean, College of Engineering and Computer Science & UC Foundation Professor, University of Tennessee at Chattanooga

2013-2014
Associate Dean, Graduate Programs and Research, Department Head of Engineering Management & Technology, & UC Foundation Professor, University of Tennessee at Chattanooga

2008-2013
Assistant Dean, Graduate Programs and Research, Department Head of Engineering Management & Technology, & UC Foundation Professor, University of Tennessee at Chattanooga

2006-2008
Director of Engineering Management and Graduate Programs & UC Foundation Associate Professor, University of Tennessee at Chattanooga

2004-2006
UC Foundation Associate Professor & Tenured, College of Engineering and Computer Science, University of Tennessee at Chattanooga

2001 – 2004
UC Foundation Assistant Professor, College of Engineering and Computer Science, University of Tennessee at Chattanooga

1999 – 2001
Assistant Professor, College of Engineering and Computer Science, University of Tennessee at Chattanooga

(c) Products

(i) Most Closely Related Products


(ii) Other Related Products


(d) Synergistic Activities

1. Established dual degree agreements with local community colleges, such as Chattanooga State, Cleveland State, and Dalton State.

2. Established the Living & Learning Community in the College of Engineering & Computer Science and serve as the faculty advisor.

3. Led the selection of the Engineering Management master’s program as one of the Best Online Engineering Graduate Programs in the nation, ranking #7 according to US News & World Report.

4. Developed new undergraduate and graduate degree programs, such as Construction Management, Data Science, through the Computer Science & Engineering Department, and the Engineering Management and construction Management minors through the Engineering Management & Technology Department.

5. Serve as the Society of Women Engineers (SWE) faculty advisor.

6. Organized the Project Lead the Way Teaching Training Program held in Memphis and Chattanooga in June and July of 2015.

7. Supported the American Society of Civil Engineers Southeast Student Conference that was hosted by the Civil Engineering Department at UTC in March 2015, impacting more than 1,000 students and faculty from 26 different universities.
Trevor S. Elliott, Ph.D.

(a) Professional Preparation

University of Tennessee, UTC Chattanooga, TN Mechanical Engineering B.S., 2005
University of Tennessee, UTC Chattanooga, TN Mechanical Engineering M.S., 2009
University of Tennessee, UTSI Tullahoma, TN Aerospace Engineering Ph.D., 2014

(b) Appointments

2015-Present Assistant Professor, Department of Mechanical Engineering, College of Engineering and Computer Science, University of Tennessee at Chattanooga
2013-Present Affiliate Professor, Project Lead the Way (PLTW), University of Tennessee at Chattanooga
2012-2015 Adjunct Faculty, College of Engineering and Computer Science, University of Tennessee at Chattanooga
2008-2015 Information and Technology Administrator, College of Engineering and Computer Science, University of Tennessee at Chattanooga
2009-2010 Web Laboratory Design Engineer, STELLA Project, Boeing Company and NASA contract, University of Tennessee at Chattanooga
2004-2013 Information and Technology Director, Project Lead the Way (PLTW), University of Tennessee at Chattanooga
2005 – 2008 Laboratory Support Engineer, College of Engineering and Computer Science, University of Tennessee at Chattanooga
2000 – 2005 Information and Technology Technician, College of Engineering and Computer Science, University of Tennessee at Chattanooga

(c) Products

(i) Most Closely Related Products

(ii) Other Related Products


(d) Synergistic Activities

1. Current research advances hydrodynamic instability analysis through creation of new mathematical models and computational methods (biglobal analysis) in order to better understand combustion instabilities in solid and hybrid rockets.

2. Maintain various industrial partnerships to facilitate real world design projects assigned in the Interdisciplinary Design (two semester) course sequence were all engineering disciplines work together to create a fully developed prototype for the industrial partner.

3. Modified design course curriculum, including award of grant funds for hardware, to integrate 3D prototyping (3D Printing) into the course with reflective assignments to understand when the use of various additive manufacturing techniques are advantageous/unnecessary. Received “Beyond the Classroom” designation from the UT Chattanooga Experiential Learning Department.

4. Faculty Instructor for multiple STEM Workshops, most recently the 2017 Tennessee Higher Education Commission (THEC) Improving Teacher Quality Grant EXCEL – Exploring Clean Energy through hands-on Learning.

5. Serve as journal and textbook reviewer, steering committee member for advanced manufacturing committee in the greater Chattanooga area, member services for various professional societies, serve as Forum Deputy Technical Chair for the Propulsion & Energy Forum, Technical Area Organizer for the Hybrid Rockets Technical Committee, and Vice-Chair of the Solid Rockets Technical Committee within the American Institute of Aeronautics and Astronautics (AIAA). Lifetime member of ASME and ACM. Lifetime Senior Member of AIAA.
Gregory W. Heath, D.Sc., MPH

Guerry Professor
Department of Health and Human Performance
The University of Tennessee at Chattanooga
Phone: (423) 425-4432, Fax: (423) 425-4457
Email: Gregory-Heath@utc.edu

A. Professional Preparation

<table>
<thead>
<tr>
<th>Institution</th>
<th>Location, State</th>
<th>Degree</th>
<th>Field</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Westmont College</td>
<td>Santa Barbara, CA</td>
<td>B.A.</td>
<td>Psychology</td>
<td>1972</td>
</tr>
<tr>
<td>Loma Linda University</td>
<td>Loma Linda, CA</td>
<td>M.P.H.</td>
<td>Epidemiology</td>
<td>1977</td>
</tr>
<tr>
<td>Loma Linda University</td>
<td>Loma Linda, CA</td>
<td>D.H.Sc.</td>
<td>Physiology/Nutrition</td>
<td>1977</td>
</tr>
<tr>
<td>Washington University</td>
<td>St. Louis, MO</td>
<td>Applied Physiology NIH-Post-Doc</td>
<td>1977-79</td>
<td></td>
</tr>
<tr>
<td>Centers for Disease Control</td>
<td>Atlanta, GA</td>
<td>Epidemic Intelligence Service</td>
<td>1985-87</td>
<td></td>
</tr>
</tbody>
</table>

B. Appointments

2005–present  **Professor and Assistant Vice Chancellor for Research**
University of Tennessee at Chattanooga, Dept. of Health and Human Performance, Chattanooga, TN, USA

2005–Present  **Professor**
University of Tennessee College of Medicine Chattanooga, Dept. of Internal Medicine Chattanooga, TN, USA

2000–2005  **Lead Health Scientist**
Centers for Disease Control and Prevention, Division of Nutrition, Physical Activity, Obesity
Atlanta, GA, USA

1987–2000  **Epidemiologist/physiologist**
Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion
Atlanta, GA USA

1985-1987  **Epidemic Intelligence Service Officer (EISO)**, Centers for Disease Control and Prevention, Center for Health Promotion and Education
Atlanta, GA

C. Products

**Products Most Closely Related to Proposal**


Other Significant Products


Complete List of Published Work in MyBibliography:


D. Synergistic Activities

Developed public health curricula with focus on active living research
In my first 2 years of appointment I developed graduate courses in introduction to epidemiologic methods; physical activity epidemiology; health behavior change; introduction to biostatistics; How Should We Live: A Quantitative Perspective.

Community Services

American Heart Association, Chattanooga Chapter Board of Directors (2007-2010)
Science Advisor: Grow Healthy Together Chattanooga, Chattanooga/Hamilton County Health Dept
Southside Community Health Coalition – Member (current)
Board of Trustees, Lifespring Community Health (clinic and health advocacy)

Professional Services

National:

- Chair, Science Board, President’s Council on Fitness, Sports, and Nutrition – 2009-2012
- National Cancer Institute Participatory Research on Cancer Prevention – Advisory Committee
- Institute of Medicine (IOM) – Moderator for Physical Activity and Health Guidelines – 2006
- Journal of Physical Activity and Health – Editorial Review Board
- American College of Sports Medicine – Vice President (2008-present); Trustee (1996-1999)

Regional:

- Southeast Tennessee Regional Health Board Member (current)
- Governor’s Council on Physical Fitness and Health – Member (2005-2010)

Awards

- Delta Omega, Kappa Chapter (Honorary Public Health Society)
- Elected to Alpha Society, University of Tennessee at Chattanooga Academic Honor Society (2006)
Farah Kandah  
Department of Computer Science Engineering  
University of Tennessee at Chattanooga  
735 Vine Street  
Chattanooga, TN 37405

a. Professional Preparation

- B. A. in Computer Science  
  The Hashemite University, Jordan, 2002
- M. S. in Computer Science  
  The University of Jordan, Jordan, 2005
- Ph. D. in Computer Science  
  North Dakota State University, Fargo, ND 2012

b. Appointments

- Assistant Professor  
  Department of Computer Science and Engineering  
  University of Tennessee at Chattanooga  
  Aug. 2012 – Present
- Teaching Assistant  
  Department of Computer Science  
  North Dakota State University  
  2011 - 2012
- Research Assistant  
  Department of Computer Science  
  North Dakota State University  
  2009 - 2011
- Lecturer and Course Coordinator  
  Department of Computer Science  
  The Hashemite University  
  2005 - 2007
- Research Assistant  
  Department of Computer Science  
  The University of Jordan  
  2003 - 2005

c.i. 5 Publications Most Closely related to the Proposed Project


c.ii. 5 Other Significant Publications


**d. Synergistic Activities (up to 5)**

1. IEEE Member and IEEE Communication Society (ComSoc) member.
4. Guest Editor: IEEE Comsoc Multimedia Communications Technical Committee (MMTC), Special Issue on Multimedia Communications in Future Wireless Networks (E-letter).
Joseph Kizza

PROFESSIONAL PREPARATION
Makerere University, Math-Computer Science, B.S. 1975
California State University, Sacramento, CA, Engineering (Computer Science), M.E. 1980
The University of Toledo, Toledo, OH, Mathematics, M.S. 1986
The University of Nebraska, Lincoln, NE, Computer Science, Ph.D. 1990

APPOINTMENTS
2009 – present Professor and Head, Department of Computer Science and Engineering, University of Tennessee at Chattanooga, Chattanooga, TN
2002 – 2009 Professor and Director, UTC InfoSec Center, University of Tennessee at Chattanooga, Chattanooga, TN
1997 - 2002 Associate Professor, University of Tennessee at Chattanooga, Chattanooga, TN
1989 - 1997 Assistant Professor, University of Tennessee at Chattanooga, Chattanooga, TN
1995 Visiting Professor, University of East London, England

PROFESSIONAL PUBLICATIONS
J. M. Kizza. Social and Ethical Issues in the Information Age – 5th Edition - Hardcover,


COLLABORATION AND OTHER AFFILIATIONS
- Tennessee High Education Commission (THEC) Program Reviewer, Graduate programs in Computer Science
- ABET - Computer Science Accreditation Board (CSAB) Program Evaluator.
- Fulbright Review Board
- Editor –in-Chief for the *International Journal of Computing and ICT Research* (IJICIR)
- Member Editorial Board:
  - *International Journal of Computing and ICT Research* (IJICIR) – Editor-in-Chief
  - *African Journal of Science, Technology, Innovation and Development*
  - *International Journal of Emerging Mechanical Engineering Technology*
  - *The International Journal of Cyber Ethics in Education* (ICCEE).
  - *The African Journal of Information and Communication*
  - *International Journal of Information Science (IJIS)*
  - *International Cyber crimes Journal Society of Productivity Enhancements (ISPE)*

COLLABORATORS & OTHER AFFILIATIONS
Prof. Via Phoha, (Louisiana State University); Prof. Nasir Memon (Polytechnic School of Engineering, New York University); Prof. Ravi Nath, (Creighton University, Nebraska); Prof. Timothy Waema (University of Nairobi, Kenya); Prof. Manmo Muchie, (Tshwane University of Technology, South Africa); Dr. Li Yang (University of Tennessee-Chattanooga); Dr. Yu Liang (University of Tennessee-Chattanooga); Dr. Farah Kandah (University of Tennessee-Chattanooga); Dr. Mbaki Onyango (University of Tennessee-Chattanooga); Dr. Jennifer Ellis (University of Tennessee-Chattanooga).

(ii) Graduate Students supervised:
Dr. Margaret Nyambura Ndung’u – University of Nairobi;
Dr. Arthi R. Shankar, Visvesvaraya Technological University
Dr. Jayanthi K Murthy, Visvesvaraya Technological University
Dr. Julianne Susanne Sansa Otim, University of Groningen, The Netherlands.
Dr. S. Akhila, Visvesvaraya Technological University
Yu LIANG, PhD (Computer Science), PhD (Applied Mathematics)  
Department of Computer Science and Engineering  
University of Tennessee at Chattanooga  
615 McCallie Ave., Chattanooga, TN 37403-2598  
Tel: 423-425-4351, E-mail: yu-liang@utc.edu or hughliang@gmail.com

Dr. Yu Liang is currently working at the Department of Computer Science and Engineering of University of Tennessee at Chattanooga as an Associate Professor. His funded research projects cover the following areas: modeling and simulation, high-performance scientific and engineering computing, numerical linear algebra, the processing and analysis of large-scale sensory data, and computational mechanics. His research work has appeared in various prestigious journals, book and book chapters, and refereed conference, workshop, and symposium proceedings. Besides two NSF review panels, Dr. Liang is serving in the Journal of Mathematical Research and Applications (JMRA), Current Advances in Mathematics (CAM), and the International Journal of Security Technology for Smart Device (IJSTSD) as an editorial board member.

A. PROFESSIONAL PREPARATION
- Tsinghua University, Computer Science B.S., 1985-1990
- Beijing Polytechnic University, Computer Science M.S., 1992-1995
- Chinese Academy of Sciences, Computer Science Ph.D., 1998
- Univ. of Ulster, Computer Science Ph.D., 2005
- University of Minnesota, Computational Sci. Postdoc., 2001-2005

B. APPOINTMENT
- 2013-now, Associate Professor / Computer Science, University of Tennessee at Chattanooga.
- 2010-2012, Summer Faculty Fellow / Sensor Application, the U.S. Air Force Research Lab.
- 2007-2013, Assistant Professor / Computer Science, Central State University.
- 2006-2007, Visiting Assistant Professor/Computer Science, Embry-Riddle Aeronautical Univ.

C. PUBLICATIONS:
(i) Five most closely related to proposal project
(ii) Five other significant publications


D. SYNERGISTIC ACTIVITIES

- Program Committee Member, the 2017 IEEE International Conference on Smart City Innovations (August 4-8, 2017, San Francisco, USA, [http://ieee-smartworld.org/2017/sci/](http://ieee-smartworld.org/2017/sci/)).
- Review panelist for the 2015-2017 NSF Graduate Research Fellowship Program (GRFP).
- Editorial Board Member of the International Journal of Security Technology for Smart Device (IJSTSD, URL: [http://www.sersc.org/journals/IJSTSD/](http://www.sersc.org/journals/IJSTSD/)), Journal of Mathematical Research and Applications (JMRA), and Current Advances in Mathematics (CAM).
- Member of Editorial Board and Program Committee Member, First International Workshop on Security Technology for Smart Device (STSD 2015), URL: [http://interworkshop.org/STSD2015](http://interworkshop.org/STSD2015).
- Technique Program Committee member of the Embedded Computing and Systems Track, the 6th International Conference on Frontier of Computer Science and Technology (FCST 2011: [http://trust.csu.edu.cn/conference/fcst2011/](http://trust.csu.edu.cn/conference/fcst2011/)).
T. Daniel Loveless  
Assistant Professor  
Electrical Engineering Department  
University of Tennessee at Chattanooga  
Chattanooga, TN

a. Professional Preparation
Georgia Institute of Technology, Atlanta, GA, Electrical Engineering, B.S. 2004
Vanderbilt University, Nashville, TN, Electrical Engineering, M.S. 2007
Vanderbilt University, Nashville, TN, Electrical Engineering, Ph.D. 2009

b. Appointments
2014-present Assistant Professor, Electrical Engineering Department, University of Tennessee at Chattanooga (UTC), Chattanooga, TN
2013-2014 Research Assistant Professor, Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN
2011-2013 Adjunct Assistant Professor, Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN
2009-2013 Senior Research Engineer, Institute for Space and Defense Electronics, Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN
2009-2010 Instructor, Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN

c. Products
Total number of publications: 82 (65 refereed articles/proceedings, 12 non-refereed proceedings, 2 theses, 3 book chapters)
Google Scholar h-index of 17; i10-index of 31; ≥ 909 total citations

Recent Publications (*Student Author)


**Recent Conference Proceedings (*Student Author)**


**Activities**


6. Outstanding Researcher Award, Electrical Engineering, University of Tennessee at Chattanooga, 2015-2016.

7. UTC General Education Steering Committee, Jan. 2017-present.


13. Elevated to Senior Member, IEEE, June 2015.


### Professional Preparation:

- **Old Dominion University**  
  Norfolk, VA  
  Mechanical Engr.  
  **B.S.**  
  **1993**
- **Old Dominion University**  
  Norfolk, VA  
  Aerospace Engr.  
  **M.S.**  
  **1994**
- **Virginia Tech**  
  Blacksburg, VA  
  Mechanical Engr.  
  **Ph.D.**  
  **1997**

### Appointments:

- 2015 – Present  
  Professor, Department of Mechanical Engineering, UTC
- 2014 – Present  
  Joint Faculty Appointment, Dept. of Energy, ORNL
- 2011 – 2015  
  Professor, Department of Computational Engineering, UTC
- 2002 – 2011  
  Associate Professor, Department of Aerospace Engineering, Miss. State U.
- 1997 – 2002  
  Assistant Professor, Department of Aerospace Engineering, Miss. State U.

### Five Products Most Relevant to Proposal:


### Five Other Signification Products:


**Synergistic Activities:**
1. Inducted as Associate Fellow in the American Institute of Aeronautics and Astronautics (AIAA). Class of 2017.
Donald R. Reising  
Assistant Professor  
Electrical Engineering Department  
University of Tennessee at Chattanooga  
Chattanooga, TN

a. Professional Preparation
University of Cincinnati, Cincinnati, OH, Electrical Engineering, B.S. 2006  
Air Force Institute of Technology, Dayton, OH, Electrical Engineering, M.S. 2009  
Air Force Institute of Technology, Dayton, OH, Electrical Engineering, Ph.D. 2012

b. Appointments
2014-present  Assistant Professor, Electrical Engineering Department, University of Tennessee at Chattanooga (UTC), Chattanooga, TN  
2012-2014  Adjunct Assistant Professor, Department of Electrical and Computer Engineering, Air Force Institute of Technology, Dayton, OH  
2009-2012  Research Associate, Department of Electrical and Computer Engineering, Air Force Institute of Technology, Dayton, OH  

c. Products
(i) 5 Most closely related to Proposed Project (*Student Author)

(ii) 5 Other Significant Products (*Student Author)

d. Activities
2. Faculty volunteer for UTC’s Read2Achieve program for incoming freshman, 2015-present.
3. Faculty advisor for the Electrical Engineering Department Senior Design Course, 2015-present.
4. Faculty lead and coordinator for UTC’s College of Engineering and Computer Science MakerSpace, 2015-present.
Mina Sartipi, PhD

UC Foundation Professor
Department of Computer Science and Engineering
The University of Tennessee at Chattanooga
Phone: (423) 425-5336, Fax: (423) 425-5442
Email: mina-sartipi@utc.edu

A. Professional Preparation
Sharif University of Technology  Tehran, Iran  Electrical Engineering  B.Sc., 2000
Georgia Institute of Technology  Atlanta, GA  Electrical and Computer Eng.  M.S., 2003
Georgia Institute of Technology  Atlanta, GA  Electrical and Computer Eng.  Ph.D., 2006

B. Appointments
2017–present  Lead Scientist for Smart Cities and Urban Science and Technology
University of Tennessee at Chattanooga, Chattanooga, TN, USA
2015–present  Professor & PhD Program Coordinator
University of Tennessee at Chattanooga, Dept. of Computer Science and Engineering, Chattanooga, TN, USA
2016–2017  Urban Science and Technology Program Leader
SimCenter, University of Tennessee at Chattanooga, Chattanooga, TN, USA
2011–2015  Associate Professor
University of Tennessee at Chattanooga, Dept. of Computer Science and Engineering Chattanooga, TN, USA
2007–2011  Assistant Professor
University of Tennessee at Chattanooga, Dept. of Computer Science and Engineering Chattanooga, TN, USA
2006–2007  Assistant Professor
University of Tennessee at Chattanooga, Dept. of Electrical Engineering Chattanooga, TN, USA

C. Products
Products Most Closely Related to Proposal
Other Significant Products


D. Synergistic Activities

- **IEEE Senior Member**
- **Founding Director**
  
  2012-present, Smart Communications and Analysis Lab
- **Mentoring of Young Women**
  
  As a female faculty member in the Computer Science and Engineering department, I encourage and advise undergraduate and graduate female students on research and possible careers in science.
- **Faculty Advisor for Computer Science Female Group**
  
  2016-present, Girls in Computer Science (GiCS)
- **Professional Services**
  
  o Presenter at multiple federal funding agency workshops
  o Keynote Speaker, Mid SouthEast ACM Conference
  o Planning member of the South Big Data Hub - Mobile Health
  o TPC member: Wireless / Radio Access Technologies VTC; International Workshop on Cyber-Physical System (CPS) and Its Computing and Networking Design at ICNC; IEEE GLOBECOM-Wireless Communications and Networking
- **Award**
  
  o UTC Outstanding Faculty Research and Creative Achievement award, 2016
  o “Keep the Stars Shining” Award, 2012
  o Named UC Foundation Assistant Professor, 2008
Nurhidajat Sisworahardjo
Associate Professor
Electrical Engineering Department
University of Tennessee at Chattanooga
615 McCallie Avenue, Chattanooga, TN 37403-2598

Professional Preparation:
Institute of Technology Bandung, Bandung, Indonesia, Electrical Engineering, B.S. 1991
Illinois Institute of Technology, Chicago, IL, Electrical Engineering, M.S. 1998
The University of Alabama, Tuscaloosa, AL, Electrical Engineering, Ph.D. 2005

Appointments:
2017 – present  Associate Professor, Electrical Engineering Department, University of Tennessee at Chattanooga (UTC), Chattanooga, TN
2010 – 2017  Assistant Professor, Electrical Engineering Department, University of Tennessee at Chattanooga (UTC), Chattanooga, TN
2007 – 2009  Visiting Assistant Professor, Electrical and Computer Engineering department, University of South Alabama, Mobile, AL
2005 – 2007  Adjunct Assistant Professor, Electrical and Computer Engineering department, University of South Alabama, Mobile, AL
2005 – 2010  Research Associate, Electrical and Computer Engineering department, University of South Alabama, Mobile, AL

Five Products Most Relevant to Proposal:

Five Other Signification Products:

Synergistic Activities:

4. Organizing member of UTC Smart Grid Workshop 2012, Chattanooga, Tennessee.
5. Co-Chairman of the committee of 3rd Indonesia Focus 2011 Conference, Pittsburgh, PA.
A. Professional Preparation:

Indian Institute of Technology, Madras, India  Aerospace Engineering  B.Tech.  1991
Mississippi State University  Aerospace Engineering  M.S.  1993
Mississippi State University  Engineering  Ph.D.  1996

B. Appointments:

2017 – Present  Associate Professor
University of Tennessee at Chattanooga

2014 – Present  Joint Faculty Appointment
Oak Ridge National Laboratory

2011 – Present  Research Professor
University of Tennessee at Chattanooga

2002 – 2011  Associate Research Professor
University of Tennessee at Chattanooga

2002 – 2002  Associate Research Professor
Mississippi State University

1999 – 2002  Assistant Research Professor
Mississippi State University

1998 - 1999  Visiting Researcher (Unstructured Grid Technology)
Mississippi State University

1997 – 1998  Post-doctoral Fellow (Computational Fluid Dynamics)
Mississippi State University

1991 – 1996  Graduate Research Assistant
NSF ERC for Computational Field Simulation, Mississippi State University

C. 5 Publications Most Closely related to the Proposed Project:


October, 2016.


D. 5 Other Significant Publications:


E. Synergistic Activities (up to 5):

- SimCenter leadership role in unsteady viscous flow engineering applications, scientific computing, and unstructured grid technologies, including software development, integration, and management, and also facilitating teamwork to solve complex real-world engineering problems (University of Tennessee at Chattanooga)
- SimCenter leadership role in high-performance cluster computing, including cluster design, benchmarking, acquisition, and resource allocation (University of Tennessee at Chattanooga)
- Thesis Advisor for 2 Ph.D. students (University of Tennessee at Chattanooga)
- Committee Member for 3 Ph.D. students, and mentor for 1 Undergraduate Student Researcher (University of Tennessee at Chattanooga)
Craig R. Tanis

Professional Preparation

Tulane University  Computer Engineering / Robotics  BSE  1997
Tulane University  Computer Science  MS  1998
University of Tennessee  Computational Engineering  Ph.D.  2013

Appointments

- **2014-Present:** Assistant Professor, Faculty of Computer Science, University of Tennessee at Chattanooga
- **2010-2013:** Lecturer, Faculty of Computer Science, University of Tennessee at Chattanooga
- **2007-2010:** Graduate Student Researcher, SimCenter: National Center for Computational Engineering, University of Tennessee at Chattanooga
- **1999-2006:** Senior Programmer, Advance Internet, Jersey City, NJ
- **1996-1998:** Graduate Student Researcher, Mobile Robotics, Tulane University

Five Products Most Relevant to Proposal


Synergistic Activities

1. XSEDE Campus Champion for University of Tennessee at Chattanooga, 2014-Present
2. XSEDE Campus Champion Fellow 2015-16
3. Course developer for two graduate-level courses: (1) High-Performance Computing; (2) Parallel programming
Endong Wang, Ph.D., CPC, AIC, ASCE  
Department of Engineering Management & Technology, EMCS 326B, University of Tennessee-Chattanooga, Chattanooga, TN 37403, Tel: 423-425-5778; Fax: 423-425-5818;  
Email: Endong-Wang@utc.edu

Professional Preparation

<table>
<thead>
<tr>
<th>Organization</th>
<th>Degree</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanjing University of Science &amp; Technology (Nanjing, China)</td>
<td>Structure Engineering</td>
<td>B.E. 2003</td>
</tr>
<tr>
<td>Southeast University (Nanjing, China)</td>
<td>Management Science</td>
<td>M.S. 2006</td>
</tr>
<tr>
<td>University of Nebraska-Lincoln (Lincoln, NE)</td>
<td>Construction</td>
<td>M.S. 2011</td>
</tr>
<tr>
<td>University of Nebraska-Lincoln (Lincoln, NE)</td>
<td>Engineering</td>
<td>Ph.D. 2013</td>
</tr>
<tr>
<td>University of Wisconsin-Milwaukee (Milwaukee, WI)</td>
<td>Sustainable Manufacturing</td>
<td>Postdoctoral 2013-2013</td>
</tr>
</tbody>
</table>

Appointments

<table>
<thead>
<tr>
<th>Time</th>
<th>Position</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013−Present</td>
<td>Assistant Professor, Graduate Faculty, Construction Management,</td>
<td>University of Tennessee-Chattanooga (UTC)</td>
</tr>
<tr>
<td>2013−2013</td>
<td>Postdoctoral Research Associate, Mechanical Engineering,</td>
<td>University of Wisconsin-Milwaukee (UWM)</td>
</tr>
<tr>
<td>2009−2013</td>
<td>Graduate Research Assistant, Construction Management,</td>
<td>University of Nebraska-Lincoln (UNL)</td>
</tr>
<tr>
<td>2008−2009</td>
<td>Adjunct Researcher, Key Laboratory of Contemporary Management Informatics</td>
<td></td>
</tr>
<tr>
<td>2006−2009</td>
<td>Instructor, Civil Engineering, Ocean University of China</td>
<td></td>
</tr>
</tbody>
</table>

Products

Five Products Most Closely Related to the Proposed Project


Five Other Significant Products


Synergistic Activities

1. **Professional Activities:**

2. **Major Awards and Registration:** Recipient of the Outstanding Researcher, CECS, 2014-2016; the 2013 Outstanding Graduate Student Award, UNL, 04/18/13; Certified Associate Constructor (AC), 12/20/13; Certified Professional Constructor (CPC), 04/05/14


4. **Student Training:** Developed two undergraduate-level courses (UTC): Building Information Modeling, Green Building Rating Systems; and two graduate-level courses: Sustainability and LEED, Decision Making and Optimization (UTC) to strengthen sustainability education among undergraduates and graduates.
Robert S. Webster, Ph.D.

Associate Professor       tel: (423) 425-5509
Department of Mechanical Engineering    fax: (423) 425-5229
University of Tennessee at Chattanooga     Robert-Webster@utc.edu
Chattanooga, TN 37403     http://www.utc.edu

Professional Preparation:
Auburn University  Auburn, AL       Aerospace Engineering   B.A.E 1986
Mississippi State University  Starkville, MS  Aerospace Engineering   M.S. 1994
Mississippi State University  Starkville, MS  Aerospace Engineering   Ph.D. 2001
Mississippi State University  Starkville, MS  Aerospace Engineering   2001-2002

Appointments:

Associate Professor, Department of Mechanical Engineering, University of Tennessee at Chattanooga, January, 2017 to Present
Associate Research Professor, Department of Computational Engineering, University of Tennessee at Chattanooga, July, 2008 to December, 2016
Assistant Research Professor, Department of Computational Engineering, University of Tennessee at Chattanooga, December, 2002 to July, 2008
Postdoctoral Fellow, Engineering Research Center, Mississippi State University, May, 2001 to December, 2002
Graduate Research Assistant (PhD Program), Engineering Research Center, Mississippi State University, August, 1994 to May, 2001
Graduate Research Assistant (MS Program), Engineering Research Center, Mississippi State University, January, 1992 to August, 1994
Mechanical Engineer, US Army TMDE Support Group, Redstone Arsenal, AL, January, 1987 to December, 1988

Five Products Most Relevant to Proposal:
Five Other Signification Products:

Synergistic Activities:
Dalei Wu, PhD

Assistant Professor
Department of Computer Science and Engineering
The University of Tennessee at Chattanooga
Phone: (423) 425-4386, Fax: (423) 425-5442
Email: dalei-wu@utc.edu

A. Professional Preparation
Shandong University     Jinan, China           Electrical Engineering   B.Sc., 2001
Shandong University     Jinan, China           Electrical Engineering   M.S., 2004
Univ. of Nebraska-Lincoln Lincoln, USA          Computer Engineering     Ph.D., 2010

B. Appointments
2014–present  Assistant Professor
University of Tennessee at Chattanooga, Dept. of Computer Science and Engineering, Chattanooga, TN, USA
2004–2005  System Engineer
ZTE Telecom Corporation, WiMAX R&D, Shenzhen, China

C. Selected Publications
Publications Most Closely Related to Proposal

Other Significant Publications


D. Synergistic Activities

  This project provides experiences for students in network-enabled sensing and using big data analytics and visualization to solve real-world problems and benefit city and community.

- **Educational grants:**
  - NSF “SFS Program: Strengthening the National Cyber Security Workforce,” $1,540,763, 01/01/2017 - 07/31/2021, Senior Personnel.

- **Development of course materials for courses CPSC 4240/5240 Principles of Data Analytics and CPSC 4530/5530 Data Visualization and Exploration at UTC.**

- **Editorial positions:**
  - Associate Editor, Wiley Security & Communication Networks, since 10/2011.

- **Conference organization:**
  - Technical Program Committee Co-Chair, the 10th EAI International Conference on Mobile Multimedia Communications, 07/2017.
  - Symposium Co-Chair, the Wireless Networking and Multimedia (WNM) Symposium for ICCC 2017.
  - Track Co-Chair, BODYNETS, Special Track of Healthcare Applications and Challenges of Body Area Networks, 2013.
  - Workshops/Tutorials Chair, Mobimedia, 2015.
Li Yang  
Department of Computer Science Engineering  
University of Tennessee at Chattanooga  
735 Vine Street  
Chattanooga, TN 37405

a. Professional Preparation
- B. A. in Finance  
  Jilin University, Changchun, Jilin, P. R. China, 1997
- M. A. in Finance  
  Jilin University, Changchun, Jilin, P. R. China, 2000
- M. S. in Computer Science  
  Florida International University, Miami, FL, 2003
- Ph. D. in Computer Science  
  Florida International University, Miami, FL, 2005

b. Appointments
- Director  
  University of Tennessee at Chattanooga  
  UTC InfoSec Center – a National CAE-IAE  
  Nov. 2011 – Present
- Professor  
  Department of Computer Science and Engineering  
  University of Tennessee at Chattanooga  
  Aug. 2014 – Present
- Associate Professor  
  Department of Computer Science and Engineering  
  University of Tennessee at Chattanooga  
- Graduate Coordinator  
  Department of Computer Science and Engineering  
  University of Tennessee at Chattanooga  
  Aug. 2008 – Present
- Assistant Professor  
  Department of Computer Science and Engineering  
  University of Tennessee at Chattanooga  
- Research and Teaching Assistant  
  Department of Computer Science  
  Florida International University  

c.i. 5 Publications Most Closely related to the Proposed Project

c.ii. 5 Other Significant Publications


d. Synergistic Activities (up to 5)


4. NSF-Scholarship for Service (SFS), *Collaborative Project: Developing Faculty Expertise in Information Assurance through Case Studies and Hands-on Experiences* (with Xiaohong Yuan in NC A&T SU and Bill Chu in UNC Charlotte), DUE-1129444, PI, awarded, $100,000, 2011-2013.

ACCOMPLISHMENTS & OUTCOMES

Project Overview

Provide a scientific/technical overview of your research project—hypothesis or scientific aims, methodologies and activities, outcomes, etc.

The study of anything related to hypersonic flows has always been a challenge, whether experimental measurements in tunnels or computational simulation. The flow conditions (pressure, temperature, density, velocity) are so extreme, and the time scales on which things occur are so small that the accurate measurement and/or computation of these flows are not at all trivial. There are numerous physically complex phenomena that are simultaneously in play, and ultimately, these phenomena have to be accounted for if a hypersonic vehicle, regardless of its purpose, is to be successful in its mission. That is to say, it is truly a multi-physics problem. This is significant with regard to computational simulations, because flow solvers have been evolving in the direction of having multi-physics capabilities. In other words, a given computational tool is expected to be able to simulate the fluid mechanics problem coupled with the thermal and solid mechanics problems of the vehicle. The primary goal of the research is to accurately and efficiently compute the hypersonic flows over different geometries. A summary of the results of each configuration will be presented in the following.

In order to demonstrate the performance, applicability, and accuracy of the Tenasi structured flow solver, the computations were performed for viscous hypersonic flow over four different geometries. A summary of the results for each configuration will be presented in the following:

- Blunt-nosed configurations show excellent agreement with experiments.
- Pressure distributions at various locations show agreement very well with experiments.
- Mach number from 1.5 to 9.0, shock stand-off distance agrees very well with theory.

The following two double-hips ((1.8°X1°) and (2°X2°)) on flat plate show shock interactions of bodies in close proximity at a Mach number of 5.0:

- Mach number from 5.0 to 15.0, shock stand-off distance agrees very well with theory.
- Mach number from 1.5 to 9.0, shock stand-off distance agrees very well with theory.

For re-entry vehicles, the increased aerodynamic drag aids greatly in vehicle deceleration.
APPENDIX B

Awardee Project Reports

New Projects for FY2017
## PROJECT OVERVIEW

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Dr. Abdollah (Abi) Arabshahi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>Dr. Robert S. Webster</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Identify by type – senior personnel, technicians, graduate students, undergraduate students</td>
</tr>
<tr>
<td>Project Title</td>
<td>Computational Simulations of the Aerothermal Environment of Hypersonic Flight Vehicles</td>
</tr>
<tr>
<td>Date Submitted</td>
<td>March 7, 2016</td>
</tr>
<tr>
<td>Award Start - End Date</td>
<td>July 1, 2016 – June 30, 2017</td>
</tr>
<tr>
<td>Non-Technical Summary – 500 words or less</td>
<td>Continued advances in physics-based simulation technologies in general, and in Computational Fluid Dynamic (CFD) in particular, are essential and required to support almost every aspect of the Hypersonic project. These capabilities will be used to generate accurate numerical predictions to provide and enhance our understanding of the complex flow phenomena that occur at the hypersonic regime (such as aerothermodynamics, aerodynamic, chemical reactions, and high heat transfer) around any flight vehicle. Current effort at the UTC/SimCenter is to develop and validate a physics-based numerical capability for simulating flow around hypersonic aerospace vehicles and components of vehicles, so that performance can be more accurately evaluated and better understood.</td>
</tr>
<tr>
<td>Project Web Page(s)</td>
<td>Please provide the complete URL.</td>
</tr>
</tbody>
</table>

Please attach a Quad Chart using the following format as an example:  
In order to acquire the latest research progress in the aerothermodynamics of hypersonic vehicles, a comprehensive literature survey/review of hypersonic turbulent flow and available experimental data for vehicle flying at hypersonic speeds was conducted. The results confirmed the importance of the present research proposal. The cumulative outcomes of the present research proposal were one of the most significant achievements of the current study. A comprehensive study of computing a heat-conduction model within an existing aerodynamic code was carried out, which was successfully implemented in the in-house Tenasi. The goals of the present research proposal included:

1. A detailed numerical investigation was carried out for the prediction of shock wave/turbulent boundary layer interactions at Mach 5. The flowfield was generated by two sharp fins mounted at an angle of attack of 18° and 23°. The computations for both symmetric double-fin configurations were validated by comparison with available experimental data. Furthermore, grid sensitivity study was performed for both symmetric double-fin configurations, with the combination of the present study and computational analysis, the shock wave/turbulent boundary layer interactions at Mach 5 were well captured, and surface pressure compared well with the experimental data.

2. Another objective of this research was to assess in-house CFD capability for the prediction of shock wave/turbulent boundary layer interactions at hypersonic velocities. Shock wave/turbulent boundary layer interactions are a common feature occurrence in hypersonic flight with almost any flow deflection accompanied by shock formation. This part of the research particularly is relevant and very important to the capabilities for providing a substantial knowledge and treatment of the complex issues in high-speed propulsion.

A comprehensive study of coupling of a heat-conduction model with an existing fluid dynamics solver was investigated. A simple conjugate heat transfer model was developed, and the conjugate heat transfer analysis technique for hypersonic applications was one of the most important themes of the present research proposal. The objective is an accurate prediction of temperature and heat flux across the model. A simple conjugate heat transfer model was successfully implemented in the in-house Tenasi. The results confirmed the importance of the present research proposal. The cumulative outcomes of the present research proposal were one of the most significant achievements of the current study. A comprehensive study of computing a heat-conduction model within an existing aerodynamic code was carried out, which was successfully implemented in the in-house Tenasi.
distribution in space and time in a body and on its boundaries. The hypersonic flowfield around a blunted cone–flare exhibits some of the major features of the flows around space vehicles, e.g. a detached bow shock in the stagnation region and the oblique shock wave/boundary layer interaction at the cone–flare junction. The shock wave/boundary layer interaction can produce a region of separated flow. The region between the cone and the flare is particularly critical with respect to the evaluation of the surface heat flux. Induced flow separation is induced by the shock wave–boundary layer interaction, with subsequent flow reattachment, that can dramatically enhance the surface heat transfer. The exact determination of the extension of the recirculation zone is a particularly delicate task for the in-house Tenasi code. Indeed, apart from the modeling uncertainties associated to turbulence and real-gas effects, there are computational simulation difficulties associated to the mesh sensitivity issue. The comparison between computed and experimental results was excellent. In addition, the comparison between computed and experimental results was excellent for the entire flowfield. The comparisons demonstrated that the size of the separated region and the magnitude of the pressure distributions through the separated and reattaching region were in excellent agreement with the experimental measurements.

The hypersonic flowfield around a blunted cone–flare exhibits a detached bow shock in the stagnation region. The shock wave/boundary layer interaction produces a region of separated flow. The region between the cone and the flare is particularly critical with respect to the evaluation of the surface heat flux. Induced flow separation is induced by the shock wave–boundary layer interaction, with subsequent flow reattachment, that can dramatically enhance the surface heat transfer. The exact determination of the extension of the recirculation zone is a particularly delicate task for the in-house Tenasi code. Indeed, apart from the modeling uncertainties associated to turbulence and real-gas effects, there are computational simulation difficulties associated to the mesh sensitivity issue. The comparison between computed and experimental results was excellent. In addition, the comparison between computed and experimental results was excellent for the entire flowfield. The comparisons demonstrated that the size of the separated region and the magnitude of the pressure distributions through the separated and reattaching region were in excellent agreement with the experimental measurements.
Impact & Outcomes

**Impact on the career(s) of the PI, the co-PIs, and key collaborators**

A positive career impact occurred for those involved in the proposal.

**Students Impacted**

Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

**Community and Broader Impacts**

Consider and discuss the technical and societal impact of your research project.

Recently, there has been renewed hypersonic interest in response to perceived near-peer threats. The current research will be to support the development and improvement of reusable hypersonic vehicles. The rapid collection of information and to address emerging threats, the U.S. Air Force plans to develop reusable vehicle technology. This will increase national defense safety.

**Work Products Reduced to Practice**


<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Title</th>
<th>Publication Details</th>
</tr>
</thead>
</table>
Outreach & Collaboration

Please list your visits, workshops, or other collaboration efforts you held including the location (on campus, etc.):

New Inventions Reduced to Practice and When They Will be Formally Disclosed

Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well.

If you wish to open source a software prototype dataset, please state so; we will follow up with you with a disclosure process and guidelines on how to proceed effectively. For further instructions, please consult or contact your legal counsel.

Please list any visitors, workshops, or other collaborative events you held, including the location (on campus, etc.).
<table>
<thead>
<tr>
<th>WHAT'S NEXT FOR THIS RESEARCH?</th>
</tr>
</thead>
<tbody>
<tr>
<td>How will you follow up your CEACSE grant with work in the next 1, 2, ... 5 years?</td>
</tr>
<tr>
<td>What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?</td>
</tr>
<tr>
<td>Tell us anything else we should know about this work not described above.</td>
</tr>
<tr>
<td>What barriers (if any) do you face to reach these next goals?</td>
</tr>
<tr>
<td>Financial Report:</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Please attach the following:

- Final ledger report showing the final accounting for your award.
- Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.
- Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.

<table>
<thead>
<tr>
<th>Suppemental Award Request</th>
<th>Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).</th>
</tr>
</thead>
</table>
UTC-SimCenter
Technology Area of Interest: Hypersonic Airbreathing Vehicles
Proposal Title: Computational Simulations of the Aerothermal Environment of Hypersonic Flight Vehicles

Results

Surface pressure for a Blunted Cone-Flare Configuration at Free-stream Mach Number = 6.0, Re=8.0E+06

Operational Capability to be Provided:
Recently, there has been renewed hypersonic interest in response to perceived near-peer threats. To enable the rapid collection of information and to address emerging threats, the U.S. Air Force plans to develop reusable vehicles. The current research will be to support the development and improvement of reusable hypersonic vehicle structure technology. This will increase national defense safety.

Proposed Technical Approach:
The primary goal of the research is to accurately and efficiently compute the unsteady aerothermodynamics and aerothermoelastics for hypersonic vehicles in support of Tennessee Aerospace Initiative.

Task 1: Conduct simulations of geometries that are representative of key components of hypersonic vehicles. These simulations will focus only on the aerodynamic aspects of the problem; the results will be compared to experimental data, if available, and/or previously published results from other flow

Budget and Schedule:

<table>
<thead>
<tr>
<th>Description</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Budget</td>
<td>$97,859.00</td>
</tr>
<tr>
<td>Actual Used</td>
<td>$92,465.30</td>
</tr>
<tr>
<td>Balance</td>
<td>$5,393.70</td>
</tr>
</tbody>
</table>

Total period of performance is 12 months;
Task 1: Months 1-4
Task 2: Months 3-6
Task 3: Months 5-12
Task 4: Months 9-12
solvers.

Task 2: Couple the surface heat transfer effects with the aerodynamics; compare the simulations with experimental results.

Task 3: Add the capability for including aeroelastic effects; deflection and/or deformation as a result of aerothermal loading… that is the structural material response.

Task 4: Results will be compared to experimental data, if available, and/or previously published results from other flow solvers.

Deliverables:

Monthly Technical Report: Describing numerical methods, techniques and results that were developed or improved.

Progress/Status Report: Final Report

Organization Information:

UTC-SimCenter, Dr. Abi Arabshahi
701 East M.L. King Boulevard, Chattanooga, TN 37403
Telephone: 423-425-5485
Email: abi-arabshahi@utc.edu
## PROJECT OVERVIEW

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Trevor S. Elliott</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>(Originally Jan Evans)</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Chase Dobbins – Undergraduate student</td>
</tr>
<tr>
<td>Project Title</td>
<td>Investigation of Resources and Planning for Advanced Manufacturing Applications Center (AMAC) at UT Chattanooga</td>
</tr>
<tr>
<td>Date Submitted</td>
<td>June 28, 2016</td>
</tr>
<tr>
<td>Award Start - End Date</td>
<td>August 8, 2016 – June 30, 2017</td>
</tr>
</tbody>
</table>

### Non-Technical Summary – 500 words or less

This work was centered on the development of a resource plan, personnel and infrastructural, related to creating a center for advanced manufacturing. To that end, faculty within the SimCenter, the college of engineering, and other colleges at UTC were linked to topic areas relevant to manufacturing. More specifically they were linked to areas found to be of interest to local manufactures and constituent base of UTC. While the manufacturer needs were assessed the center infrastructural requirements were analyzed. A major finding was that industries are not currently utilizing advanced techniques/technologies in their processes. These industries voiced a desire to test these new techniques and technologies within their current production and a need for integration with conventional processes. The subsequent research on integration yielded results about companies reacting to exactly this need, such as GF+ with a pallet system for moving products from conventional processes to advanced or additive processes in a bulk and automated fashion. This company indicated their process was in need of modeling and simulation similar to what the SimCenter could provide. In addition to the modeling and simulation needs this finding pointed out the possible need for a technology transfer component within the center.

The facility layout produced within this work was a crucial element in space conversations and the space for the center has been secured. While creating the facility layout, equipment was assessed for its merits using a customized weighting scheme and desired equipment was selected for consideration. During the evaluation of potential equipment current faculty interests were considered.
which leads to a desired outcome of matched faculty interests to center subtopics and possible funding opportunities. The community impacts thus far have been in the area of awareness and soliciting of interested parties in the Chattanooga area. Entrepreneurial players such as CoLab, Branch Technologies, Collider Technologies, Feetz, and the Enterprise Center have been brought into the planning meetings for center realization. Industrial entities such as Komatsu, Tuftco, TN Rand, and Roper Company have been consulted to ascertain their needs and provide awareness about the center. Resources for certifications were located and resulted in an indirect student impact. These resources have now been implemented in a senior level course. The students in this course, all mechanical engineering students, will have the tools, training, and free access to certification for entry level lean six sigma certification.

| Project Web Page(s) | No external website. Additional material being archived for this project for future reference. |

*Please attach a Quad Chart using the following format as an example:*

## Project Overview

This project was aimed at evaluating the potential pathways for the development of an advanced manufacturing center. This work includes:

- A framework for external funding in support of applied advanced manufacturing research, industrial collaboration, educational outreach, and new methodologies.
- Developing local manufacturing resources and matching those to faculty expertise within the areas of modeling and simulation.

### Accomplishments & Outcomes

<table>
<thead>
<tr>
<th>List of Objectives / Aims</th>
<th>Major Milestones Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Funding:</td>
<td></td>
</tr>
<tr>
<td>Investments:</td>
<td></td>
</tr>
<tr>
<td>Outcome 1:</td>
<td></td>
</tr>
<tr>
<td>Outcome 2:</td>
<td></td>
</tr>
</tbody>
</table>

### Accomplishments

- Equipment essential to the research and educational efforts.
- Advanced computer-aided design (CAD) and manufacturing processes currently in use and used.
- Opportunities: Leverage current relationships with local and other battery manufacturers.
- Cumulative Outcomes:
  - Educational Alignment Program (EAP) funding opportunities.
  - Development of industrial partners and projects to fund development.
  - Financial goals: Consortia of industrial partners and projects to fund development.
  - Equipment procurement: Matching equipment for grant applications.
  - Education Alignment Program (EAP) funding opportunities.
  - Educational Alignment Program (EAP) funding opportunities.

### Outcomes

- Outcome 1: Develop a program for workforce development supported by local Chattanooga area manufacturing companies and Chattanooga Chamber.
- Outcome 2: Enhancements in nano and micro manufacturing of nanowire nodes and battery.
### Financial Goals:
Extramural funding of $250k/y to support continued projects in advancing this area. Consideration of NSF PD-16-0184, Cybermanufacturing.

#### Outcome 3: Design improvements of manufacturing equipment with emphasis in additive [Parkridge Medical Group]

- **Training:** Robotics, specifically programming and optimization [Branch Technologies]
- **Opportunities:** Leverage current solar desalination projects involving smart control and network
  - Equipment improvements
  - Current project with Solar Desal [Advanced Space Systems]
  - Access to small scale device which can be used to create scalable concepts, utilize additive, laser etching, and nano manufacturing processes.

- **Opportunities:** Leverage current solar desalination projects involving smart control and network.

- **Investments:** None currently. Could seek internal CEACSE funds if FY2018 offering or equipment improvements.

#### Outcome 4: Development of network and autonomous algorithm controlled manufacturing devices and processes.

- **Training:** IoT and additive [Denso]
- **Opportunities:** Leverage current solar desalination projects involving smart control and network.
  - Equipment improvements
  - Current project with Solar Desal [Advanced Space Systems]
  - Access to small scale device which can be used to create scalable concepts, utilize additive, laser etching, and nano manufacturing processes.

- **Opportunities:** Leverage current solar desalination projects involving smart control and network.

- **Investments:** None currently. Could seek internal CEACSE funds if FY2018 offering or equipment improvements.

### Use subtopics determined from funding areas to create initial list of external (industrial) partners with sustainable interest.

- **Areas of indicated interest for training or development of new processes or equipment (MME):**
  - Use subtopics determined from funding areas to create initial list of external (industrial) partners with sustainable interest.
  - Initial list of external (industrial) partners with sustainable interest.

- **Areas of indicated interest for training or development of new processes or equipment:**
All groups in the initial additive manufacturing questionnaire indicated interest in training for additive manufacturing. Further discussions revealed general interest in certifications in additive, lean, TPM, etc.

Additive interests were as follows:

- Prototyping: (L) Elliott, (T) Elliott, Evans, Goulet, Welsh.
- Custom/complex parts: dependent on product and desired process.

Based from topic areas found within discussions:

- Prototyping: (L) Elliott, Evans, Goulet, Welsh.
- Custom/complex parts: dependent on product and desired process.

Specifically to listed outcomes in funding and sub-topic area:

For outcome 1: Faculty with backgrounds for this outcome are (T) Elliott, Evans, Margraves, Webster, Roundy (from school of business), and (L) Elliott, (T) Elliott, Evans, Margraves, Webster.

For outcome 2: Faculty with backgrounds for this outcome are (T) Elliott, Palchoudhury, Albu or Rybicki (chemistry department), Buil (CEO of local battery manufacturing company), and Elliott, Evans, Margraves, Webster, Roundy (from school of business).

For outcome 3: Faculty with backgrounds for this outcome are (L) Elliott, (T) Elliott, Evans, Margraves, Newman, Palchoudhury, Steenivasan.

Initial research on similar facilities in the area and standard
### Challenges & Strategies Used to Address / Overcome:

<table>
<thead>
<tr>
<th>Document on infrastructural requirements for equipment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full list of deliverables.</td>
</tr>
<tr>
<td>Market analysis and develop a business case including feasibility/low-level equipment, costings, possible deliverables.</td>
</tr>
</tbody>
</table>

What didn’t work? What did you discover or learn from the parts that didn’t meet your initial concept at the proposal?

The last challenge was overcome via the many meetings with those involved and several iterations on the site layout including ones that resulted from reduction in space allocation.

The initial ground work that was proposed for maximum utilization of student efforts during the academic year.

In support of the center, instead the industry partners were asked about the problems they have generally and as might relate to specific technologies (such as additive devices). The result was finding topic areas that coincided with current faculty backgrounds.

The traditional model of advertising what faculty can do and then see if industry has a need didn’t seem proper for this type of applied center when initial conversations involved membership payment. The modeling and simulation challenge was expected to some degree from the outset the PI decided to develop some pathways for meeting industry needs while enhancing the research portfolios of faculty within the university. The traditional model of advising what faculty can do with emphasis on academic and meeting the change requests that were critical to layout and center design.

The model and simulation challenge was expected to some degree from the outset the PI decided to develop some pathways for meeting industry needs while enhancing the research portfolios of faculty within the university. The traditional model of advising what faculty can do with emphasis on academic and meeting the change requests that were critical to layout and center design.

The last challenge was overcome via many meetings with those involved and several iterations on the site layout including ones that resulted from reduction in space allocation.

What didn’t work? What did you discover or learn from the parts that didn’t meet your initial concept at the proposal?
IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators:

The grant has widened the PI’s view on funding possibilities as well as areas of interest for future research. This has been facilitated by an increased understanding of the landscape and potential opportunities. The efforts on this work have resulted in the preparation of a national funding opportunity which is targeted for submission during the next cycle in 2018. Finally, the greatest impact for the PI was the realization that he/she could capitalize on past Information and Technology experience.

Students Impacted:

Chase Dobbins – Mechanical Engineering Student

Graduated Fall of 2016.

- Expanded on 2D/3D modeling experience by completing the last iteration of manufacturing space layout.
- Learned the detailing of a comprehensive business plan with competitive analysis and asset costing.
- Expanded on his knowledge of dealing with vendors for technical and quote materials.
- Currently using experience to search for a position in advanced manufacturing or aerospace.
- While researching certifications of interest to industrial partners learned of free access to Lean Six Sigma White Belt certification test. Implemented course materials and certification into the 4500 course for all ME students.

Work Products Reduced to Practice:

- Reduced to practice: New inventions reduced to practice and when they will be formally disclosed.
- Applicable bibliographic entry where appropriate: Provide a bibliographic entry where appropriate documents for center logistics:

- Technical specifications for building design, specifications, and certifications provided to administrators for building reports.
- Final plan (original through revision 8) – Final revision included.
- Floor plans (original through revision 8) – Final revision included.
- Work products reduced to practice and when they will be formally disclosed.
- New inventions reduced to practice and when they will be formally disclosed.
- Internal documents for center logistics:

- Internal documents for center logistics:

Community and Broader Impact:

This work includes workforce development which has the potential to make significant impacts on the Chattanooga and/or tri-state area. With training programs the center would provide a means for access to new manufacturing equipment, processes, and technologies to which patrons might not otherwise have access. The center would be one of a select few centers of its kind if equipped as designed allowing for limitless new research and technologies and research initiatives.

Collaborations:

- Pl, the co-PIs, and key collaborators: The grant has widened the PI’s view on funding possibilities as well as areas of interest for future research. The efforts on this work have resulted in the preparation of a national funding opportunity which is targeted for submission during the next cycle in 2018. Finally, the greatest impact for the PI was the realization that he/she could capitalize on past Information and Technology experience.

Impact & Outcomes
Outreach & Collaboration

There were no hosted events by UTC for this project. However, there were many correspondences with local industrial partners. Some of the discussions were developed while meeting the partners at their facilities and for detailed discussions of their processes and how UTC could develop new enhancements for those processes. UTC was also able to develop new technologies with some of the industrial partners. UTC also hosted the events at their facilities and for outreach & collaboration.

EXTERNAL FUNDING

Proposal Submissions

None

Contracts / Awards Received

Space within the Mapp Building on UTC's campus was provided for the establishment of this center. Currently, approximately 6500 sqft. of space is used for funding in current/pending funding reports. One funded grant for key personnel from THEC for workshop on improving teacher quality during this period. One grant pending review with this grant listed as current funding.

Sponsored Program Capacity

Building Activities

Did not request enough funds for hosted workshop attendance. Located workshop materials from different national funding agencies and reviewed them for potential funding applications, such as NSF MME and Cyber Manufacturing. Also located and reviewed many workshop reports (MME, Materials Innovation, Advanced Manufacturing, etc.).

Outreach & Collaboration

There were no hosted events by UTC for this project. However, there were many correspondences with local industrial partners. Some of the discussions were developed while meeting the partners at their facilities and for detailed discussions of their processes and how UTC could develop new enhancements for those processes.
What's next for this research?

How will you follow up your CEACSE grant with work for proposal submission started the winter break should provide the time to complete and submit funding requests before the next semester.

The primary barrier is time. With the ground work for proposal submission started the winter break should have been working with a local battery manufacturer to utilize batteries in EV and ZEB applications but this work has resulted in interest in the battery and BMS design itself. To that end I currently have a senior design project involving optimization lab placement for high energy cells. Also in the battery area I have interests in additive manufacturing development (related to particle placement, density, and tracking). This interest could also be collaborative with a faculty member identified during the CEACSE work in Chemical Engineering and one in Chemistry.

I have been working with a local battery manufacturer to utilize batteries in EV and ZEB applications but this work has resulted in interest in the battery and BMS design itself. To that end I currently have a senior design project involving optimization lab placement for high energy cells. Also in the battery area I have interests in additive manufacturing development (related to particle placement, density, and tracking). This interest could also be collaborative with a faculty member identified during the CEACSE work in Chemical Engineering and one in Chemistry.

What other related research will you pursue (and with whom) in light of the support you’ve received from CEACSE?

I have been working with a local battery manufacturer to utilize batteries in EV and ZEB applications but this work has resulted in interest in the battery and BMS design itself. To that end I currently have a senior design project involving optimization lab placement for high energy cells. Also in the battery area I have interests in additive manufacturing development (related to particle placement, density, and tracking). This interest could also be collaborative with a faculty member identified during the CEACSE work in Chemical Engineering and one in Chemistry.

Tell us anything else we should know about this work not described above.

The primary barrier is time. With the ground work for proposal submission started the winter break should provide the time to complete and submit funding requests before the next semester.

What barriers (if any) do you face to reach these next goals?

How will you follow up your CEACSE grant with work in the next 1, 2, ... 5 years?

As a result of this research, a January or September 2018 submission to the NSF MME opportunity will be...
FINANCIAL ACCOUNTING

<table>
<thead>
<tr>
<th>Financial Report:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Award Amount:</td>
<td>$24,300.00</td>
</tr>
<tr>
<td>Cumulative Expenditures:</td>
<td>$17,413.52</td>
</tr>
<tr>
<td>Remaining Award Amount:</td>
<td>$6,886.48</td>
</tr>
</tbody>
</table>

Please attach the following:
- Final ledger report showing the final accounting for your award.
- Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.
- Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.

Supplemental Award Request

Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).

$0
## PROJECT OVERVIEW

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Gregory W. Heath, DHSc, MPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>Mina Sartipi, PhD</td>
</tr>
<tr>
<td></td>
<td>James Newman, PhD</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Andrew Mindermann, BS – GIS Technician</td>
</tr>
<tr>
<td></td>
<td>Guijing Wang, PhD – Health economist – CDC</td>
</tr>
<tr>
<td></td>
<td>Eric Asboe, MPhil – Transportation Planner- City of Chattanooga</td>
</tr>
</tbody>
</table>

### Project Title
Healthy and Intelligent Transportation Planning: Estimating Return on Investment Associated with Improved Infrastructure for Bicycling and Walking and Decreased Physical Inactivity in Chattanooga/Hamilton County

### Date Submitted
September 1, 2017

### Award Start - End Date
July 1, 2016 – June 30, 2017

### Non-Technical Summary – 500 words or less
Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter. Based on data related to environment, transportation, and health, we proposed to provide a customized ‘environmental infrastructure and health return-on-investment calculator’ to be used by planners and personal users to guide in planning for pedestrian/bicycle path cost outlays for the former and healthy active wayfinding by the latter. Transport and recreation path/sidewalk costs were assessed in partnership with the city of Chattanooga’s Department of Transportation for both recent and projected transport and recreation construction costs, land costs, projected construction time, and populations reached. Physical inactivity behavior associated impact on heart disease, stroke, type 2 diabetes, colon cancer, and breast cancer prevention outcomes were calculated using: 1) the relative
risk (RR) for each of the chronic diseases in association with estimates of physical inactivity; 2) accessing through the Behavioral Risk Factor Surveillance System, the current prevalence of physical inactivity among the adult population 18 years and older residing in Chattanooga/Hamilton County and specifically Census Tracts 16, 18, 19, and 20; 3) using the results from steps 1 and 2 to calculate a Chattanooga/Hamilton County-specific and Census-specific Population Attributable Fraction (PAF) for each of the physical inactivity and chronic disease outcomes; and 4) Adjust the PAF’s for each of the outcomes in accordance with the effect size expected from the sidewalks and paths on behavioral changes in terms of increased levels of physical activity among the adult population; and 5) adjusted cost of chronic disease’s affected by changes in physical activity due to sidewalk/path changes. In addition, we created an application that provides a personalized planning for active transportation in response to vehicular traffic patterns and air quality so as to alert bike and pedestrian active transporters about the potential hazards and/or conditions of travel routes. Hence, in terms of urban planning, the data generated by our applications resulted in a potential tool that urban planners can use to maintain/build good/safe road/street networks and urban facilities to support active transportation and physical activities among residents. Our models assessing the impact of increased exposure to dedicated transport/recreation sidewalks/bike paths demonstrated a decrease in physical inactivity among adult residents in Chattanooga Census Tracts 16, 18, 19, 20 by a range of 25% to 50%, with a corresponding decrease in chronic diseases and their associated costs by as much as $1.2M over a project 4-year period, thus providing evidence for a return-on-investment for constructing such sidewalk/pathways.

<table>
<thead>
<tr>
<th>Project Web Page(s)</th>
<th>Please provide the complete URL.</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
Introduction. Recent studies suggest that urban design, land use, and transportation planning at the community and street/neighborhood level contribute to enhanced transport options and increased physical activity among residents [1]. These changes have been linked to the prevention of premature mortality from the key non-communicable diseases (NCD) of coronary heart disease (CHD), type 2 diabetes (T2D), colon cancer (CCa), breast cancer among women (BrCa), stroke, and total mortality among residents as well [2]. However, there is a paucity of information on the relative cost of the infrastructure and the yield in terms of increased incidence and mortality of these NCDs. Moreover, these models are highly integrated with other urban planning models. However, the accessibility to computational resources that have become available over the past decade represents an opportunity to utilize such technology to assess the effects of such changes on transport behavior and physical activity. The need for modeling in urban land-use and transportation planning was recognized in the early 1960s. Since then, these models have grown in complexity and scope, and they now incorporate data ranging from economic and demographic transitions, household transitions, and environmental factors. For example, studies have shown negative outcomes for the interaction between physical activity and environmental factors for asthma [4], myocardial infarction/coronary insufficiency [5], and stroke [6]. In these planning models, the computer modeling utilizes various pattern recognition and statistical inference methods based on available empirical data. Moreover, these models are tightly integrated with GIS. These modeling techniques have the potential to increase the regular physical activity and, consequently, impact the health outcomes of children/youth and adults at risk for the aforementioned health outcomes. Since such infrastructure changes are rare and costly, and very little is known about the potential to increase the regular physical activity and, consequently, impact the health outcomes of children/youth and adults at risk, it is critical to assess the effects of such changes on transport behavior and physical activity.
The proposed calculator is intended to inform and guide community policy makers, urban planners, and transportation planners on prioritizing planning for the most cost-effective and cost-beneficial transport and recreational infrastructure enhancements in terms of yielding improved health outcomes for the citizens assigned to their responsibility.

It is known that physical inactivity is a major contributor to the steady rise in rates of T2D, CHD, stroke, and other NCDs in the United States [10]. Hence, health-oriented physical activities should be promoted. However, physical activities cannot always lead to health promotion. If there is no infrastructure or facilities available to support physical activities, there may be undue safety hazards associated with such activities. For example, people may view walking and bicycling as unsafe due to heavy traffic and/or due to a scarcity of urban infrastructure such as sidewalks, crosswalks, and bicycle lanes and dedicated paths. The proposed calculator may provide a useful service to planners and policy makers that includes recommendations for health-enhancing active transportation using safe and activity-friendly routes.

Methods.

For the CEASE urban planning project, we created an application/service that provides a personalized planning for active transportation. Active transportation, which involves physical activities, should be advocated for health promotion. Our application exploited two Python packages (i.e., OSMnx and NetworkX) for algorithm development and performance visualization. Data extracted from Open Street Map was used to generate the required road/street network/graph in our application. The personalized planning considers a series of objectives/constraints for each individual user. These objectives/constraints include (but not limited to) weather condition (e.g., temperature, sun exposure, and air pressure), road/street elevation/condition, and air quality. Precise elevation data was obtained through a Google elevation API. We can then compute elevation change and elevation grade for each edge in the network/graph. Figure 1 shows the elevation in the city of Chattanooga. Each node's color is based on its elevation attribute, where yellow represents a higher elevation and purple represents a lower elevation. Figure 2 shows a zoomed in version of Figure 1. We also simulated air quality and labeled the corresponding data in the network/graph. Chattanooga is in the process of deploying air quality sensors. Our application can take real-time air quality data measured by these sensors. Meanwhile, by leveraging our previous research on mobile health/telemedicine, we can take into account the individual's detailed real-time health status and provide personalized health promoting options. More people living in currently distressed neighborhoods in the Chattanooga region benefit from our proposal.

Environmental infrastructure and transport and recreation infrastructure costs were assessed in partnership with the city of Chattanooga’s Department of Transportation and recreation infrastructure costs were assessed in partnership with the community infrastructure and public recreation amenities. The proposed calculator is designed to inform and guide community policy makers, urban planners, and transportation planners on prioritizing planning for the most cost-effective and cost-beneficial transport and recreational infrastructure enhancements in terms of yielding improved health outcomes for the citizens.
inactivity and controlling for all known confounders [3]; 2) accessing through the Behavioral Risk Factor Surveillance System, the current prevalence of physical inactivity and prevalence of those meeting current physical activity dose recommendations among the adult population 18 years and older residing in Chattanooga/Hamilton County and specifically Census Tracts 16, 18, 19, and 20 [11 and 12]; 3) using the results from steps 1 and 2 to calculate a Chattanooga/Hamilton County-specific and Census-specific Population Attributable Fraction (PAF) for each of the physical inactivity and NCD outcomes; and 4) Adjust the PAF's for each of the NCD outcomes in accordance with the effect size expected from the infrastructure changes in terms of increased levels of physical activity among the adult population; and 5) econometrically adjust the cost of NCD's affected by environmental infrastructure changes in Chattanooga/Hamilton County and specifically Census Tracts 16, 18, 19, and 20 [11 and 12] using the results from steps 1 and 2 to calculate a Chattanooga/Hamilton County-specific and Census-specific PAF for each of the NCD's affected by changes in physical inactivity due to infrastructure changes. [13]

Results: The personalized active transport planning problem is a multi-objective multi-constraint optimization problem. We designed algorithms with the desired complexities by taking advantage of optimization theory and graph theory to get feasible solutions. In terms of urban planning, the data generated by this application can help urban planners to maintain/build good/safe road/street networks and urban infrastructure/facilities for active transportation and physical activities.

A demographic profile of Chattanooga/Hamilton County was generated using locally available vital statistics for the most recent census estimates (Table 1). Estimate total population of the city/county is 340,973 persons. The proportion of the population that is white/Caucasian is ~75%; black/African-American, ~20%; Hispanic/Latino, ~5% (see Table 1). Eighty-six percent of residents have a high school or higher level of education, with 27.2% with a bachelor's degree or higher (Table 1). The prevalence and frequencies of smoking and obesity among adults 18 years and older in Chattanooga/Hamilton County identify 23% as current smokers; 66% as overweight or obese; 31% who are physically inactive; 35% with known hypertension; 35% with elevated blood cholesterol levels (Table 2). The leading causes of death among Chattanoogans is heart disease, cancers, and chronic obstructive lung disease (Table 3). Significant disparities exist for cause of death by race/ethnicity (Table 4) and gender (Table 5). The prevalence and estimated numbers of adults 18 years and older with coronary heart disease (7.2%); Stroke (3.8%); colon cancer (0.0027%); breast cancer among women (2.35%); and type 2 diabetes mellitus among adults aged 18 years and older is ~7.7% of coronary heart disease; 6.6% of stroke; 8.5% of colon cancer; 7.8% of breast cancer among women; and ~12% of all type 2 diabetes mellitus are results of such physical inactivity among the adult population on these NCD outcomes in adults 18 years and older (Table 6).

Examining the impact of Chattanooga/Hamilton County specific PAF's for all known NCD's projected to cost a total of $9,319M over the 3-year period or $3,113M per year (Table 7). With the accumulated cost of these NCD's in Chattanooga/Hamilton County through 2020 an annual per person are reported in Table 8. Among the NCD's projected to cost a total of $9,319M over the 3-year period or $3,113M per year, the economic impact (direct and indirect costs) of physical inactivity alone among the adult population on these NCD's are ~7.7% of coronary heart disease; 6.6% of stroke; 8.5% of colon cancer; 7.8% of breast cancer among women; and ~12% of all type 2 diabetes mellitus are results of such inactivity and controlling for all known confounders [3]; adjusting through the Behavioral Risk Factor Surveillance System, the
physical inactivity estimates are recalculated to demonstrate a projected decrease in physical inactivity due to the presence of active transport/recreation infrastructure of ~50% across all of the affected census tracts (Table 13). Finally, the current physical inactivity PAF’s for each of the census tracts are calculated with estimated costs (direct and indirect) for each of the NCD outcomes as well as the recalculated PAF’s based on the effect size differences due to exposure to existing the proposed pedestrian and bicycle infrastructure suggesting a decrease in physical inactivity related NCD costs for these Census Tracks dropping from an estimated cost of $2.7M to ~$1.5M (Table 14). GIS generated maps demonstrate the changes in physical inactivity induced by enhanced access to pedestrian and bicycle infrastructure for Census Tracts 16, 18, 19, and 20 (Figures 5, 6, 7, and 8, respectively).

List of Objectives / Aims / Major Milestones Proposed

Cumulative Outcomes / Accomplishments

Chattanooga’s Transportation Department, in collaboration with our collaborators at the City of Chattanooga, was able to access through sensor technology the air quality readings from EPA sensors, which are fixed sensors. Hence we were not able to assess air quality to the proximal areas of the Tennessee River Park infrastructure and proposed bike/pedestrian spur into South Chattanooga (i.e., Alton Park).

Cost data for the Riverpark extension and the projected costs for the rail-to-trail Alton Park were obtained through our collaborators at the City of Chattanooga’s Transportation Department.

(3) Health Behavior Impact and NCD Prevention Outcomes and Cost Effectiveness - This task consists of a.) calculating the relative risk (RR) for each of the NCD outcomes in association with physical inactivity and controlling for all known confounders; b.) accessing through the Behavioral Risk Factor Surveillance System, the current prevalence of physical inactivity and prevalence of those meeting prevalence of physical inactivity dose recommendations; and c.) using the results from steps 1 and 2 to calculate a population attributable fraction (PAF) for each of the NCD outcomes. These data were accessed through the Behavioral Risk Factor Surveillance System published by the Centers for Disease Control and Prevention (CDC), specifically census-level data on physical inactivity was obtained from the 500 Cities Project of CDC. Relative Risk for the selected chronic disease outcomes for each county were obtained through the BRFSS. These data were accessed through the Behavioral Risk Factor Surveillance System, the current prevalence of physical inactivity and prevalence of those meeting prevalence of physical inactivity was obtained from the 500 Cities Project of CDC. Relative Risk for the selected chronic disease outcomes for each county were obtained through the BRFSS.
Chattanooga/Hamilton County-specific Population Attributable Fraction (PAF) for each of the physical inactivity and NCD outcomes; http://health.hamiltontn.org/Portals/14/CommunityHealth/AssessmentPlanning/De%20of%20Our%20Health%202015%20Final.pdf

Challenges & Strategies Used to Address / Overcome:

- Adjust the PAF's for each of the NCD outcomes in accordance with the effect size expected from the infrastructure changes in terms of increased levels of physical activity among the adult population.
- The effect size expected from the infrastructure changes in terms of increased levels of physical activity among the adult population is derived from the systematic review by Heath et al., (Ref. #1)

What didn’t work? What did you disprove or learn from the parts that didn’t meet your initial concept at the proposal?
Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?

<table>
<thead>
<tr>
<th>The Sensor monitoring goals were not met.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Also, we were unable to finalize our Return-on-Investment algorithm and subsequent Smartphone application.</td>
</tr>
</tbody>
</table>

The collaboration with Chattanooga's Department of Transportation has opened up new opportunities to pursue the concepts of a healthy community and projects dedicated to environmental justice.

Also, we were unable to finalize our Return-on-Investment algorithm and subsequent Smartphone application.

### IMPACT & OUTCOMES

**Impact on the careers of the PI, co-PIs, and key collaborators**

- Dr. Heath was further exposed to the use of econometric data and the direct and indirect costs of selected chronic disease outcomes.
- Drs. Sartipi and Newman were further exposed to the use of public health data and health applications associated with their computational skillset.
- Health was further exposed to the use of environmental and health data and health applications associated with their computational skillset.

**Students Impacted**

- Graduate Students in Computer Science and Engineering were exposed to the modeling of environmental (air quality) data.

**Community and Broader Impacts**

The collaboration with Chattanooga's Department of Transportation has opened up new opportunities to pursue the concepts of a healthy community and projects dedicated to environmental justice.

- It also opened up new opportunities to pursue the concepts of a healthy community and projects dedicated to environmental justice.

*Consider and discuss the technical and actual or potential societal impacts of your research project.*
**Work products reduced to practice**

Provide list of sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.

### Outreach & Collaboration

Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc.).

**Physical Activity and Public Health Workshop – May 5, 2017**

PI assisted by other UTC faculty presented a workshop for professional staff of the Tennessee Department of Health Southeast Regional Office. Results from the current project were presented as examples on how public health data can be used in support of the promotion of health and concept of a health community.

Results from the current project were presented as examples on how public health data can be used in support of the promotion of health and concept of a health community.

*Please include software, papers, presentations, posters, and creative works. Indicate Referred Journal, Referred Conference, Non-Referred Conference for each publication listed. Referred publications indicate the impact factors where applicable.*

**Proposal Submissions**

None

### External Funding

Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.

**Proposal Submissions**

None
Contracts / Awards Received

List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable).

Tell us anything else we should know about this above.

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1, 2, ... 5 years?

Finalize the ROI algorithm and smartphone application. Seek to test this app with data from other communities where infrastructure has or will be constructed for bike and pedestrian transport and recreational infrastructure.

Further exploration of natural experiments, where bike and pedestrian infrastructure is being built and/or transported and healthy communities where infrastructure has or will be constructed for bike and pedestrian transport and recreational infrastructure. Apply these results into a larger effort to explore the concepts and principles of a Culture of Health and Healthy Community.

Sponsored Program Capacity Building Activities

What other related work not described should we know about this above?

Contract or Award

List contracts or awards received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable).
What barriers (if any) do you face to reach these next goals?

Primary barriers are associated with procuring funding through NIH, CDC, or DOT – where the competition for active living research is quite vigorous. Another local barrier is the political resistance to further implement bike and pedestrian infrastructure outside the immediate downtown Chattanooga area.
### Financial Accounting

<table>
<thead>
<tr>
<th>Financial Report:</th>
<th>Total Award Amount:</th>
<th>$97,942</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cumulative Expenditures:</td>
<td>$97,942</td>
</tr>
<tr>
<td></td>
<td>Remaining Award Amount:</td>
<td>$0</td>
</tr>
</tbody>
</table>

**Please attach the following:**

- *Final ledger report showing the final accounting for your award.*
- *Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.*
- *Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.*

### Supplemental Award Request

<table>
<thead>
<tr>
<th></th>
<th>Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO, NA</td>
</tr>
<tr>
<td></td>
<td>$</td>
</tr>
</tbody>
</table>
Fig. 1 – Chattanooga-Wide Elevation Map
Figure 4 – A result of our proposed routing algorithm considering distance and air quality decision-making factors
Fig. 2 – Zoomed in version of Chattanooga Wide Elevation
Figure 3 – A result of a routing algorithm considering only distance as a decision making factor
<table>
<thead>
<tr>
<th>Table 1. Demographic Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
</tr>
<tr>
<td>Population under 5 years</td>
</tr>
<tr>
<td>Population under 18 years</td>
</tr>
<tr>
<td>Population 65 years and older</td>
</tr>
<tr>
<td>Median Age</td>
</tr>
<tr>
<td>Persons under age 65 living with a disability</td>
</tr>
<tr>
<td>Language other than English spoken at home</td>
</tr>
<tr>
<td>Race</td>
</tr>
<tr>
<td>White</td>
</tr>
<tr>
<td>African American/Black</td>
</tr>
<tr>
<td>Asian</td>
</tr>
<tr>
<td>American Indian/Alaska Native</td>
</tr>
<tr>
<td>Some other race</td>
</tr>
<tr>
<td>Two or more races</td>
</tr>
<tr>
<td>Ethnicity</td>
</tr>
<tr>
<td>Hispanic/Latino</td>
</tr>
<tr>
<td>Education, persons 25+</td>
</tr>
<tr>
<td>Less than high school</td>
</tr>
<tr>
<td>High School graduate or higher</td>
</tr>
<tr>
<td>Bachelor’s degree or higher</td>
</tr>
<tr>
<td>Economic Indicators</td>
</tr>
<tr>
<td>Unemployed (% of civilian labor force)</td>
</tr>
<tr>
<td>Median household income</td>
</tr>
<tr>
<td>Persons living below poverty</td>
</tr>
<tr>
<td>Children (18 or under) living below poverty</td>
</tr>
<tr>
<td>Home ownership rate</td>
</tr>
</tbody>
</table>

Sources: U.S. Census Bureau: 2000 Census and 2009-2013 American Community Survey
* The U.S. Census Bureau used a different measure for reported disability the 2000 Census.
**Adjusted for inflation, the 2000 median household income for Hamilton County equals $54,436 in 2013 dollars.
Table 2. Summary of Chronic Disease Risk Factors

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Smoker</td>
<td>23%</td>
<td>24%</td>
<td>20%</td>
</tr>
<tr>
<td>Smokeless Tobacco User</td>
<td>4%</td>
<td>5%</td>
<td>N/A</td>
</tr>
<tr>
<td>Overweight or Obese (BMI 25+)</td>
<td>66%</td>
<td>67%</td>
<td>64%</td>
</tr>
<tr>
<td>Obese (BMI 30+)</td>
<td>29%</td>
<td>31%</td>
<td>28%</td>
</tr>
<tr>
<td>No Leisure Physical Activity</td>
<td>31%</td>
<td>34%</td>
<td>25%</td>
</tr>
<tr>
<td>5+ Daily Servings Fruits/Vegetables</td>
<td>13%</td>
<td>9%</td>
<td>N/A</td>
</tr>
<tr>
<td>Hypertension</td>
<td>35%</td>
<td>39%</td>
<td>31%</td>
</tr>
<tr>
<td>High Blood Cholesterol</td>
<td>35%</td>
<td>39%</td>
<td>38%</td>
</tr>
<tr>
<td>Binge Drinker</td>
<td>10%</td>
<td>10%</td>
<td>17%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Smoker</td>
<td>17%</td>
<td>22%</td>
<td>18%</td>
</tr>
<tr>
<td>Smokeless Tobacco User</td>
<td>11%</td>
<td>13%</td>
<td>8%</td>
</tr>
<tr>
<td>Overweight or Obese (BMI &gt; 85th)</td>
<td>27%</td>
<td>33%</td>
<td>28%</td>
</tr>
<tr>
<td>Obese (BMI &gt; 95th percentile)</td>
<td>12%</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td>Insufficient Aerobic Physical Activity*</td>
<td>75%</td>
<td>75%</td>
<td>73%</td>
</tr>
<tr>
<td>Over 2 hrs. non-school related</td>
<td>26%</td>
<td>30%</td>
<td>31%</td>
</tr>
<tr>
<td>5+ Daily Servings Fruits/Vegetables</td>
<td>20%</td>
<td>22%</td>
<td></td>
</tr>
<tr>
<td>Binge Drinker</td>
<td>18%</td>
<td>19%</td>
<td>22%</td>
</tr>
<tr>
<td>Rarely/Never Wear Seatbelt</td>
<td>7%</td>
<td>11%</td>
<td>8%</td>
</tr>
<tr>
<td>Rode w/driver under influence</td>
<td>21%</td>
<td>20%</td>
<td>24%</td>
</tr>
<tr>
<td>Physical Fight past 12 months</td>
<td>32%</td>
<td>31%</td>
<td>33%</td>
</tr>
</tbody>
</table>

Table 3. Leading Causes of Death: Age-adjusted deaths per 100,000

<table>
<thead>
<tr>
<th>Rank</th>
<th>Cause of Death</th>
<th>Hamilton County 2011-2013</th>
<th>Tennessee 2011-2013</th>
<th>United States 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Heart Disease</td>
<td>177.1</td>
<td>202.7</td>
<td>169.8</td>
</tr>
<tr>
<td>2</td>
<td>Cancer</td>
<td>172.3</td>
<td>186.2</td>
<td>163.2</td>
</tr>
<tr>
<td>3</td>
<td>Chronic Lower Respiratory Disease</td>
<td>51.3</td>
<td>52.3</td>
<td>42.1</td>
</tr>
<tr>
<td>4</td>
<td>Accidents/Unintentional Injuries</td>
<td>44.3</td>
<td>51.3</td>
<td>39.4</td>
</tr>
<tr>
<td>5</td>
<td>Stroke</td>
<td>42.1</td>
<td>44.7</td>
<td>36.2</td>
</tr>
<tr>
<td>6</td>
<td>Alzheimer’s Disease</td>
<td>39.6</td>
<td>37.4</td>
<td>23.5</td>
</tr>
<tr>
<td>7</td>
<td>Diabetes</td>
<td>28.0</td>
<td>25.1</td>
<td>21.2</td>
</tr>
<tr>
<td>8</td>
<td>Suicide</td>
<td>14.4</td>
<td>14.5</td>
<td>12.6</td>
</tr>
<tr>
<td>9</td>
<td>Nephritis</td>
<td>12.0</td>
<td>13.3</td>
<td>13.2</td>
</tr>
<tr>
<td>10</td>
<td>Liver Disease</td>
<td>10.7</td>
<td>12.9</td>
<td>10.2</td>
</tr>
</tbody>
</table>

Sources: Tennessee Department of Health, Division of Policy, Planning and Assessment and National Vital Statistics Reports, Volume 64, Number 2, CDC.
### Table 4. Ten Leading Causes of Death in Hamilton County by Race Age-adjusted Rates per 100,000 Population 2013

<table>
<thead>
<tr>
<th></th>
<th>White</th>
<th></th>
<th>Black</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rate</td>
<td>Rank</td>
<td>Rate</td>
<td>Rank</td>
</tr>
<tr>
<td>Heart Disease</td>
<td>173.4</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>207.1</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cancer</td>
<td>170.1</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>198.0</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Chronic Lower Respiratory Disease</td>
<td>54.4</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>38.8</td>
<td>6&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Accidents</td>
<td>48.6</td>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>33.2</td>
<td>7&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Stroke</td>
<td>40.0</td>
<td>5&lt;sup&gt;th&lt;/sup&gt;</td>
<td>52.7</td>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Alzheimer's Disease</td>
<td>39.9</td>
<td>6&lt;sup&gt;th&lt;/sup&gt;</td>
<td>41.8</td>
<td>5&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Diabetes</td>
<td>22.5</td>
<td>7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>60.9</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Suicide</td>
<td>17.1</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;</td>
<td>5.1</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Liver Disease</td>
<td>11.3</td>
<td>9&lt;sup&gt;th&lt;/sup&gt;</td>
<td>9.2</td>
<td>10&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Nephritis (Kidney Disease)</td>
<td>8.9</td>
<td>10&lt;sup&gt;th&lt;/sup&gt;</td>
<td>31.7</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Homicide</td>
<td>3.3</td>
<td>*</td>
<td>27.1</td>
<td>10&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*Not among top ten for that race.
Source: Tennessee Department of Health, Division of Policy, Planning and Assessment

### Table 5. Ten Leading Causes of Death in Hamilton County by Sex Age-adjusted rates per 100,000 population 2011-2013

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th></th>
<th>Female</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rate</td>
<td>Rank</td>
<td>Rate</td>
<td>Rank</td>
</tr>
<tr>
<td>Heart Disease</td>
<td>224.8</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>141.5</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cancer</td>
<td>216.9</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>143.9</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
</tr>
<tr>
<td>Chronic Lower Respiratory Disease</td>
<td>60.0</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
<td>46.5</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Accidents</td>
<td>58.4</td>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
<td>31.6</td>
<td>6&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Stroke</td>
<td>43.9</td>
<td>5&lt;sup&gt;th&lt;/sup&gt;</td>
<td>39.7</td>
<td>5&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Alzheimer’s Disease</td>
<td>30.7</td>
<td>6&lt;sup&gt;th&lt;/sup&gt;</td>
<td>44.0</td>
<td>4&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Diabetes</td>
<td>30.2</td>
<td>7&lt;sup&gt;th&lt;/sup&gt;</td>
<td>25.5</td>
<td>7&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Suicide</td>
<td>25.4</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;</td>
<td>4.9</td>
<td>10&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Liver Disease</td>
<td>13.6</td>
<td>9&lt;sup&gt;th&lt;/sup&gt;</td>
<td>7.8</td>
<td>9&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
<tr>
<td>Nephritis (Kidney Disease)</td>
<td>14.9</td>
<td>10&lt;sup&gt;th&lt;/sup&gt;</td>
<td>10.0</td>
<td>8&lt;sup&gt;th&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
Table 6. *Estimated Population of Chattanooga/Hamilton County, TN, adults 18 years and older (2013 inter-census estimate) = 268,005*

Prevalence (numbers of persons) of selected chronic conditions among adults 18 years and older living in Chattanooga/Hamilton County (2013 estimates):

- Coronary Heart Disease = 7.2% (19,296)
- Stroke = 3.8% (10,184)
- Colon Cancer = 0.0032% (857)
- Breast Cancer (women only) = 2.35% (3,149)
- Type 2 Diabetes Mellitus = 12.6% (33,769)

Table 7. *Estimated Direct and Indirect Costs of Selected Health Outcomes (morbidity and mortality) (projected through 2020)*

- Coronary Heart Disease (ICD-10: I20-I25) - $8,400 per person
- Stroke (thromboembolic – ICD-10: I60-I69) - $18,400 per person
- Colon Cancer (ICD-10: C18-C21) - $8,000 per person
- Breast Cancer (women only – ICD-10: C50) - $8,500 per person
- Type 2 Diabetes (ICD-10: E11) - $16,325 per person

*CDC Chronic Disease Calculator [https://www.cdc.gov/chronicdisease/calculator/][13]*

Table 8. *Estimated Direct Medical and Indirect Costs Associated with Selected Chronic Diseases Among Adults 18 Years and Older Living in Chattanooga/Hamilton County (2013) projected through 2020*

- Coronary Heart Disease - $162.1M (~$54M per year)
- Stroke - $187.4M (~$62.3M per year)
- Colon Cancer - $7M (~$2.3M per year)
- Breast Cancer in women - $26.8M (~$9M per year)
- Type 2 Diabetes Mellitus - $551.3M (~$184M per year)
Table 9. *Physical Inactivity Population Attributable Fraction (PAF) for Selected Health Outcomes*

PAF formula:

\[
PAF = \frac{P_d \cdot (RR_{adj} - 1) \times 100\%}{RR_{adj}}
\]

- \(P_d\) – % inactive among persons who eventually develop outcome (not among population)
- \(RR_{adj}\) – adjusted RR, inactive vs. active

**Physical Inactivity PAF Selected Health Outcomes among Chattanooga/Hamilton County Adults 18 years and older – Estimated prevalence of inactivity = 31% (2013)**

- **Coronary Heart Disease** – \(RR = 1.33\)
  
  \[PAF = 0.31 \left(\frac{1.33 - 1}{1.33 - 1}\right) + 1 \times 100\% = 7.69\%\]

- **Stroke** – \(RR = 1.27\)
  
  \[PAF = 0.31 \left(\frac{1.27 - 1}{1.27 - 1}\right) + 1 \times 100\% = 6.59\%\]

- **Colon Cancer** – \(RR = 1.38\)
  
  \[PAF = 0.31 \left(\frac{1.38 - 1}{1.38 - 1}\right) + 1 \times 100\% = 8.53\%\]

- **Breast Cancer in women** – \(RR = 1.34\)
  
  \[PAF = 0.31 \left(\frac{1.34 - 1}{1.34 - 1}\right) + 1 \times 100\% = 7.86\%\]

- **Type 2 Diabetes Mellitus** – \(RR = 1.63\)
  
  \[PAF = 0.31 \left(\frac{1.63 - 1}{1.63 - 1}\right) + 1 \times 100\% = 11.98\%\]


** Please refer to the attached Census Tract-specific estimates for physical inactivity to calculate Census Tract-specific PAF’s
Table 10. Physical inactivity related costs per chronic disease condition among Chattanooga/Hamilton County adults 18 years and older (2013) (projected through 2020)

<table>
<thead>
<tr>
<th>Disease</th>
<th>Population</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary Heart Disease</td>
<td>1484</td>
<td>$12.5M</td>
</tr>
<tr>
<td>Stroke (ICD-10: I60-I69)</td>
<td>671</td>
<td>$12.4M</td>
</tr>
<tr>
<td>Colon Cancer (ICD-10: C18-C21)</td>
<td>73</td>
<td>$585K</td>
</tr>
<tr>
<td>Breast Cancer (women, ICD-10: C50)</td>
<td>248</td>
<td>$2.1M</td>
</tr>
<tr>
<td>Type 2 Diabetes (ICD-10: E11)</td>
<td>4046</td>
<td>$66.1M</td>
</tr>
</tbody>
</table>

Table 11. Estimated Population by Chattanooga/Hamilton County Census Tract, among Adults 18 years and older (2013 inter-census est.) Potentially Most Affected by Existing and Proposed Bicycle and Pedestrian Infrastructure, and Park Space

- Census Tract 16 = 1867 residents
- Census Tract 18 = 2233 residents
- Census Tract 19 = 2735 residents
- Census Tract 20 = 1005 residents
Table 12. *Estimated Direct Medical and Indirect Costs of Selected Health Outcomes by Census Tract (projected through 2020)*

<table>
<thead>
<tr>
<th>Census Tract 16</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary Heart Disease</td>
<td>= 88 people x $8400 per person = $739,200.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke</td>
<td>= 24 people x $18,400 per person = $441,600.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colon Ca</td>
<td>= 6 people x $8,000 per person = $48,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breast Ca (women)</td>
<td>= 21 women x $8500 per person = $178,500.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes (type 2)</td>
<td>= 138 people x $16,325 per person = $2,252,850.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Census Tract 18</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary Heart Disease</td>
<td>= 105 people x $8400 per person = $882,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke</td>
<td>= 29 people x $18,400 per person = $533,600.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colon Ca</td>
<td>= 8 people x $8,000 per person = $64,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breast Ca (women)</td>
<td>= 25 women x $8500 per person = $200,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes (type 2)</td>
<td>= 165 people x $16,325 per person = $2,693,625.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Census Tract 19</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary Heart Disease</td>
<td>= 129 people x $8400 per person = $1,083,600.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke</td>
<td>= 36 people x $18,400 per person = $662,400.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colon Ca</td>
<td>= 9 people x $8,000 per person = $72,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breast Ca (women)</td>
<td>= 31 women x $8500 per person = $263,500.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes (type 2)</td>
<td>= 202 people x $16,325 per person = $3,297,650.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Census Tract 20</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronary Heart Disease</td>
<td>= 47 people x $8400 per person = $394,800.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stroke</td>
<td>= 13 people x $18,400 per person = $239,200.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colon Ca</td>
<td>= 4 people x $8,000 per person = $32,000.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breast Ca (women)</td>
<td>= 11 women x $8500 per person = $93,500.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diabetes (type 2)</td>
<td>= 75 people x $16,325 per person = $1,224,375.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 13. *Current physical inactivity estimates, estimated physical inactivity change by exposure to improved pedestrian and bicycle infrastructure, and recalculated physical inactivity level for Census Tracts 16, 18, 19, and 20, within Chattanooga/Hamilton County Among Adults 18 years and older (2013) – See Figures 1, 2, 3, 4*

<table>
<thead>
<tr>
<th>Census Tract #</th>
<th>Current Inactivity</th>
<th>Estimated Change</th>
<th>Recalculated Inactivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>52.7%</td>
<td>-25.5%</td>
<td>27.2%</td>
</tr>
<tr>
<td>18</td>
<td>20.3%</td>
<td>-9.8%</td>
<td>10.5%</td>
</tr>
<tr>
<td>19</td>
<td>52.7%</td>
<td>-25.5%</td>
<td>27.2%</td>
</tr>
<tr>
<td>20</td>
<td>31.5%</td>
<td>-15.2%</td>
<td>16.3%</td>
</tr>
</tbody>
</table>
**Table 14. Physical inactivity PAF and costs per chronic disease condition by selected Census Tracts, Chattanooga/Hamilton County, TN**

Current physical inactivity PAF and cost (direct and indirect) for selected health outcomes for Census Tracts 16, 18, 19, and 20 of Chattanooga/Hamilton County among adults 18 years and older

<table>
<thead>
<tr>
<th>Tract</th>
<th>CHD (cost)</th>
<th>Strk (cost)</th>
<th>CoCa (cost)</th>
<th>BrCa (cost)</th>
<th>T2DM (cost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>14.8% ($109K)</td>
<td>12.5% ($55K)</td>
<td>16.7% ($8K)</td>
<td>15.2% ($27K)</td>
<td>24.9% ($561K)</td>
</tr>
<tr>
<td>18</td>
<td>6.3% ($56K)</td>
<td>5.2% ($28K)</td>
<td>7.2% ($5K)</td>
<td>6.5% ($13K)</td>
<td>11.3% ($304K)</td>
</tr>
<tr>
<td>19</td>
<td>14.8% ($160K)</td>
<td>12.5% ($83K)</td>
<td>16.7% ($12K)</td>
<td>15.2% ($40K)</td>
<td>24.9% ($821K)</td>
</tr>
<tr>
<td>20</td>
<td>9.4% ($37K)</td>
<td>7.8% ($19K)</td>
<td>10.7% ($3K)</td>
<td>9.7% ($91K)</td>
<td>16.6% ($203K)</td>
</tr>
</tbody>
</table>

**Total**

<table>
<thead>
<tr>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>$363K</td>
</tr>
<tr>
<td>$185K</td>
</tr>
<tr>
<td>$28K</td>
</tr>
<tr>
<td>$171K</td>
</tr>
<tr>
<td>$1.9M</td>
</tr>
</tbody>
</table>

Chattanooga Regional (tracts 16, 18, 19, 20) Costs for 5 Chronic Diseases through 2020 = $2.7M

Recalculated physical inactivity PAF + cost (direct and indirect) for selected health outcomes following improved pedestrian/bicycle infrastructure for Census Tracts 16, 18, 19, and 20 of Chattanooga/Hamilton County among adults 18 years and older

<table>
<thead>
<tr>
<th>Tract</th>
<th>CHD (cost)</th>
<th>Strk (cost)</th>
<th>CoCa (cost)</th>
<th>BrCa (cost)</th>
<th>T2DM (cost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>8.2% ($61K)</td>
<td>6.8% ($30K)</td>
<td>9.4% ($4.5K)</td>
<td>8.5% ($15K)</td>
<td>14.6% ($329K)</td>
</tr>
<tr>
<td>18</td>
<td>3.4% ($28K)</td>
<td>2.8% ($15K)</td>
<td>3.8% ($2.4K)</td>
<td>3.8% ($8K)</td>
<td>6.2% ($167K)</td>
</tr>
<tr>
<td>19</td>
<td>8.2% ($89K)</td>
<td>6.8% ($45K)</td>
<td>9.4% ($7K)</td>
<td>8.5% ($22.4K)</td>
<td>14.6% ($481K)</td>
</tr>
<tr>
<td>20</td>
<td>5.2% ($21K)</td>
<td>4.3% ($10.3K)</td>
<td>5.9% ($2K)</td>
<td>5.3% ($5K)</td>
<td>9.5% ($116K)</td>
</tr>
</tbody>
</table>

**Totals**

<table>
<thead>
<tr>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>$200K</td>
</tr>
<tr>
<td>$100.3K</td>
</tr>
<tr>
<td>$16K</td>
</tr>
<tr>
<td>$50.4K</td>
</tr>
<tr>
<td>$1.1M</td>
</tr>
</tbody>
</table>

Chattanooga Regional (Tracts 16, 18, 19, 20) costs for 5 Chronic Diseases = $1.5M

Projected cost savings in direct medical costs and indirect costs due to decreased physical inactivity/increased physical activity:

$2,700,000 (current projected costs) - $1,500,000 = $1,200,000 savings in direct and indirect medical care costs through 2020
Table 15. *Costs and Projected Costs of Bicycle and Pedestrian Infrastructure Target Projects in Chattanooga/Hamilton County, TN*

1. Tennessee RiverWalk Extension – Ross’ Landing @ Riverfront Parkway to the Wheland Foundry Trailhead - adjacent to St. Elmo Avenue – total distance, 3 miles. Geographic areas potentially most affected (Census Tracts 16, 18, 19, 20) – total cost, $16M
2. Proposed park and rail-to-trail conversion connection to the RiverWalk Extension:
   a. Park (Bell Middle School Location, Census Tract 19)
      i. Total estimated construction cost $887,000 (funded initiative)
      ii. Projected construction completion – 07/01/2017
   b. Proposed Rail-to-Trail spur connection to the RiverWalk Extension
      i. ROW Acquisition: $800,000
      ii. Design and Construction: $2,052,285
      iii. Total: $2,852,285
3. Total infrastructure costs = $19,739,285
4. Indirect benefits (unmeasured) – increased tourism; improved QOL; Decreased pedestrian and bicycle morbidity and mortality; improved air quality; decreased asthma emergencies
5. Direct and indirect cost benefits due to decreased physical inactivity/increased physical activity = $1,200,000 through 2020

**Projected Physical Activity Increase Effect Size for Pedestrian and Bicycle Infrastructure**

1. Street-scale urban design/land-use interventions – median effect size = 48.4%

Figure 7.

Figure 8.
References


**PROJECT OVERVIEW**

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. Daniel Loveless, Ph.D.</td>
<td></td>
</tr>
<tr>
<td>Co-PI(s)</td>
<td>N/A</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Identify by type – senior personnel, technicians, graduate students, undergraduate students</td>
</tr>
<tr>
<td>Graduate Students: Amee Patel, Matthew Joplin</td>
<td></td>
</tr>
<tr>
<td>Undergraduate Students: Ellis Richards, Ryan Boggs</td>
<td></td>
</tr>
<tr>
<td>Project Title</td>
<td>Modeling Space and Defense Environmental Effects in Emerging Integrated Circuit Technologies</td>
</tr>
<tr>
<td>Date Submitted</td>
<td>August 30, 2017</td>
</tr>
<tr>
<td>Award Start - End Date</td>
<td>July 1, 2016 – June 30, 2017</td>
</tr>
</tbody>
</table>

**Non-Technical Summary – 500 words or less**

Typical electronics reliability modeling tools reside in a proprietary industry setting, employ techniques for a specific need, and are inappropriate for emerging integrated circuit technologies. Further, current methods involve extrapolation of short-term degradation profiles for predicting long-term behavior and lead to inaccurate and over constrained reliability predictions, and significantly limit the use of emerging integrated technologies in large distributed systems. This effort involved development of a stochastic based modeling technique for capturing intrinsic parameter fluctuations that account for time-dependent workload conditions influencing electronics reliability. Further, a novel method for measuring the stochastic behavior of atomic-level defects within electronics devices was developed. The hardware was provided to Sandia National Laboratories for measurement of time-dependent reliability in advanced and emerging semiconductor technologies. Future work will involve the collection of data for further improvement of the stochastic models, and the integration of the models into industry-standard simulation tools. This work offers a fundamentally new approach to evaluating system-level reliability vulnerabilities, enabling new approaches for mitigation, and has the potential for transforming
the way industry assesses electronic device, component, and system reliability.

<table>
<thead>
<tr>
<th>Project Web Page(s)</th>
<th>Please provide the complete URL.</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

*Please attach a Quad Chart using the following format as an example:*

Moore's Law scaling has been predicted to be at its end for years; yet, disruptive integrated circuit technologies such as the multi-gate transistor (FinFET), fully depleted silicon on insulator (FDSOI), and the gate-all-around transistor (GAAFET) have provided avenues for continued technology scaling. While scaling and performance continues to improve, these emerging technologies have introduced new reliability concerns. Process- and device-induced failures, device-level reliability, and back-end-of-line limitations have been identified as bottlenecks to system reliability, illustrating the need for aggressive, fail-safe reliability studies. The work presented here focuses on developing tools for measurement of the stochastic atomic level defects in advanced FinFET and FDSOI devices. The P.I. developed a time-dependent defect instrument for measurement of the stochastic atomic level defects in advanced FinFET devices. The models were designed to be compatible with industry-standard circuit simulation software and provide a unique approach for describing the reliability failure mechanisms. Further, the models were designed to be compatible with industry-standard circuit simulation software and provide a unique approach for describing the reliability failure mechanisms. The work was conducted in collaboration with academic and industrial leaders in the area of high reliability, low power microelectronics. Details on the two primary tasks are as follows:

1) Task 1: Design and fabricate novel instrument for detection of time-dependent defects.
   Conventional empirical measurements of shifts in performance parameters (such as threshold voltage and gate leakage current) due to stress conditions involve capturing parametric shifts during the onset of failure, which have been shown to exhibit sudden and permanent shifts. Conventional empirical measurements of shifts in performance parameters (such as threshold voltage and gate leakage current) due to stress conditions involve capturing parametric shifts during the onset of failure, which have been shown to exhibit sudden and permanent shifts. Further, many reliability mechanisms are difficult to measure due to the fast recovery once stress conditions are removed. This task focused on the development of a fast measure-stress...

2) Task 2: Develop and implement stochastic modeling techniques for describing reliability failure mechanisms.
   Electrochemical technologies such as nanowires and quantum computing...
measure (MSM) technique to observe both stress-induced degradation and defect recovery mechanisms under 1 μsec timescales. Rather than performing DC current-voltage (I-V) measurements at each stress step, the threshold voltage will be directly measured in the time domain. Following a 10 sec stress period at 130 °C (V\text{GS} = -1.5 V, V\text{DS} = 0 V), the recovery I-V transients at threshold in 32 nm SOI MOSFET devices are shown following 10 sec of elevated temperature stress (130 °C). The gate-to-source and drain-to-source bias voltages were V\text{GS} = -1.5 V and V\text{DS} = 0 V, respectively. The transients show semi-discrete changes over time corresponding to the emissions of trapped charged particles. However, the recovery mechanisms allow for the capture of stress and recovery transients of the threshold voltage by biasing the devices with a precision current at around the threshold. Such an approach is weakly dependent on changing in mobility [2] and is conducive to obtaining stochastic profiles of the defect capture and emission times.

The MSM method is designed and is currently under fabrication at Sandia National Laboratories, where it will be utilized for recovery mechanisms.
The general approach is to model any given parameter of a transistor as a random variable, which can be expressed as (1):

\[
\theta = \{\theta_1, \theta_2, ..., \theta_n\} \quad \text{where } \theta_i \text{ is the mean and standard deviation of } \theta_i \text{ from location } \phi_i \text{ on the transistor.}
\]

This approach can be derived as follows:

The general approach to modeling variation of electrical device parameters requires the development of stochastic reliability models that can be used to inform initial stochastic models and determination of the stochastic parameter space. This approach also enables large scale transparent simulations rather than through parametric sampling approaches used in previous approaches.
This work served as the preliminary evidence to support a proposal to the NSF CAREER program in July, 2017. Further, collaboration with Sandia National Laboratories was established and ongoing. Sandia is in the process of integrating the instrument developed in Task 1 into their advanced device experimental flow. Data will be shared with UTC to support further model development and refinement. This stochastic approach will be used to model the dominant reliability failure mechanisms in FinFET devices. Then, the model will be generalized such that any number of chip level parameters can be included to model system level reliability and fault tolerance. Under simultaneous changes in process, voltage, temperature, and reliability constraints, the model framework has been described analytically; further refinement of the model will be performed following acquisition of data. Future model development will involve integration into computational tools.

### References:


### List of Objectives / Aims / Major Milestones / Proposed Cumulative Outcomes / Accomplishments

<table>
<thead>
<tr>
<th>Objective / Aim / Milestone</th>
<th>Proposed Outcomes / Accomplishments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design and fabricate novel instrument for detection of time-dependent defects.</td>
<td>Successful design and delivery to Sandia National Laboratories.</td>
</tr>
<tr>
<td>Describe basic stochastic approach to modeling variation of electrical device parameters on overall system.</td>
<td>Model framework has been described analytically; further refinement of the model will be performed following acquisition of data. Future model development will involve integration into computational tools.</td>
</tr>
<tr>
<td>Develop capability for simulation of electric behavior under simultaneous changes in process, voltage, temperature, and reliability constraints.</td>
<td>Cadence integrated circuit design and analysis software, and Lumerical’s optical/electrical software for simulation of advanced electronic and optical devices have been acquired. Lumerical has been integrated into computing clusters at the SimCenter, allowing for finite element time domain modeling and simulation of advanced devices.</td>
</tr>
<tr>
<td>Test bed for custom computational models discussed in Task 2.</td>
<td>Successful design and delivery to Sandia National Laboratories.</td>
</tr>
<tr>
<td>Support model development as well as software, tools, and computational infrastructure needed for these efforts.</td>
<td>Further development of the instrument is on-going. Sandia is in the process of integrating the instrument developed in Task 1 into their advanced device experimental flow. Data will be shared with UTC to support further model development and refinement. This stochastic approach will be used to model the dominant reliability failure mechanisms in FinFET devices. Then, the model will be generalized such that any number of chip level parameters can be included to model system level reliability and fault tolerance. Under simultaneous changes in process, voltage, temperature, and reliability constraints, the model framework has been described analytically; further refinement of the model will be performed following acquisition of data. Future model development will involve integration into computational tools.</td>
</tr>
</tbody>
</table>

### References:

Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

1) Acquiring data for modeling verification: Assessment of long-term degradation is challenging due to lack of data. However, collaboration with Sandia National Laboratories was established to facilitate acquisition of data on highly relevant and advanced devices. The collaboration is mutual beneficial as they receive access to the advanced instrumentation developed in Task J.

2) Issues with graduate student workers that were unanticipated. This was partly due to mismatch in skillsets, and partly due to turnover in students. This was address by hiring two undergraduate student assistants. The method was particularly effective, and had significant impact on the students. One student stayed on as a Graduate Research Assistant at UTC, and one took a Graduate Research position at Vanderbilt University.

3) Challenges arose when you did not meet goals. Negative results are important too and should be explained and documented. How’d you learn besides what you achieved at the proposal?

What didn’t work? What did you disprove or learn from the parts that didn’t meet your initial concept at the proposal?

N/A

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and Key Collaborators

This work will provide a fundamentally new approach to evaluating system-level reliability, enabling new approaches for mitigation. Rather than focusing on process control, this work will provide a means to quantify the physical limitations of variability with respect to the impact on system reliability. The stochastic methodology is technology agnostic and will allow for rapid expansion into emerging technologies such as quantum computing.

The work utilized the PI's theoretical and experimental skills and expanded upon his established research program that focuses on highly-reliable electronics systems. The research allowed the PI to maintain established collaborations and to build a foundation for future work in emerging computing technologies, placing the PI at the forefront of radiation and reliability modeling for future technology generations.

The work utilized the PI's theoretical and experimental skills and expanded upon his established research program that focuses on highly-reliable electronics systems. The research allowed the PI to maintain established collaborations and to build a foundation for future work in emerging computing technologies, placing the PI at the forefront of radiation and reliability modeling for future technology generations.
Students Impacted

Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

Amee Patel: Mrs. Patel was partially funded by the award and facilitated student training on relevant software for the design of the MSM instrument. Mrs. Patel graduated with her M.S. degree in Electrical Engineering and took a position as an embedded systems designer for a defense company.

Ellis Richards: Mr. Richards was partially funded by the award as an undergraduate student. He utilized the Lumerical software suite for simulation and analysis of photonic structures. After graduation, Ellis joined a research team at a national laboratory and is currently exploring high-reliability systems.

Matthew Joplin: Mr. Joplin was partially funded by the award and was responsible for the design and layout of the MSM instrument. He is now a graduate student at UTC.

Ryan Boggs: Mr. Boggs was partially funded by the award and continued with efforts started by Ellis and is now a graduate student at UTC. Ryan is also supporting the modeling effort.

Community and Broader Impacts

Consider and discuss the technical and actual or potential societal impacts of your research project.

This effort enhanced student theoretical foundations in STEM and introduced students to practical engineering and design. Students had the opportunity to work with industry leaders and received hands-on training in model development and experimental design.

The MSM instrument is currently in fabrication and will be installed at Sandia as well as UTC. Planned submissions to the IEEE International Reliability and Physics Symposium and the IEEE Nuclear, Space, and Electronic Components Conference, 2018. The MSM instrument is currently being used to enhance students' theoretical foundations in nuclear, space, and electronic systems. The project provided students with opportunities to explore high-reliability systems, such as those encountered in space systems, while preparing for professional exposure.

Work products reduced to practice: Please include any software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference, or Other. Provide a bibilographical entry where appropriate.

1) The MSM instrument is currently in fabrication and will be installed at Sandia as well as UTC.

New inventions reduced to practice and when they will be formally disclosed: Please consider and include new software products that are subject to copyright, but also methods and systems that are potentially patentable. If you filed an invention disclosure, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you on how to proceed effectively for UTC and the UT system. Consider and include new software products that are subject to copyright, but also methods and systems that are potentially patentable. If you filed an invention disclosure, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you on how to proceed effectively for UTC and the UT system.
Outreach & Collaboration

Please list any workshops, or other collaborative events did you hold, indicate the location (on campus, etc.).

External Funding

<table>
<thead>
<tr>
<th>Proposal Submissions</th>
</tr>
</thead>
</table>

Sponsored Program Capacity Building Activities

Interactions with program officers from:
- National Science Foundation (NSF), Dimitri Pavlidis, Mary Parks
- Office of Naval Research (ONR), Pauline Park
- Defense Threat Reduction Agency (DTTRA), Pauline Park

Please list any non-faculty sponsored workshops or training activities, such as attending on-campus workshops, etc.

Contracts / Awards Received

None

Proposal Submissions

None
How will you follow up your CEACSE grant with work in the next 1, 2, … 5 years?

This work has helped establish collaboration with Sandia, and has strengthened other collaborations by helping capacity building. I have had some success in early development of a research program, and am now primarily in the process of building. I believe this work will help pursue funding at NIST, and help pursue NSF funding.

What barriers (if any) do you face to reach these next goals?

Capacity building. I have had some success in early development of a research program, and am now primarily in the process of building. I believe this work will help pursue funding at NIST, and help pursue NSF funding.

What other related research will you pursue (and with whom) in light of the support you’ve received from CEACSE?

In addition to reliability and advanced integrated circuit-related efforts, I am pursuing research related to Cyber Physical Systems, sensors, and embedded systems. Primary collaborators include Dr. Donald Reising, Dr. Mina Sartipi. However, I have pursued funding with additional collaborators such as Drs. Louie Elliott, Raga Ahmed, Nur Ahsan, and Aldo McLean as well.

Tell us anything else we should know about this work not described above.

N/A
# FINANCIAL ACCOUNTING

<table>
<thead>
<tr>
<th>Financial Report:</th>
<th>Total Award Amount:</th>
<th>$25,213</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cumulative Expenditures:</td>
<td>$21,632</td>
</tr>
<tr>
<td></td>
<td>Remaining Award Amount:</td>
<td>$3,581</td>
</tr>
</tbody>
</table>

Please attach the following:

- Final ledger report showing the final accounting for your award.
- Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.
- Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.

| Supplemental Award Request | Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned). | N/A | $3,581 |
# PROJECT OVERVIEW

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Donald R. Reising, Ph.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>Mina Sartipi, Ph.D. and T. Daniel Loveless, Ph.D.</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Identify by type – senior personnel, technicians, graduate students, undergraduate students</td>
</tr>
<tr>
<td>Project Title</td>
<td>Smart Buildings Through Smarter Models</td>
</tr>
<tr>
<td>Date Submitted</td>
<td>August 30, 2017</td>
</tr>
<tr>
<td>Award Start - End Date</td>
<td>July 1, 2016 – June 30, 2017</td>
</tr>
<tr>
<td>Non-Technical Summary – 500 words or less</td>
<td>The effort assessed current building energy models and investigated methods by which to improve them using integrated sensor data. The goal was to improve upon the existing model to facilitate real-time, high-fidelity energy usage and efficiency analysis. The existing modeling software, used in this work, requires extensive knowledge of the building’s construction (e.g., materials, dimensions), occupancy, and systems (e.g., HVAC, lighting). The program then returns a projected energy usage and efficiency based upon this model; thus, the accuracy of these projections rely heavily upon the accuracy of the model. However, the sensor data facilitates direct energy usage and efficiency based upon measured values without any knowledge of the building’s construction, occupancy, and systems. This project advanced the SimCenter’s work within the area of Urban Systems in which energy efficiency is a key focus. This work serves as a key preliminary step in the development of a process by which to facilitate real-time, high-fidelity energy usage and efficiency analysis with the goal of improving energy usage across the community.</td>
</tr>
<tr>
<td>Project Web Page(s)</td>
<td>N/A</td>
</tr>
</tbody>
</table>
The effort assessed current building energy models such as EnergyPlus, DOE2, EQUEST, etc., by which to improve existing building energy models to reflect real-time, high-fidelity energy usage and efficiency analyses. This was accomplished via three complementary approaches:

- **Task 1: Assessment of Existing Building Energy Models**
  - Objective: Evaluate existing building energy models that reflect real-time, high-fidelity energy usage and efficiency analyses. This was accomplished via three complementary approaches:
    - A scientific/technological overview of your research project – Hypotheses of scientific dimensions, methodologies, and activities, etc.
    - A comprehensive scientific overview of your research project – Hypotheses of scientific dimensions, methodologies, and activities, etc.
    - An integrative scientific overview of your research project – Hypotheses of scientific dimensions, methodologies, and activities, etc.

The effort assessed current building energy models such as EnergyPlus, DOE2, EQUEST, etc., by which to improve existing building energy models to reflect real-time, high-fidelity energy usage and efficiency analyses. This was accomplished via three complementary approaches:

- **Task 2: Integration of Weather Data and Building/Room Orientation**
  - Objective: Integrate weather data and building/room orientation data into the EnergyPlus model.
  - Procedure: Import weather data and building orientation data into the EnergyPlus model to improve the accuracy of energy usage predictions.

- **Task 3: Assessment of Building Systems**
  - Objective: Assess the effectiveness of building systems in reducing energy usage.
  - Procedure: Evaluate the performance of heating, ventilation, and air conditioning (HVAC) systems, lighting, and water systems to identify areas for improvement.

The model constructed in EnergyPlus is shown in Figure 1.
Once the EMCS 303 room model was constructed, then EnergyPlus™ was used to model the temperature and energy consumption of the room. The estimated energy consumption for this same day was 4.828 kilojoules. It is important to note that the accuracy of the EnergyPlus™ model is skewed, but in what ways we are not entirely sure. The real issue is the lack of an accurate baseline and model to use for comparison. This future work will look to use a building (i.e., a single family home) in which all of the necessary information to construct the EnergyPlus™ model is known.

Once the EMCS 303 room model was constructed, then EnergyPlus™ was used to model the temperature (i.e., a single family home) in which all of the necessary information to construct the EnergyPlus™ model is known.
Task 2: Data Driven Energy Consumption Prediction

The ML model to estimate current A/C energy consumption. LSTM explores outdoor temperature as the input sequence. Remaining data was used for model validation purposes. Previous A/C energy consumption and outdoor temperature were used as the inputs for the model training purpose and the data from June 1st, 2014 to August 30th, 2014. The data from June 1st, 2014 to July 26th, 2014 was used for the model training purpose. For this house, we extracted the temperature from the energy consumption and the outdoor temperature was used as the input for the model training purpose. The dataset was used to demonstrate the performance of the LSTM model. We used one house as an example to demonstrate the performance of the LSTM model.

In reality, it is hard for us to find the complete dataset to perform such a research. Thus, we resort to the dataset provided by the NREL. The dataset includes hourly A/C energy consumption and outdoor temperature. This dataset includes hourly A/C energy consumption and outdoor temperature. Also, the NVIDIA GPU was utilized to speed up the computation process.

In reality, it is hard for us to find the complete dataset to perform such a research. Thus, we resort to the dataset provided by the NREL. The dataset includes hourly A/C energy consumption and outdoor temperature. This dataset includes hourly A/C energy consumption and outdoor temperature. Also, the NVIDIA GPU was utilized to speed up the computation process.

Figure 2: EnergyPlus predicted temperature for February 2, 2017.
Table 1. The performances of A/C energy consumption estimation

<table>
<thead>
<tr>
<th>Method</th>
<th>RMSE</th>
<th>MAE</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLP</td>
<td>0.3594</td>
<td>0.2569</td>
<td>0.8941</td>
</tr>
<tr>
<td>LSTM</td>
<td>0.4882</td>
<td>0.3594</td>
<td>0.8045</td>
</tr>
</tbody>
</table>

Figure 3. Estimated A/C energy consumption by MLP.
Figure 4. Estimated A/C energy consumption by LSTM

Task 3: Investigation of Smart Building CPS

In this task, a CPS-based solution comprised of networked sensors was developed for real-time acquisition of parameters relevant to energy consumption within a building. Demonstration of the concept was performed in room 303 of the EMCS building on the UTC campus. Eight low-cost wireless and wired nodes were installed for measuring temperature, humidity, and pressure. The sensors were located at the room cost wireless and wired nodes were installed for measuring temperature, humidity, and pressure. These results demonstrate the effectiveness of the proposed data-driven models.

Compared with indoor temperature, the A/C set point is more constant and has a higher correlation with A/C energy consumption. Hence, the A/C set point should be acquired as an input for the data-driven models. Moreover, the performance of data-driven models is highly dependent on the quality of data. In order to pursue the federal funding to further support the proposed smart building research, our next step is to build a complete/high-quality dataset with multiple data sources by exploring the latest Internet of Things technologies.

Even though the results are encouraging, there are some major limitations in this study. First, we were not able to test the A/C set points. Even though the results are encouraging, there are some major limitations in this study. First, we were not able to test the A/C set points.

The performances of A/C energy consumption estimation are shown in Table 1. These results demonstrate the effectiveness of proposed data-driven models.
represented using a 3D grid in which each point of the grid is assigned a temperature value. The temperature values assigned to each grid point are determined using steady-state analysis based upon the temperature measured at the room boundaries by the eight sensors. The result is a distribution of the temperature within the room for a specific instance of time. For each time step, the room is subdivided into differential sub-volumes in which heat flow into and out of each sub-volume is approximated by a differential energy balance equation. The heat supplied to the room by summation across all time increments is used to calculate the total energy consumed for one day and compared to the estimated energy consumption value provided by EnergyPlus®. In Task 1, EnergyPlus® is tested and validated using industry methods such as those outlined in the American National Standards Institute (ANSI) American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and International Energy Agency Solar Heating and Cooling Consumption/Efficiency of a Room. EnergyPlus® is tested and validated using a 3D grid in which each point of the grid is assigned a temperature value. The temperature values assigned to each grid point are determined using steady-state analysis based upon the temperature measured at the room boundaries by the eight sensors. The result is a distribution of the temperature within the room for a specific instance of time. For each time step, the room is subdivided into differential sub-volumes in which heat flow into and out of each sub-volume is approximated by a differential energy balance equation. The heat supplied to the room by summation across all time increments is used to calculate the total energy consumed for one day and compared to the estimated energy consumption value provided by EnergyPlus®.
The work also illuminated precision and accuracy challenges associated with the sensors. Although the sensors conducted a self-calibration, the lesson learned will be invaluable to refining external funding as well as future work and to predict if a room is under a single room. However, this work successfully served as proof-of-concept demonstration of the proposed work and single-room limitations. The conclusions that can be drawn is that we cannot predict the energy consumption for the building and it would be difficult to instrument a building as well as the complexity associated with the modeling and simulation tools energyPlus, limiting the project to a single room also limited the conclusions that can be drawn. Nonetheless, the number of sensors needed initially for the proposal was too small an entire building. However, this was an unrealistic goal based upon initial time; the number of sensors needed expanded the scope.

1) The project originally targeted an entire building, but limited time and resources shifted the focus to a single building.
2) Networking the sensors throughout a building is limited in this effort through the use of a single room, but may become an issue as we expand the scope.
3) It was determined that the mounting location of the sensors led to induced biases within the measurements. This was very apparent for measured temperature. The constructed sensors were mounted in two ways: (1) on-board with the microcontroller, and (2) off-board and separated from the microcontroller by a wire/cable. All of the on-board temperature measurements were higher than those from the off-board sensor.

Challenges & Strategies Used to Address / Overcome:

| Domain | Methodology
|--------|-------------
| FDTD | Developed low-cost hardware for gathering data, developed a 3-dimensional heat transfer and energy consumption using FDTD
| | Successfully demonstrated use of hardware for real-time acquisition of data and sensor
| | Successfully demonstrated energy consumption of the building by taking advantage of

Data Driven Energy Consumption Prediction

- Made EnergyPlus well-suited for use in this project.
- Programmed (IA SC) BESTest (Building Energy Simulation Test) standards [1].

Investigation of Smart Building CPS

- Developed a model for the building, developed a model for the building.
- Successfully estimated energy consumption of the building by taking advantage of
IMPACT & OUTCOMES

Students Impacted

Mohammed Fadul: Mr. Fadul is seeking a Master’s of Science in Electrical Engineering. Mr. Fadul carried out all of the work related to the construction of the building energy model within the modeling and simulation tool EnergyPlus. This work exposed Mr. Fadul to an area in which he had little to no experience in, and he excelled. This work was invaluable to further developing his critical thinking and problem-solving skills as well as expanding his data science expertise with a real-world application. This was a great opportunity for him to translate his skill set from undergraduate to graduate level of work.

Jin Cho: Jin is finishing his Master’s degree in Computer Science this fall. This was a great opportunity for him to expand his data science expertise with a real-world application. The networked sensor array’s efforts with sensor calibration and network design led to competition of the dissertation.

Amee Patel: Mrs. Patel was partially funded by the award as assistant research faculty. Her efforts with sensor calibration and network design led to competition of the dissertation.

Students Impacted

Mohammed Fadul: Mr. Fadul is seeking a Master’s of Science in Electrical Engineering. Mr. Fadul carried out all of the work related to the construction of the building energy model within the modeling and simulation tool EnergyPlus.

Jin Cho: Jin is finishing his Master’s degree in Computer Science this fall. This was a great opportunity for him to expand his data science expertise with a real-world application. The networked sensor array’s efforts with sensor calibration and network design led to competition of the dissertation.

Amee Patel: Mrs. Patel was partially funded by the award as assistant research faculty. Her efforts with sensor calibration and network design led to competition of the dissertation.

Students Impacted

Mohammed Fadul: Mr. Fadul is seeking a Master’s of Science in Electrical Engineering. Mr. Fadul carried out all of the work related to the construction of the building energy model within the modeling and simulation tool EnergyPlus.

Jin Cho: Jin is finishing his Master’s degree in Computer Science this fall. This was a great opportunity for him to expand his data science expertise with a real-world application. The networked sensor array’s efforts with sensor calibration and network design led to competition of the dissertation.

Amee Patel: Mrs. Patel was partially funded by the award as assistant research faculty. Her efforts with sensor calibration and network design led to competition of the dissertation.

Impact on the career(s) of the PI, Co-PI’s and Key Collaborators

Co-PI (Dr. Sartipi): This was a great opportunity for Mina to work with Electrical Engineering faculty. This has opened up other opportunities that they can work together on Smart City projects with and Dr. Loveless.

Co-PI (Dr. Sartipi): This was a great opportunity for Mina to work with Electrical Engineering faculty. This has opened up other opportunities that they can work together on Smart City projects with and Dr. Loveless.

Co-PI (Dr. Loveless): This project is the first successful hardware re-configuration and implementation of a real-time extraneous load program, which is necessary to the research. This experience is invaluable to Dr. Reising’s success in managing large, national labs and large scale, complex multi-disciplinary research projects. This experience has provided the ability to manage and guide a funded program with a simple and supportive environment. Dr. Reising’s success in securing federal funding for the project and in obtaining similar grants in the future.

Co-PI (Dr. Loveless): This project is the first successful hardware re-configuration and implementation of a real-time extraneous load program, which is necessary to the research. This experience is invaluable to Dr. Reising’s success in managing large, national labs and large scale, complex multi-disciplinary research projects. This experience has provided the ability to manage and guide a funded program with a simple and supportive environment. Dr. Reising’s success in securing federal funding for the project and in obtaining similar grants in the future.

Co-PI (Dr. Loveless): This project is the first successful hardware re-configuration and implementation of a real-time extraneous load program, which is necessary to the research. This experience is invaluable to Dr. Reising’s success in managing large, national labs and large scale, complex multi-disciplinary research projects. This experience has provided the ability to manage and guide a funded program with a simple and supportive environment. Dr. Reising’s success in securing federal funding for the project and in obtaining similar grants in the future.

Co-PI (Dr. Loveless): This project is the first successful hardware re-configuration and implementation of a real-time extraneous load program, which is necessary to the research. This experience is invaluable to Dr. Reising’s success in managing large, national labs and large scale, complex multi-disciplinary research projects. This experience has provided the ability to manage and guide a funded program with a simple and supportive environment. Dr. Reising’s success in securing federal funding for the project and in obtaining similar grants in the future.

Co-PI (Dr. Loveless): This project is the first successful hardware re-configuration and implementation of a real-time extraneous load program, which is necessary to the research. This experience is invaluable to Dr. Reising’s success in managing large, national labs and large scale, complex multi-disciplinary research projects. This experience has provided the ability to manage and guide a funded program with a simple and supportive environment. Dr. Reising’s success in securing federal funding for the project and in obtaining similar grants in the future.

Co-PI (Dr. Loveless): This project is the first successful hardware re-configuration and implementation of a real-time extraneous load program, which is necessary to the research. This experience is invaluable to Dr. Reising’s success in managing large, national labs and large scale, complex multi-disciplinary research projects. This experience has provided the ability to manage and guide a funded program with a simple and supportive environment. Dr. Reising’s success in securing federal funding for the project and in obtaining similar grants in the future.

Co-PI (Dr. Loveless): This project is the first successful hardware re-configuration and implementation of a real-time extraneous load program, which is necessary to the research. This experience is invaluable to Dr. Reising’s success in managing large, national labs and large scale, complex multi-disciplinary research projects. This experience has provided the ability to manage and guide a funded program with a simple and supportive environment. Dr. Reising’s success in securing federal funding for the project and in obtaining similar grants in the future.
Community & Broader Impact

Consider and discuss the technical and actual or potential societal impacts of your research project.

The potential impacts of this project is the initial development of a process by which to determine the energy usage and efficiency of a building using passive, benign sensors that require little to no knowledge of the building’s construction, occupants, and systems. The outcomes of this project are foundational to achieving more energy efficient buildings.

New Inventions Reduced to Practice

Reduced to practice and when they will be formally disclosed; Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software product, please indicate and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software product, please indicate.

Work Products Reduced to Practice:

Provide a bibliographic entry where appropriate; Masters Theses and Doctoral Dissertations. Available at: http://scholar.utc.edu/theses/526.


Outreach & Collaboration

Please list any workshops, workshops or other collaborative events did you hold indicating the location (on campus, etc.).

Participation in the 2017 Research Dialogues held on the UTC campus on April 11-12, 2017.
Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.

Contracts / Awards Received

None

External Funding

Projected Dates: September 2017 – Release of RFP; November 2017 – Pre-proposal Submission, February 2018

Proposals Submissions

Please list of sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1-2 ... 5 years?

We are currently in the process of writing a proposal that will be submitted to the National Science Foundation's NSF Smart & Connected Communities (S&CC) Program Solicitation. The solicitation was released in September of 2016 with the final submission due in February of 2017. The 2016 solicitation was released in September of 2016 with the final submission due in February of 2017. The solicitation has yet to be released. However, the pre-proposal for this submission is part of the Grants Writing Workshop underway here at UTC. This pre-proposal will be used to guide program officers' interests as well as serve as the foundation of the full proposal.

Contracts / Awards Received

None

Sponsored Program Capacity

Building Activities

Dr. Sartipi and Reising participated in "Chattanooga's Smart City Testbed" workshop on April 4, 2017. This workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding "smart" city. It focused heavily on brainstorming sessions within the areas of: Transportation, Energy, and Public Health.

Dr. Sartipi and Loveless participated in a "smart cities" workshop in May of 2017 in Cadiz, Spain. The workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding "smart cities". It was heavily focused on brainstorming sessions within the areas of: Transportation, Energy, and Public Health.

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1-2 ... 5 years?

We are currently in the process of writing a proposal that will be submitted to the National Science Foundation's NSF Smart & Connected Communities (S&CC) Program Solicitation. The solicitation was released in September of 2016 with the final submission due in February of 2017. The solicitation has yet to be released. However, the pre-proposal for this submission is part of the Grants Writing Workshop underway here at UTC. This pre-proposal will be used to guide program officers' interests as well as serve as the foundation of the full proposal.

Contracts / Awards Received

None

Sponsored Program Capacity

Building Activities

Dr. Sartipi and Reising participated in "Chattanooga's Smart City Testbed" workshop on April 4, 2017. This workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding "smart" city. It focused heavily on brainstorming sessions within the areas of: Transportation, Energy, and Public Health.

Dr. Sartipi and Loveless participated in a "smart cities" workshop in May of 2017 in Cadiz, Spain. The workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding "smart cities". It was heavily focused on brainstorming sessions within the areas of: Transportation, Energy, and Public Health.
What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?

This work actually served a fundamental role in determining where some of the key focus areas lie. More specifically, it identified some key challenges that must be addressed to facilitate S&CC. In addition to wireless network security, there are significant challenges surrounding the accuracy and precision of sensors. For instance, in this work we used eight temperature sensors deployed within the same room (EMCS 303). The measured temperatures, from each device, experienced up to a 15°C temperature disparity. The other challenge involves the coordination of cyber-physical systems. This specific challenge is one of the most pressing issues in today’s society, and we need to address it before we can move forward with practical applications. The concept of Smart Grids (SG) is an example of this, where the interaction between the electrical and physical systems is crucial. This work currently involves the Electrical Engineering Department and will soon include the Computer Science Department. There is also potential collaboration between Andrew Rogers of the Enterprise Center, The City of Chattanooga, and Oak Ridge National Laboratory, and the Enterprise Center on the July 27, 2017. This meeting brought to light some potential collaboration opportunities. The City of Chattanooga, and the Enterprise Center are interested in working with Vanderbilt University, The City of Chattanooga, and Oak Ridge National Laboratory. The goal is to create bridges between these collaborations by coordinating in meetings and workshops whenever possible. One case of this was a meeting with Vanderbilt University, The City of Chattanooga, and Oak Ridge National Laboratory.

What barriers (if any) do you face to reach these goals?

Finding the appropriate sponsoring agency as well as collaborators within the area of smart building and smart grid is not described above. This CEACSE award actually has spurred additional work in the area of wireless device/network security (e.g., wireless sensor networks, autonomous vehicles). This work directly relates to 5GCC. The City of Chattanooga, and the Enterprise Center are interested in working with Vanderbilt University, The City of Chattanooga, and Oak Ridge National Laboratory.
## FINANCIAL ACCOUNTING

<table>
<thead>
<tr>
<th>Financial Report:</th>
<th>Total Award Amount:</th>
<th>$99,753</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cumulative Expenditures:</td>
<td>$93,702</td>
</tr>
<tr>
<td></td>
<td>Remaining Award Amount:</td>
<td>$6,051</td>
</tr>
</tbody>
</table>

Please attach the following:

- Final ledger report showing the final accounting for your award.
- Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.
- Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.

### Supplemental Award Request

Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).

<table>
<thead>
<tr>
<th>Supp. Award Request</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>
# PROJECT OVERVIEW

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mina Sartipi, Ph.D.</td>
</tr>
<tr>
<td>Co-PI(s)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Craig Tanis, Ph.D.</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Identify by type – senior personnel, technicians, graduate students, undergraduate students</td>
</tr>
<tr>
<td></td>
<td>Undergraduate Students: Robert Barber, Caleb Campbell</td>
</tr>
<tr>
<td></td>
<td>Graduate Students: Hector Suarez, Austin Harris</td>
</tr>
<tr>
<td>Project Title</td>
<td>Smart Urban Connectivity Powered by Mobility-on-Demand Public Transportation and Citywide Public Communications</td>
</tr>
<tr>
<td>Date Submitted</td>
<td>August 30, 2017</td>
</tr>
<tr>
<td>Award Start - End</td>
<td>July 1, 2016 – June 30, 2017</td>
</tr>
</tbody>
</table>

## Non-Technical Summary – 500 words or less

In order to confront unprecedented challenges due to the rapid urbanization, we started a fundamental research on smart urban connectivity. We investigated the methodologies, feasibilities, and potentials of two essential connectivity paradigms for urban futures, i.e., cooperative mobility and citywide wireless communications. We developed a real-time graph for the streets of the city of Chattanooga that can be updated by crowdsourcing, designed personalized routing algorithms that consider features such as health, air quality, and elevation, and investigated a small testbed for advanced wireless communications. The proposed research involved computationally intensive data analytics, graph analytics, simulation and modeling, optimization, operations research, and urban planning. This project advanced the SimCenter’s work within the area of Urban Systems in which transportation and wireless communications are key focuses.

## Project Web Page(s)

Please provide the complete URL.

N/A
Task I: Prototyping a data structure representing connectivity of road ways using open source maps

The goal of this software development project was to prototype and populate a data structure representing the topographical layout of streets and sidewalks in Chattanooga, associating each with relevant metadata (distance, elevation, traffic conditions) and enabling efficient path searches for fleet routing. As the project concludes, we have a working prototype meeting these goals, and we have demonstrated intelligent path planning with real-world data. We have leveraged existing third-party solutions, so that other map providers could be used if needed. The Java portion of this project used Open Street Map (OSM) raw XML data to create a custom graph data structure to represent intersections and path information. The programming language used for the CEACSE project was Java 8. This project made use of an open source OSM data parser called Basic OSM Parser to read in the OSM XML data and create the graph data structure.

The following two search algorithms were demonstrated: single source shortest path and A* search algorithms with this data structure, with edge weights calculated by Euclidean distance, Elevation effect heuristics and simulated traffic data. An advantage of designing custom data structures is that one can add custom attributes to the data structure such as custom graph edge weights that include weather data and traffic congestion. Another advantage is that one can add custom attributes to the data structure such as custom graph edge weights that include weather data and traffic congestion. The following two search algorithms were demonstrated: single source shortest path and A* search algorithms.

The Java portion of this project used OSM data provided by the OpenStreetMap project, a considerable amount of time and effort was spent manually working with OpenStreetMap data feeds to populate the adjacency list data structure. A considerable amount of time and effort was spent manually working with OpenStreetMap data feeds to populate the adjacency list data structure. The adjacency list is that one can add custom attributes to the data structure such as custom graph edge weights that include weather data and traffic congestion. The Java portion of this project used Open Street Map (OSM) raw XML data to create a custom graph data structure(s) such as an adjacency list graph data structure. The adjacency list graph data structure can be searched using the following algorithms: A Star Search and Shortest Path Search (Dijkstra's algorithm). An advantage of designing custom data structures is that one can add custom attributes to the data structure such as custom graph edge weights that include weather data and traffic congestion.

To accomplish these goals, an adjacency list graph data structure was designed to represent intersections (vertices) and roads/sidewalks (edges). This project was a working prototype meeting these goals, and we have demonstrated intelligent path planning with real-world data. The goal of this software development project was to prototype and populate a data structure representing the topographical layout of streets and sidewalks in Chattanooga, associating each with relevant metadata (distance, elevation, traffic conditions) and enabling efficient path searches for fleet routing. As the project concludes, we have a working prototype meeting these goals, and we have demonstrated intelligent path planning with real-world data.
The search algorithms used to find route list were A Star Search and Single Source Shortest Path search. The following data are the route list generated from the CEACSE Java code, where Node Lat and Node Lon refer to Node Latitude and Node Longitude respectively.

<table>
<thead>
<tr>
<th>Node ID: N202596950</th>
<th>Node Lat: 35.0454582</th>
<th>Node Lon: -85.3003297</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node ID: N202596948</td>
<td>Node Lat: 35.0446116</td>
<td>Node Lon: -85.3007771</td>
</tr>
<tr>
<td>Node ID: N202695954</td>
<td>Node Lat: 35.0439783</td>
<td>Node Lon: -85.3011414</td>
</tr>
<tr>
<td>Node ID: N202608349</td>
<td>Node Lat: 35.0432349</td>
<td>Node Lon: -85.3015638</td>
</tr>
<tr>
<td>Node ID: N202596948</td>
<td>Node Lat: 35.0441682</td>
<td>Node Lon: -85.3040337</td>
</tr>
<tr>
<td>Node ID: N202740500</td>
<td>Node Lat: 35.0430927</td>
<td>Node Lon: -85.3046207</td>
</tr>
</tbody>
</table>

Table 1. A list of nodes along the shortest path

The left map consists of the generated GPS route coordinates of the Java shortest path algorithm. In order to compare the algorithms, a standard map search engine called GraphHopper was used. The map on the right used GraphHopper with the same start and end coordinates. Notice that the paths are very similar which shows that the implemented Java search algorithms give realistic results.
Two Python packages (i.e., OSMNX and NetworkX) were exploited for algorithm design/development and performance visualization/evaluation. Data extracted from Openstreetmap was used to construct the required road/street network/graph. The single source shortest path algorithm provided by OSMNX was used in order to verify the results from the Java code. The road network used was generated from the same geographical area as used in the Java code. The application inputs are geographic coordinates of the source and destination points. The shortest path algorithm was used to generate the route from the source to the destination. A list of nodes that defines this route was used for comparison.

### Table 2. A list of Nodes along the shortest path

<table>
<thead>
<tr>
<th>Node Path</th>
<th>Source Node ID</th>
<th>Destination Node ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>202662066, 202740503, 202740506, 202596948, 202695954, 202608349</td>
<td>202740500, 202740503, 202596950</td>
<td>202596950</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Destination (Latitude, Longitude)</th>
<th>Origin (Latitude, Longitude)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(35.045453, -85.300355)</td>
<td>(35.0430927, -85.3046207)</td>
</tr>
</tbody>
</table>

Figures 1. Java A Star Search
Figure 2 illustrates the route (i.e., the shortest path) generated from the Python code. The nodes that make up this route are listed in Table 1. Figure 3 shows the architecture design of Traci. Figure 3 shows the architecture design of Traci. The routing algorithm can be written in Python. Python acts as the client, which interacts with SUMO, and Traffic Control Interface (Traci). The routing algorithm can be written in both Java and Python. Python acts as the client, which interacts with SUMO, and Traffic Control Interface (Traci). The routing algorithm can be written in both Java and Python. The results generated by both Python and Java codes utilize the same nodes while traversing through the same route, which therefore proves the accuracy of the Java code. Based on the current results, we can further implement more complex functions using Java and the corresponding framework.

Task II: Building a simulation environment to model and simulate traffic.

Next, we built a powerful/generic simulation environment to study the challenging vehicle routing problems. The results generated by both Python and Java codes utilize the same nodes while traversing through the same route, which therefore proves the accuracy of the Java code. Based on the current results, we can further implement more complex functions using Java and the corresponding framework.

The final prototype code demonstrates the ability to successfully work with map data and arbitrary sensor data, and integrating work with SUMO and Traci is yet to be done concerning meaningful multi-parameter heuristic edge weights. Going forward, this project would include custom geographic database can be effectively used on a range of future problems.

Table 1. The nodes that make up this route are listed in Figure 2. The nodes that make up this route are listed in Figure 2.

- 202740500
- 202740503
- 202695954
- 202608349
- 202596948
- 202596950

Table 2. The shortest path (shown in Figure 2) generated from the Java code consists of the following nodes (202662066, 202695954, 202740500, 202740503, 202608349, 202596948, 202596950).
<table>
<thead>
<tr>
<th>List of Objectives / Aims / Major Milestones Proposed</th>
<th>Cumulative Outcomes / Accomplishments</th>
</tr>
</thead>
</table>

- **Objectives:**
  - Prototyping a data structure to represent the city connectivity graph with relevant metadata
  - Developing intelligent path planning
  - Cooperative routing

- **Cumulative Outcomes / Accomplishments:**
  - Successfully prototyped and populated a data structure representing the topographical layout of streets and sidewalks in Chattanooga, associating them with relevant metadata (distance, elevation, traffic conditions) and enabling efficient path searches for fleet routing.
  - An adjacency list graph data structure was designed to represent intersections (vertices) and roads/sidewalks (edges) that is populated with data provided by the OpenStreetmap project.
  - Address connectivity issues by designing a general-purpose multi-parameter edge weight algorithm.
  - Developed intelligent path planning algorithms that successfully work with map data and arbitrary sensor data to generate meaningful multi-parameter edge weights to find personalized paths.
  - Built a powerful/generic simulation environment to study the challenging vehicle routing problems with primary goals of minimizing congestion through cooperative routing and minimizing travel times through intelligent vehicle routing algorithms.
  - The single vehicle routing algorithms are prone to selfish behavior, which can induce many new problems. Based on this generic simulation environment, we put our research effort on cooperative routing to address the congestion of other vehicles of the whole intelligent transportation system.
  - The adjacency vertex routing algorithms are prone to be selfish without consideration of other vehicles or the whole intelligent transportation system, which can induce many new problems. Based on this generic simulation environment, we put our research effort on cooperative routing to address the congestion of other vehicles of the whole intelligent transportation system.

- **Cooperative Routing:**
  - Developed intelligent path planning algorithms that successfully work with map data and arbitrary sensor data to generate meaningful multi-parameter edge weights to find personalized paths.
  - An adjacency list graph data structure was designed to represent intersections (vertices) and roads/sidewalks (edges) that is populated with data provided by the OpenStreetmap project.

- **Developing Intelligent Path Planning:**
  - Developed intelligent path planning algorithms that successfully work with map data and arbitrary sensor data to generate meaningful multi-parameter edge weights to find personalized paths.
  - An adjacency list graph data structure was designed to represent intersections (vertices) and roads/sidewalks (edges) that is populated with data provided by the OpenStreetmap project.

- **Cooperative Routing:**
  - Developed intelligent path planning algorithms that successfully work with map data and arbitrary sensor data to generate meaningful multi-parameter edge weights to find personalized paths.
  - An adjacency list graph data structure was designed to represent intersections (vertices) and roads/sidewalks (edges) that is populated with data provided by the OpenStreetmap project.
Vehicle routing is a well-studied problem. Traditionally, the routing for an individual vehicle mainly considered the source and destination locations and exploited the shortest path algorithm or A∗ search algorithm based on graph theory. The single vehicle routing algorithms are prone to be selfish without consideration of other vehicles or the whole intelligent transportation system, which can induce many new problems. Based on this generic simulation environment, we put our research effort on cooperative routing to address the problems caused by the single vehicle routing and achieve the global optimum in some sense. For example, in a collaborative mobility-on-demand public transportation system, we need to search for the desired routes for all the buses collaboratively. Each vehicle can be considered as an agent that can make decisions independently. However, the joint consideration of demand, traffic, bus, and passenger information is also essential for the cooperative routing problem. Through simulation, we can get all quantitative performance measures (such as travel distance, travel time, stop time, and pollution emission) to quantify the benefits of cooperative routing. Furthermore, this simulation environment can be used to investigate many other emerging intelligent transportation-related problems, which can provide us a lot of preliminary insights and valuable insights to pursue more significant collaborative projects funded by the external funding agencies.
SUMO is a microscopic, inter-and multi-modal and space continuous traffic flow simulation. SUMO along with other frameworks is being used to help investigate and test the cooperative routing system. SUMO is a time-discrete simulation whose time step is 1 second. Our primary goal is to minimize congestion through cooperative routing. We focus on rerouting all vehicles in the simulation at each time step based on the current state of the simulation and vehicles. As a result, the average vehicles drive distance and drive time should be reduced.
of very few outdoor real-world testbeds.

City-wide testbed: Due to limited time and budget we focus on one street on campus. Although the scale is much smaller, this is still one

<table>
<thead>
<tr>
<th>Challenges &amp; Strategies Used to Address / Overcome:</th>
</tr>
</thead>
</table>
| 1) Intelligent decision center: Originally we planned to study demand and feasibility of decision making for vehicle route and mobility.
2) City-wide testbeds: Limited time and resources shift our focus to the last two items.
|}

**Advanced Wireless Communication (Pilot Study)**

- Successfully developed a small real-world testbed on a 3^rd street close to ENCS.
- Easily configured by simply using the network configuration provided by the startup.
- Successfully implemented and tested the system.
- Evaluated the system's performance and efficiency.
- Identified potential issues and areas for improvement.
- Discussed and addressed any challenges encountered during the pilot study.
- Learned valuable lessons from the pilot study.

**What didn’t work? What did you disprove or learn from the parts that didn’t meet your initial concept at the proposal?**

- Even though the sources and destinations of these vehicles are close, roads based on the objectives and constraints of the cooperative routing problem, that is, the same time, hence different vehicles may be required to different
- Annotation: Information shared by the startup ENCS is also a potential solution to congestion.

<table>
<thead>
<tr>
<th>Challenges to Tackle:</th>
</tr>
</thead>
</table>
| 1) Intelligent decision center: Originally we planned to study demand and feasibility of decision making for vehicle route and mobility.
2) City-wide testbeds: Limited time and resources shift our focus to the last two items.
|}

**Add rows as needed:**

<table>
<thead>
<tr>
<th>Challenges to Tackle:</th>
</tr>
</thead>
</table>
| 1) Intelligent decision center: Originally we planned to study demand and feasibility of decision making for vehicle route and mobility.
2) City-wide testbeds: Limited time and resources shift our focus to the last two items.
|}

**Advantages of Proposing, that you encountered - Particularly if you were impacted from achieving the objectives and milestones approved in your proposal:**

- Improved network connectivity and performance.
- Enhanced data transfer speeds.
- Reduced latency and increased efficiency.
- Streamlined communication processes.
- Increased reliability and robustness.
- Enhanced user experience and satisfaction.

**What did you learn?**

- Improved understanding of network dynamics.
- Enhanced knowledge of system architecture and operation.
- Gained insights into user behavior and preferences.
- Improved system design and optimization.
- Gained valuable lessons for future projects and initiatives.

**What could you improve on?**

- Collaboration and communication with stakeholders.
- System integration and compatibility.
- Resource allocation and management.
- Scoping and planning of future projects.
- Risk assessment and mitigation strategies.

**What did you accomplish?**

- Developed and implemented a robust and efficient system.
- Achieved significant milestones and objectives.
- Successfully tested and validated the system.
- Gained valuable insights and lessons.
- Improved system design and optimization.
- Enhanced user experience and satisfaction.

**What did you learn?**

- Improved understanding of network dynamics.
- Enhanced knowledge of system architecture and operation.
- Gained insights into user behavior and preferences.
- Improved system design and optimization.
- Gained valuable lessons for future projects and initiatives.

**What could you improve on?**

- Collaboration and communication with stakeholders.
- System integration and compatibility.
- Resource allocation and management.
- Scoping and planning of future projects.
- Risk assessment and mitigation strategies.
Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?

While our goal was to design a mobility-on-demand, shared ride public transportation, we were limited by time and resources. We learned that the dynamic map of the city, intelligent and personalized routing algorithms were needed before we could focus on the demand and service management of the project. Furthermore, instead of testing the feasibility of small cells at the city level, we focused on one street. Through this experience we had an opportunity to work closely with The Enterprise Center, EPB, and Chattanooga DOT. By prototyping a dynamic real-time map for the city of Chattanooga, investigating personalized routing algorithms, and designing cooperative routing we paved the path for our long-term goal of dynamic flexible route public transportation.

Our project was a research project with real-time payoff and as a huge step towards the larger „smart cities” concept and discusses the technical and actual or potential societal impacts of your research project.

Impact on the career(s) of the PI (Dr. Sartipi):
This was a great opportunity for Mina to work with Dr. Tanis and has opened up other opportunities that they can work together on Smart City projects with the goal of securing federal funding.

Impact on the career(s) of the co-PI (Dr. Tanis):
This award was Dr. Tanis’s first Urban Sciences project and first collaboration with Dr. Sartipi. Through this project they met key participants in the Regional Smart Cities Initiative and laid the groundwork for future collaborative projects.

Students Impacted:
Robert Barber: Robert learned more about routing algorithms as well as Python packages. After being involved in this exciting research project, Robert decided to stay for graduate school.

Caleb Campbell: Caleb was able to expand his knowledge on graph theory and data structures.

Hector Suarez and Austin Harris were able to work on several aspects of this project. They also learned to manage the project and how to appoint them to set the goals, justify them, and work with the team.

Robert Barber: Robert learned how to manage the project and how to appoint them to set the goals, justify them, and work with the team.

Students Impacted:

Community and Broader Impacts:
Our project was a research project with real-time payoff and as a huge step towards the larger „smart cities” concept and discusses the technical and actual or potential societal impacts of your research project.

The Enterprise Center, EPB, and Chattanooga DOT.

By prototyping a dynamic real-time map for the city of Chattanooga, investigating personalized routing algorithms, and designing cooperative routing we paved the path for our long-term goal of dynamic flexible route public transportation which will impact all citizens of Chattanooga.

Co-PI (Dr. Tanis): This was Dr. Tanis’s first Urban Sciences project and first collaboration with Dr. Sartipi. Through this project they met key participants in the Regional Smart Cities Initiative and laid the groundwork for future collaborative projects.

Students Impacted:
Robert Barber: Robert learned more about routing algorithms as well as Python packages. After being involved in this exciting research project, Robert decided to stay for graduate school.

Caleb Campbell: Caleb was able to expand his knowledge on graph theory and data structures.

Hector Suarez and Austin Harris were able to work on several aspects of this project. They also learned to manage the project and how to appoint them to set the goals, justify them, and work with the team.

Robert Barber: Robert learned how to manage the project and how to appoint them to set the goals, justify them, and work with the team.
New inventions reduced to practice and when they will be formally disclosed; If you wish to open source a software prototype data set, please state so; we will follow up with you to explore the process of disclosing open-source software. Indicate so here or well. If you wish to obtain source code from an invention disclosure, please provide any copyright or software license disclosures during the period of performance. Provide information about the source code, including any software or intellectual property licenses that are required to distribute, use, modify, and reproduce the software. If you filed an invention disclosure, please provide any copyright or software license disclosures during the period of performance. Provide information about the source code, including any software or intellectual property licenses that are required to distribute, use, modify, and reproduce the software.

Please consider and include new software products that are subject to copyright but also methods and systems that are patentable. If you filed an invention disclosure, please provide any copyright or software license disclosures during the period of performance. Provide information about the source code, including any software or intellectual property licenses that are required to distribute, use, modify, and reproduce the software. If you filed an invention disclosure, please provide any copyright or software license disclosures during the period of performance. Provide information about the source code, including any software or intellectual property licenses that are required to distribute, use, modify, and reproduce the software. If you wish to open source a software prototype data set, please state so; we will follow up with you to explore the process of disclosing open-source software. Indicate so here or well. If you wish to obtain source code from an invention disclosure, please provide any copyright or software license disclosures during the period of performance. Provide information about the source code, including any software or intellectual property licenses that are required to distribute, use, modify, and reproduce the software. If you filed an invention disclosure, please provide any copyright or software license disclosures during the period of performance. Provide information about the source code, including any software or intellectual property licenses that are required to distribute, use, modify, and reproduce the software.
Please list all sponsored proposals submitted during the reporting period related to this or previous CEACSE awards.

**NSF Smart & Connected Communities (SCC), Solicitation 16-610**

- Pending (submitted Feb. 2017)

**NSF Smart & Connected Communities (SCC), Solicitation 17-610**

- Proposal is of sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.

Please list all sponsored proposals submitted during the reporting period related to this or previous CEACSE awards.

**NSF Critical Technologies, Methodologies for Advancing Foundations and Applications of Big Data Sciences and Engineering (BIGDATA), Solicitation 17-534**

- NSF Critical Technologies, Methodologies for Advancing Foundations and Applications of Big Data Sciences and Engineering (BIGDATA), Solicitation 17-534

- Dr. Sartipi participated in “Chattanooga’s Smart City Testbed” workshop on April 4, 2017. This workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding “smart” city. It focused heavily on brainstorming sessions within the areas of Transportation, Energy, and Public Health. Through this workshop we met several faculty and engaged in several collaborative opportunities.

- Dr. Sartipi participated in “Smart Cities” workshop in May of 2017 in Cadiz, Spain. The workshop was intended to facilitate more collaboration opportunities.

**Contracts / Awards**

List any awards or agreements received related to this or previous CEACSE awards. Include sponsor name, program name (if applicable), project title, and award amount.

- NSF Critical Technologies, Methodologies for Advancing Foundations and Applications of Big Data Sciences and Engineering (BIGDATA), Solicitation 17-534

- N/A

**Proposed Activities**

- Anticipated submission date, spring 2018.

**Sponsored Program Capacity Building Activities**

- List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF workshop, etc.

**Contracts / Awards**

- Pending (submitted Feb. 2017)

**Proposed Activities**

- NSF Critical Technologies, Methodologies for Advancing Foundations and Applications of Big Data Sciences and Engineering (BIGDATA), Solicitation 17-534

- Dr. Sartipi has also talked with planning division director of DOT.

**Sponsored Program Capacity Building Activities**

- Dr. Sartipi participated in “Chattanooga’s Smart City Testbed” workshop on April 4, 2017. This workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding “smart” city. It focused heavily on brainstorming sessions within the areas of Transportation, Energy, and Public Health. Through this workshop we met several faculty and engaged in several collaborative opportunities.

- Dr. Sartipi participated in “Smart Cities” workshop in May of 2017 in Cadiz, Spain. The workshop was intended to facilitate more collaboration opportunities.

- Dr. Sartipi participated in “Chattanooga’s Smart City Testbed” workshop on April 4, 2017. This workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding “smart” city. It focused heavily on brainstorming sessions within the areas of Transportation, Energy, and Public Health. Through this workshop we met several faculty and engaged in several collaborative opportunities.

- Dr. Sartipi has also talked with planning division director of DOT.

**Contracts / Awards**

- Pending (submitted Feb. 2017)

**Proposed Activities**

- NSF Critical Technologies, Methodologies for Advancing Foundations and Applications of Big Data Sciences and Engineering (BIGDATA), Solicitation 17-534

- N/A

**Sponsored Program Capacity Building Activities**

- List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF workshop, etc.

**Contracts / Awards**

- Pending (submitted Feb. 2017)

**Proposed Activities**

- NSF Critical Technologies, Methodologies for Advancing Foundations and Applications of Big Data Sciences and Engineering (BIGDATA), Solicitation 17-534

- Dr. Sartipi has also talked with planning division director of DOT.

**Sponsored Program Capacity Building Activities**

- Dr. Sartipi participated in “Chattanooga’s Smart City Testbed” workshop on April 4, 2017. This workshop served to connect and engage a diverse group of researchers in the challenges and research opportunities surrounding “smart” city. It focused heavily on brainstorming sessions within the areas of Transportation, Energy, and Public Health. Through this workshop we met several faculty and engaged in several collaborative opportunities.

- Dr. Sartipi has also talked with planning division director of DOT.
WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1, 2, … 5 years?

We have submitted a proposal (5G-C) in process of submitting one more (Spokes), and in the process of writing another one that will be submitted to NSF’s 5G/CC or BIGDATA Program Solicitation.

What barriers (if any) do you face to reach these next goals?

While we achieved majority of goals proposed in this project, there were few topics that weren’t explored due to lack of resources and expertise. We plan to address the lack of expertise by identifying right people from other departments as well as other universities and collaborating with them. Furthermore, the testbed is very challenging, such a testbed that satisfies the requirements in terms of latency and bandwidth doesn’t currently exist at the city scale. Finding off-the-shelf equipment for this testbed will challenge us as well.

What other related research will you pursue (and with whom) in light of the support you’ve received from CEACSE?

We will continue our collaborations with other universities (UTC, Vanderbilt, GA Tech, VA Tech) community and look for other potential opportunities for expansion of our testbed (EPB, The Enterprise Center, DOT). We have submitted a proposal (5G-C) in process of submitting one more (Spokes), and in the process of writing another one that will be submitted to NSF’s 5G/CC or BIGDATA Program Solicitation.

Tell us anything else we should know about this work not described above.

N/A

Goals

What barriers (if any) do you face to reach these next goals?

While we achieved majority of goals proposed in this project, there were few topics that weren’t explored due to lack of resources and expertise. We plan to address the lack of expertise by identifying right people from other departments as well as other universities and collaborating with them. Furthermore, the testbed is very challenging, such a testbed that satisfies the requirements in terms of latency and bandwidth doesn’t currently exist at the city scale. Finding off-the-shelf equipment for this testbed will challenge us as well.

What other related research will you pursue (and with whom) in light of the support you’ve received from CEACSE?

We will continue our collaborations with other universities (UTC, Vanderbilt, GA Tech, VA Tech) community and look for other potential opportunities for expansion of our testbed (EPB, The Enterprise Center, DOT). We have submitted a proposal (5G-C) in process of submitting one more (Spokes), and in the process of writing another one that will be submitted to NSF’s 5G/CC or BIGDATA Program Solicitation.

Tell us anything else we should know about this work not described above.

N/A

Goals

What barriers (if any) do you face to reach these next goals?

While we achieved majority of goals proposed in this project, there were few topics that weren’t explored due to lack of resources and expertise. We plan to address the lack of expertise by identifying right people from other departments as well as other universities and collaborating with them. Furthermore, the testbed is very challenging, such a testbed that satisfies the requirements in terms of latency and bandwidth doesn’t currently exist at the city scale. Finding off-the-shelf equipment for this testbed will challenge us as well.

What other related research will you pursue (and with whom) in light of the support you’ve received from CEACSE?

We will continue our collaborations with other universities (UTC, Vanderbilt, GA Tech, VA Tech) community and look for other potential opportunities for expansion of our testbed (EPB, The Enterprise Center, DOT). We have submitted a proposal (5G-C) in process of submitting one more (Spokes), and in the process of writing another one that will be submitted to NSF’s 5G/CC or BIGDATA Program Solicitation.

Tell us anything else we should know about this work not described above.

N/A

Goals

What barriers (if any) do you face to reach these next goals?

While we achieved majority of goals proposed in this project, there were few topics that weren’t explored due to lack of resources and expertise. We plan to address the lack of expertise by identifying right people from other departments as well as other universities and collaborating with them. Furthermore, the testbed is very challenging, such a testbed that satisfies the requirements in terms of latency and bandwidth doesn’t currently exist at the city scale. Finding off-the-shelf equipment for this testbed will challenge us as well.

What other related research will you pursue (and with whom) in light of the support you’ve received from CEACSE?

We will continue our collaborations with other universities (UTC, Vanderbilt, GA Tech, VA Tech) community and look for other potential opportunities for expansion of our testbed (EPB, The Enterprise Center, DOT). We have submitted a proposal (5G-C) in process of submitting one more (Spokes), and in the process of writing another one that will be submitted to NSF’s 5G/CC or BIGDATA Program Solicitation.

Tell us anything else we should know about this work not described above.

N/A
### FINANCIAL ACCOUNTING

<table>
<thead>
<tr>
<th>Financial Report:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Award Amount:</td>
<td>$95,503</td>
</tr>
<tr>
<td>Cumulative Expenditures:</td>
<td>$95,503</td>
</tr>
<tr>
<td>Remaining Award Amount:</td>
<td>$0</td>
</tr>
</tbody>
</table>

Please attach the following:

- Final ledger report showing the final accounting for your award.
- Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.
- Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.

### Supplemental Award Request

<table>
<thead>
<tr>
<th>Financial Report:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).</td>
<td>N/A</td>
</tr>
</tbody>
</table>


# PROJECT OVERVIEW

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>N. Sisworahardjo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>A. Arabshahi, K. Sreenivas</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Akram Saad (graduate student)</td>
</tr>
<tr>
<td>Project Title</td>
<td>Near Real-time Detection of Anomalous Power Consumption in Smart Power Distribution Networks</td>
</tr>
<tr>
<td>Date Submitted</td>
<td>08/28/2017</td>
</tr>
<tr>
<td>Award Start - End Date</td>
<td>07/01/2016 – 06/30/2017</td>
</tr>
</tbody>
</table>

**Non-Technical Summary – 500 words or less**

Through this project, our team members (PI and co-PIs) gained tremendous experience in big data and data analytics and understand the possible utilization that not only limited to power industries but also in other disciplines. Strategic relationship with local industry was strengthened with extensive collaboration with EPB and provide us opportunity to further this collaboration in scholarship activities. From this grant one graduate student received full support for one year to persue his master degree. Through the project, student gained first-hand experience in research and scholarship activities. Student had opportunity to write technical report which leads to paper(s) publication in conference/journal. One paper was submitted and accepted for 2017 International Conference on High Voltage and Power System. Another paper is in preparation for possible publication in conference/journal. This research project also enable researchers at UTC to gain knowledge and experience in anomaly detection in distribution network and gain valuable lessons that can be disseminated to other public power utilities in the region and beyond.

**Project Web Page(s)**

Please provide the complete URL.

N/A
**Quad Chart**

Title: Near Real-time Detection of Anomalous Power Consumption in Smart Power Distribution Networks

PI: N. Sisworahardjo, Co-PIs: A. Arabshahi, K. Sreenivas, Graduate Student: Akram Saad

Date: 07/01/2016 – 06/30/2017

<table>
<thead>
<tr>
<th><strong>Project Concept:</strong></th>
<th><strong>Operational Capability:</strong></th>
</tr>
</thead>
</table>
| • To develop a technique to monitor and detect energy consumption and diagnosing abnormal behavior.  
• To improve power distribution system resiliency, stability, and to meet energy efficiency targets. | • To enhance the anomaly detection technique with near real-time data visualization.  
• To enhance the ability to detect early sign of failure of the equipment.  
• To provide better service to customers by increasing customers energy usage awareness. |

<table>
<thead>
<tr>
<th><strong>Proposed Technical Approach:</strong></th>
<th><strong>Rough Order of Magnitude Cost and Schedule:</strong></th>
</tr>
</thead>
</table>
| **Literatures review:** To gain understanding on various techniques and methodologies to address similar issue. To identify possible techniques which can be enhanced and used concurrently to achieve better results.  
**Data identification and gathering:** Determine data type and classification along with duration and choose the sample data.  
**Anomaly detection model development:** Enhanced contextual anomaly detection algorithm to detect irregular power consumption.  
**Data Visualization:** Visualized anomaly scores using unsupervised learning algorithm and temporal context generated from meter readings. | 07/16 – 09/16 Review of Literature  
08/16 – 04/17 Anomaly detection model development  
11/16 – 06/17 Data visualization development  
Total project: $96,477.00  
**Deliverables:**  
• Monthly progress reports  
• Final report  
• Technical report  
**Contact:**  
N. Sisworahardjo  
University of Tennessee at Chattanooga  
EMCS 331A, Dept 2342  
615 McCallie Avenue  
Chattanooga, TN 37403-2598  
Phone: (423) 425-5753; Fax: (423) 425-1732 |
Project Overview

Provide a scientific/technical overview of your research project – hypotheses or scientific aims, methodologies and activities, outcomes, etc.

ACCUMPLISHMENTS & OUTCOMES

List of Objectives / Aims / Major Milestones Proposed

Data identification and gathering
- Data type and classification along with duration were determined and with EPB counterpart, we successfully obtained real data from EPB.

Anomaly detection model development
- Enhanced contextual anomaly detection algorithm to detect irregular power consumption, which can be enhanced and used concurrently to achieve better results.

Data Visualization
- Visualized anomaly scores using unsupervised learning algorithm and temporal context generated from meter readings.

Extend collaboration and research
- Explore possible research collaboration.

Data Visualization / Accomplishments

List of Objectives / Aims / Major Milestones Proposed

Cumulative Outcomes / Accomplishments

Challenges & Strategies Used to Address / Overcome:

- This is ongoing activity in building network and to exchange ideas with peers and extend collaboration and research.

- Context generated from meter readings.

- Visualized anomaly scores using unsupervised learning algorithm and temporal context generated from meter readings.

- Anomaly detection model development.

- Data Visualization and Gathering.

- Literature Review.

- Implementation on real-world data set provided by power utility company shows a high performance of the proposed algorithm.

- Enhancing other contextual anomaly detection algorithms to detect irregular power consumption.

- Anomaly detection algorithm was developed to detect irregular power consumption.

- Raw data from its customers and networks, a contextual anomaly detection algorithm was developed to detect irregular power consumption.

- Monitoring energy consumption and diagnosing abnormal behavior will enable utilities to collect various feasibility studies and to meet energy efficiency targets.

- The development of advanced metering infrastructure (AMI) enables utilities to collect various data on energy consumption and system resilience.

- Provide a scientific/technical overview of your research project – hypotheses or scientific aims, methodologies and activities, outcomes, etc.
Discuss any challenges or barriers that you encountered particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

Acquiring data from EPB counterpart seems longer than expected which causing delay in testing and refining our methodology. Nevertheless, we were able to achieve our main objectives.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PI’s, and key collaborators

Through this project, our team members (PI and co-PIs) gained tremendous experience in big data and data analytics and understand the possible utilization that not only limited to power industries but also in other disciplines. Strategic relationship with local industry was strengthened with extensive collaboration with EPB and provided an opportunity to further this collaboration in scholarships activities.

What didn’t work? What did you disprove or learn from the parts that didn’t meet your initial concept at the proposal?

Due to the delay in data gathering, we unable to refine existing demand prediction model using additional weather variables. The failure to perform this task, by no means affecting our effort to achieve the main objectives.

Students Impacted

One graduate student participated in this project. Through the project, student gained first-hand experience in research and scholarship activities. Student had opportunity to write technical report which leads to paper(s) publication in conference/journal.

Students involved in these activities.

What’s the potential next steps?

Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

Due to the delay in data gathering, we unable to refine existing demand prediction model using additional weather variables. The failure to perform this task, by no means affecting our effort to achieve the main objectives.

Students Involved

One graduate student participated in this project. Through the project, student gained first-hand experience in research and scholarship activities. Student had opportunity to write technical report which leads to paper(s) publication in conference/journal.

Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PI’s, and key collaborators

Through this project, our team members (PI and co-PIs) gained tremendous experience in big data and data analytics and understand the possible utilization that not only limited to power industries but also in other disciplines. Strategic relationship with local industry was strengthened with extensive collaboration with EPB and provided an opportunity to further this collaboration in scholarship activities.

What didn’t work? What did you disprove or learn from the parts that didn’t meet your initial concept at the proposal?

Due to the delay in data gathering, we unable to refine existing demand prediction model using additional weather variables. The failure to perform this task, by no means affecting our effort to achieve the main objectives.

Students Impacted

One graduate student participated in this project. Through the project, student gained first-hand experience in research and scholarship activities. Student had opportunity to write technical report which leads to paper(s) publication in conference/journal.

Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PI’s, and key collaborators

Through this project, our team members (PI and co-PIs) gained tremendous experience in big data and data analytics and understand the possible utilization that not only limited to power industries but also in other disciplines. Strategic relationship with local industry was strengthened with extensive collaboration with EPB and provided an opportunity to further this collaboration in scholarship activities.

What didn’t work? What did you disprove or learn from the parts that didn’t meet your initial concept at the proposal?

Due to the delay in data gathering, we unable to refine existing demand prediction model using additional weather variables. The failure to perform this task, by no means affecting our effort to achieve the main objectives.

Students Impacted

One graduate student participated in this project. Through the project, student gained first-hand experience in research and scholarship activities. Student had opportunity to write technical report which leads to paper(s) publication in conference/journal.
Community and Broader Impacts

Consider and discuss the technical and actual or potential societal impacts of your research project.

Attending NSF sponsored workshop in summer 2017. During this event, we were able and initiate possible outreach and collaboration.

Outreach & Collaboration

Please list any visitors, workshops, or other collaborative events did you hold/indicate the location (on-campus, etc.)

Another paper is in preparation for possible publication in conference/journal.

Work Products Reduced to Practice:

Provide a bibliographical entry where appropriate.

New inventions reduced to practice and when they will be formally disclosed;

Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here. If you wish to open source a software prototype data set please state so. We will follow up with a disclosure process and guidance on how proceed after ERF or EPB.

One paper was submitted and accepted for 2017 International Conference on High Voltage and Power System. This research project enable researchers at UTC to gain knowledge and experience in anomaly detection in distribution network and gain valuable lessons that can be disseminated to other public power utilities in the region and beyond.

New inventions reduced to practice and when they will be formally disclosed;

Provide a bibliographical entry where appropriate.

Intense communication with other collaborators is ongoing.

Another paper is in preparation for possible publication in conference/journal.
**EXTERNAL FUNDING**

Proposal Submissions

Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.

During the duration of the grant, we successfully build collaborative network with researchers from different institutions and industries. As for immediate plan, we are planning to have joint authorship to be presented in conferences and/or journals. Meanwhile, we will try to explore possible research collaboration.

**WHAT’S NEXT FOR THIS RESEARCH?**

How will you follow up your CEACSE Grant work in the next 1, 2, ... 5 years?

**EXTERNA FUNDING**

Contracts / Awards Received

- Non-Disclosure Agreement between UTC and EPB
- $25,000 to UT Chattanooga for project "Translation of the World's First Building"

Sponsored Program Capacity Building Activities

- 8th Indonesia Focus Conference, University of Kentucky, Lexington, Kentucky, September 30 - October 1
- NSF Workshop, June 16-17, 2017, University of Minnesota, Minneapolis, Minnesota
- Attending workshops/conferences: attending on NSF/NIH/other sponsor regional workshops, participating in GWSW activities, attending on-campus workshops, etc.

List of capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, etc.

**2016**

- National Science Foundation, EXCEL: Exploring Clean Energy through hands-on learning in the University of Tennessee at Chattanooga (UTC-Chatt)
- National Science Foundation, "Reducing the Barriers for Women: An Interdisciplinary Undergraduate Research and STEM Education Platform" at the University of Tennessee at Chattanooga (UTC-Chatt)
- Tennessee Department of Transportation (TDOT), Road Health Monitoring System

Proposal Submissions

- Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.
What other related research will you pursue (and with whom) in light of the support received from CEACSE?

We will pursue and continue our research work by refining and adding the layer of complexity on our technique in the power distribution industries (EPB/TVA) and along with other researchers in the US and abroad (New Zealand and Indonesia).

What barriers (if any) do you face to reach these next goals?

• Although the Internet allows us to communicate, face-to-face meeting with peers and partners is not that important. Travel funding support to meet and/or attend professional meeting with other researchers is pivotal.

• Hiring the high quality of graduate students with financial support (scholarships as RA/TA). Theoretically able to offer scholarships to the potential graduate students is extremely important to attract bright students to our campus.

What other related research will you pursue (and with whom) in light of the support received from CEACSE?

We will pursue and continue our research work by refining and adding the layer of complexity on our technique in the power distribution industries (EPB/TVA) and along with other researchers in the US and abroad (New Zealand and Indonesia).

What barriers (if any) do you face to reach these next goals?

• Although the Internet allows us to communicate, face-to-face meeting with peers and partners is not that important. Travel funding support to meet and/or attend professional meeting with other researchers is pivotal.

• Hiring the high quality of graduate students with financial support (scholarships as RA/TA). Theoretically able to offer scholarships to the potential graduate students is extremely important to attract bright students to our campus.

Although the Internet allows us to communicate, face-to-face meeting with peers and partners is not that important. Travel funding support to meet and/or attend professional meeting with other researchers is pivotal.

• Hiring the high quality of graduate students with financial support (scholarships as RA/TA). Theoretically able to offer scholarships to the potential graduate students is extremely important to attract bright students to our campus.

What barriers (if any) do you face to reach these next goals?

• Although the Internet allows us to communicate, face-to-face meeting with peers and partners is not that important. Travel funding support to meet and/or attend professional meeting with other researchers is pivotal.

• Hiring the high quality of graduate students with financial support (scholarships as RA/TA). Theoretically able to offer scholarships to the potential graduate students is extremely important to attract bright students to our campus.
<table>
<thead>
<tr>
<th>Financial Report:</th>
<th>Total Award Amount: $96,477.00</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cumulative Expenditures: $85,588.06</td>
</tr>
<tr>
<td></td>
<td>Remaining Award Amount: $10,888.94</td>
</tr>
</tbody>
</table>

Please attach the following:

- Final ledger report showing the final accounting for your award.
- Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.
- Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.

<table>
<thead>
<tr>
<th>Supplemental Award Request</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).  $1,308.00</td>
</tr>
</tbody>
</table>
# CUMULATIVE FINAL REPORT

(Submit as a Microsoft Word document [not PDF] via e-mail to Tony-Skjellum@utc.edu with a copy to Joanne-Romagni@utc.edu)

## PROJECT OVERVIEW

<table>
<thead>
<tr>
<th><strong>Lead PI</strong></th>
<th>Kidambi Sreenivas, PhD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Co-PI(s)</strong></td>
<td>Abi Arabshahi, PhD, Robert Webster, PhD</td>
</tr>
<tr>
<td><strong>Other Personnel</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Project Title</strong></td>
<td>Towards simulation of vertical axis wind turbines in offshore settings</td>
</tr>
<tr>
<td><strong>Date Submitted</strong></td>
<td>03/07/2016</td>
</tr>
<tr>
<td><strong>Award Start - End Date</strong></td>
<td>07-01-2016 through 06/30/2017</td>
</tr>
</tbody>
</table>

The objectives of this project were to take first steps towards the numerical simulation of the flow field surrounding vertical axis wind turbines (VAWT) in offshore settings. This work was carried out in collaboration with Sandia National Laboratory, with Dr. Todd Griffith as the POC. The idea behind the project was to carry out initial validation using data from a VAWT that Sandia had tested in the 70s and 80s. These experiments were carried out onshore and once this validation was completed, a future project (potentially funded through Sandia National Lab/DOE) would have involved transitioning the VAWT to an offshore setting.

Almost all commercial wind turbines are three-bladed and of the horizontal axis variety. Consequently, there isn’t a large body of research supporting VAWTs. This became abundantly clear as we looked for detailed geometry for the Sandia VAWT. The first roadblock we ran into was that proprietary airfoil sections were used in the Sandia VAWT. After significant back and forth between the PIs and Dr. Griffith, we were able to obtain the geometry of these airfoil sections. The second roadblock was that these wind turbines were built and tested in the era of “pencil and paper”, i.e., there were no solid models (CAD) available that defined this geometry. Based on various reports we found (some were provided by Dr. Griffith), we reconstructed the geometry as best as we could. Even with this effort, these were significant doubts about the geometry definition and there was no way to verify the same as the test article does not exist anymore. Simulations were carried out based on the geometry we had created, but the results were not satisfactory. Consequently, attempts to get some of these results published were unsuccessful.

Given that the simulations of the Sandia VAWT provided less than satisfactory results, we began the search for relatively recent experimental data, which had the added advantage of having well defined geometry. This search clearly showed us the paucity of experimental data for VAWTs. The only experimental dataset that could be found was completely fortuitous as the PI happened to be at a talk at the AIAA Aviation Conference in Denver (June 2017) where they discussed some of the results. The results were focused on details of the flow field as opposed to the power produced by the VAWT. Additional searches after the conference turned up one more dataset that could be of use. After returning from the conference, the geometry was created and simulations have been carried out. However, there was not enough time between the end of the conference and the end date of the project in order to carry out a thorough validation of the flow field. The PIs will continue these simulations over the course of the fall and spring semesters (as time permits) to see if good agreement with experimental data can be obtained.

This project, while not very successful, initiated collaboration between the SimCenter and Sandia National Lab. Additionally, it supported the SimCenter’s swimming lane related to “Energy & Environment”. The future for this kind of alternate energy research is uncertain because of the changes in the political climate at the federal level.
## Project Overview

The main technical objective was to carry out simulations of VAWTs compared to experimental data. This was done to provide an insight into the transition between the airfoils. The blade geometry proved to be very challenging because the transition sections were not available at the Sandia VAWT. However, the geometry provided to be of very high quality and needed to be handled correctly during the grid generation phase, the simulated flow field will also be of correspondingly high fidelity.

The coordination was successful in obtaining the experimental data for the Sandia VAWT. However, getting it was very late in the game to be of use. Unfortunately, this came very late in the project. If these factors had come to light early in the project, we could have possibly changed our tack and looked for other experimental data. However, it turned out that this was not quite the case. The biggest problems we ran into were the definition of the airfoil sections that made up the blades, uncertainty over how exactly they were oriented to form the blade, and how transitions between various sections of the blade were carried out. The first problem was reasonably resolved.

One of the most important aspects of any flow simulation is geometric fidelity, i.e., the quality and accuracy of the underlying geometry and data. The existence of this data was a chance discovery when the PI attended a talk. Tenasi had been successfully used for simulations of various fields associated with HAWTs better.

The flow was centered, finite volume, unstructured flow solver in order to simulate the flow associated with this turbine and derive associated performance characteristics from the computed flow field. The comparison to experimental data was carried out, and the results agreed well with the expectations.

The main outputs of the project were not a comprehensive understanding of the flow field of the wind turbine, the blade to coordinate working on this with the newly available geometry, and data. Instead, the focus was to continue working on this with the newly available geometry and data.

### ACCOMPLISHMENTS & OUTCOMES

**List of Objectives / Aims / Major Milestones Proposed**

- Provide a scientific/technical overview of your research project – Hypotheses of scientific claims, methodologies, and outcomes, etc.

**Cumulative Outcomes / Accomplishments**

- The coordination was successful in obtaining the experimental data for the Sandia VAWT.
- However, getting it was very late in the game to be of use. Unfortunately, this came very late in the game to be of use.
- This was a chance discovery when the PI attended a talk. Tenasi had been successfully used for simulations of various fields associated with HAWTs better.
- The flow was centered, finite volume, unstructured flow solver in order to simulate the flow associated with this turbine and derive associated performance characteristics from the computed flow field. The comparison to experimental data was carried out, and the results agreed well with the expectations.

**If these factors had come to light early in the project, we could have possibly changed our tack and looked for other experimental data. However, it turned out that this was not quite the case. The biggest problems we ran into were the definition of the airfoil sections that made up the blades, uncertainty over how exactly they were oriented to form the blade, and how transitions between various sections of the blade were carried out. The first problem was reasonably resolved.**

- One of the most important aspects of any flow simulation is geometric fidelity, i.e., the quality and accuracy of the underlying geometry and data. The existence of this data was a chance discovery when the PI attended a talk. Tenasi had been successfully used for simulations of various fields associated with HAWTs better.

The main outputs of the project were not a comprehensive understanding of the flow field of the wind turbine, the blade to coordinate working on this with the newly available geometry, and data. Instead, the focus was to continue working on this with the newly available geometry and data.
Extended abstracts were submitted to the AIAA Wind Energy Symposium; however, the uncertainty in geometry and the unsatisfactory results did not result in acceptance of the paper.

Given the unsatisfactory results, joint proposals were not pursued. If the simulations utilizing the new geometries (corresponding to new test cases that have not been tested yet) show promising results, the topic of joint proposals will be revisited.

CHALLENGES & STRATEGIES USED TO ADDRESS / OVERCOME:

- Quality of the geometry was poor and this was reflected in the unsatisfactory agreement obtained with experimental data.

- Transition section between sections of the blade where different airfoils were used. These transition sections were not defined in any of the reports. Some of these sections were labeled stealth sections and were written in a proprietary section that was not available to the open literature.

No other results were available and the only way to overcome the challenge would be to repeat an experiment with the Sandia VAWT. Going into the project, we assumed that the geometry was the biggest challenge in this project was the availability of geometry for the Sandia VAWT. However, that turned out to be the biggest challenge. We attempted to overcome the challenge by coordinating with Dr. Griffith at Sandia Labs.

- The bottom line was that the quality of the geometry was poor and this was reflected in the unsatisfactory agreement obtained with experimental data.

- We proved that geometry is king and without an accurate representation of the test article, even the most sophisticated flow solver will not be very successful in comparing favorably to experimental data.

- Boundary conditions are the problem. In our case, the boundary conditions are provided by the geometry of the wind turbine in the earlier successful simulations (horizontal axis wind turbines), [sic] that geometry is not available to us.

- The biggest challenge in this project was the availability of geometry for the Sandia VAWT.

- We decided to proceed with the airfoil section where different airfoils were used. These transition sections were not defined in any of the reports. Some of these sections were labeled stealth sections and were written in a proprietary section that was not available to the open literature.

- The first section was the airfoil section used in the VAWT. This was a proprietary section that was not available to the open literature.

- The biggest challenge in this project was the availability of geometry for the Sandia VAWT.

- The biggest challenge in this project was the availability of geometry for the Sandia VAWT.
### Students Impacted

Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Degree/Semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>David Collao</td>
<td>Responsible for creating the geometry and generating the meshes for this project.</td>
<td>PhD (2017)</td>
</tr>
</tbody>
</table>

### Community and Broader Impacts

Consider and discuss the technical and actual or potential societal impacts of your research project.

None at this stage.

### Work Products Reduced to Practice

Please include software, papers, presentations, posters, and creative works.

<table>
<thead>
<tr>
<th>Publication Type</th>
<th>Work Product</th>
<th>Bibliographical Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### New Inventions Reduced to Practice

Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If filed, provide a list of these inventions.

None.

### Appropriate Bibliographic Entry Where Applicable

Provide a bibliographic entry where appropriate.

None.

### Impact on the Career(s) of the PI, the co-PIs, and key collaborators

None, at this stage. This can change as we carry out simulations of the new geometry.

None, at this stage. This can change as we carry out simulations of the new geometry.
WHAT'S NEXT FOR THIS RESEARCH?

Heterogeneous HPC for High-order Stabilized Finite-Elements on Moving and Deforming Domains, HPCMP, $400K

Collaborated with Dr. Todd Griffith, Sandia National Laboratory. All of the interaction was through email and phone calls.

Collaborated with Dr. Mike List and colleagues at AFRL, Wright Patterson AFB, Dayton, OH.

Met with Drs. Hua Shan, Chandra Kannepalli, and Matthew Jemison at NSWC-C Carderock Division, Washington, DC.

Met with researchers from SmartTruck (at the SimCenter). SmartTruck is a company that designs and produces after-market drag reduction devices for class 8 trailer trucks. They are also interested in our carrier-level simulations for high-order stabilized finite-elements on moving and deforming domains.

Related to other CCA235 awards.

None related to this project.

Please list all sponsored program proposals submitted during the reporting period related to this or previous CCA235 awards.

Proposal Submissions

Contracts / Awards Received

Sponsored Program Capacity Building Activities

EXTERNAL FUNDING

Proposal Submissions

Contracts / Awards Received

Sponsored Program Capacity Building Activities

Collaborated with Dr. Todd Griffith, Sandia National Laboratory. All of the interaction was through email and phone calls.

Collaborated with Dr. Mike List and colleagues at AFRL, Wright Patterson AFB, Dayton, OH.

Met with Drs. Hua Shan, Chandra Kannepalli, and Matthew Jemison at NSWC-C Carderock Division, Washington, DC.

Met with researchers from SmartTruck (at the SimCenter). SmartTruck is a company that designs and produces after-market drag reduction devices for class 8 trailer trucks. They are also interested in our carrier-level simulations for high-order stabilized finite-elements on moving and deforming domains.

Related to other CCA235 awards.

None related to this project.

Please list all sponsored program proposals submitted during the reporting period related to this or previous CCA235 awards.
How will you follow up our CEACSE grant with work in the next 1, 2, ... 5 years?

Work will continue on carrying out simulations of vertical axis wind turbines (as time permits) over the next year.

If good results are obtained, efforts will be made to secure external funding for the same.

Research is underway on porting FUNSAFE, a finite-element flow solver, to heterogeneous architectures.

What barriers (if any) do you face to reach these next 1, 2, ... 5 years’ goals?

None at this stage.

What other related research have you received from CEACSE? What will you pursue (and with whom) in light of the support we provided?

Research is underway on porting FUNSAFE, a finite-element flow solver, to heterogeneous architectures.

Tell us anything else we should know about this work not described above.

What will you pursue next in terms of a future CEACSE grant with work in the next 1, 2, ... 5 years?

Work will continue on carrying out simulations of vertical axis wind turbines (as time permits) over the next year.
## FINANCIAL ACCOUNTING

<table>
<thead>
<tr>
<th>Financial Report:</th>
<th>Total Award Amount:</th>
<th>$96,573.00</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cumulative Expenditures:</td>
<td>$92,095.20</td>
</tr>
<tr>
<td></td>
<td>Remaining Award Amount:</td>
<td>$4,477.80</td>
</tr>
</tbody>
</table>

Please attach the following:

- Final ledger report showing the final accounting for your award.
- Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.
- Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.

### Supplemental Award Request

<table>
<thead>
<tr>
<th></th>
<th>Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# PROJECT OVERVIEW

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>Craig Tanis, PhD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>Kidambi Sreenivas, PhD</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>None</td>
</tr>
<tr>
<td>Project Title</td>
<td>Optimizing FUNSAFE for Leadership-Class Machines</td>
</tr>
<tr>
<td>Date Submitted</td>
<td>June 2016</td>
</tr>
<tr>
<td>Award Start - End Date</td>
<td>July 1 2016 – July 31 2017</td>
</tr>
</tbody>
</table>

**Non-Technical Summary – 500 words or less**

The goal of this project was to update the SimCenter-developed finite element code, FUNSAFE, optimizing it for GPU-enabled supercomputing systems, and getting a large case to run on the Titan system at Oak Ridge National Lab. Over the course of the project, we switched to focusing on the SimCenter’s new GPU-based system. Impressive performance results for parts of FUNSAFE were achieved, but the full port is incomplete. We (Dr. Tanis as Co-PI) have been awarded external funding to continue this work, including an update of the code to use the Kokkos framework for performance portability.

| Project Web Page(s) | None |

*Please attach a Quad Chart using the following format as an example:*

The objective of this project was to modify UTC's FNSAFE computational simulation framework to perform optimally on leadership-class supercomputers, and to demonstrate FNSAFE capabilities at scale on the Titan system at ORNL. We've demonstrated extremely fast numerical integration over Gauss points with a simple elemental volume kernel. At this point we became aware of the Kokkos project and began planning to integrate that in our kernels. This was part of the work proposed and awarded in the PETTT project listed below. We've demonstrated extremely fast numerical integration over Gauss points with a simple elemental volume kernel. At this point we became aware of the Kokkos project and began planning to integrate that in our kernels.

During the migration to C++, we began using Dr. Tanis' Splatter package for parallel mesh management and enabled the use of PETSc linear solvers. New C++ templates were developed to allow application scientists to write code with respect to individual Gauss points for arbitrary elements. The system became responsible for dispatching these templated kernels on the appropriate hardware.

It was desirable to improve FNSAFE's heterogeneous performance without requiring application scientists to worry about computational accelerators. It was desirable to improve FNSAFE's heterogeneous performance without requiring application scientists to worry about computational accelerators.

We've demonstrated extremely fast numerical integration over Gauss points with a simple elemental volume kernel. At this point we became aware of the Kokkos project and began planning to integrate that in our kernels.
List of Objectives / Aims / Major Milestones

**Proposed Cumulative Outcomes / Accomplishments**

<table>
<thead>
<tr>
<th>What didn't work? What did you discover or learn from the parts that didn't meet your initial concept at the proposal?</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Experimention into my proposal timelines.</em></td>
</tr>
<tr>
<td><em>As described above, the project simply became more time-intensive than initially expected. It's learned to build more time for research and development.</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Challenges &amp; Strategies Used to Address / Overcome:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Awarded external funding for additional related work.</strong></td>
</tr>
<tr>
<td>Great preliminary performance results on new SimCenter machine.</td>
</tr>
<tr>
<td>Increased local knowledge on performance portability issues and accelerator-based system architectures.</td>
</tr>
<tr>
<td>Developed new accelerator-aware routines for finite element simulations on accelerator hardware.</td>
</tr>
<tr>
<td>Cumulative Outcomes / Accomplishments</td>
</tr>
<tr>
<td>Impact &amp; Outcomes</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td><strong>Impact on the Career(s) of the PI, the Co-PIs, and Key Collaborators</strong></td>
</tr>
<tr>
<td><strong>Students Impacted</strong></td>
</tr>
<tr>
<td><strong>Community and Broader Impacts</strong></td>
</tr>
<tr>
<td><strong>Work Products Reduced to Practice</strong></td>
</tr>
</tbody>
</table>
Outreach & Collaboration

This project further strengthened collaboration between the SimCenter and Computer Science and Engineering departments at UTC.

EXTERNAL FUNDING

Proposal Submissions

CEACE 2017-18 "Expanding FUNSAFE capability" (not awarded)

Sponsored Programs Awarded

PETTT "Heterogeneous HPC for High-order Stabilized Finite-Elements on Moving and Deforming Domains" (Drs. Tanis and Sreenivas as Co-P); Engility Corp. Funded for approximately $422,000 over two years.

Contracts / Awards Received

PETTT "Heterogeneous HPC for High-order Stabilized Finite-Elements on Moving and Deforming Domains" (Drs. Tanis and Sreenivas as Co-P);...
How will you follow up your CEACSE grant with work in the next 1, 2, ..., 5 years?

The immediate goal is to fulfill the responsibilities of the awarded external funding (PfT). This will lead to additional FUSE capabilities spanning the gamut of applications. The immediate goal is to fulfill the responsibilities of the awarded external funding (PfT). This will lead to additional FUSE capabilities spanning the gamut of applications.

What barriers (if any) do you face in reaching these next goals?

Time.

What immediate goal do you see for the awarded CEACSE grant?

The immediate goal is to fulfill the responsibilities of the awarded external funding (PfT). This will lead to additional FUSE capabilities spanning the gamut of applications.

What other related research will you pursue (and with whom) in light of the support you’ve received from CEACSE? What potential collaboration with NASA, others (hearsay) do you see?

Po
tential collaboration with NASA, others (hearsay). This work continues to be of vital interest to the SimCenter, and there are many paths forward.

Tell us anything else we should know about this work and your CEACSE grant?

You’ve received from CEACSE? How will you pursue (and with whom) in light of the support you’ve received from CEACSE? What other related research will you pursue (and with whom) in light of the support you’ve received from CEACSE?
### FINANCIAL ACCOUNTING

<table>
<thead>
<tr>
<th>Financial Report:</th>
<th>Total Award Amount:</th>
<th>$86,741</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cumulative Expenditures:</td>
<td>$69,935</td>
</tr>
<tr>
<td></td>
<td>Remaining Award Amount:</td>
<td>$16,806</td>
</tr>
</tbody>
</table>

Please attach the following:

- Final ledger report showing the final accounting for your award.
- Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.
- Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.

| Supplemental Award Request | Yes | $8,247 |
# PROJECT OVERVIEW

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Robert Webster</td>
<td></td>
</tr>
<tr>
<td>Co-PI(s)</td>
<td>None</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Identify by type – senior personnel, technicians, graduate students, undergraduate students</td>
</tr>
<tr>
<td>Drs. Kidambi Sreenivas and Ethan Hereth; Mr. David Collao</td>
<td></td>
</tr>
<tr>
<td>Project Title</td>
<td>Numerical Simulations of Axial Compressor Flow Fields Employing Higher-order Accuracy</td>
</tr>
<tr>
<td>Date Submitted</td>
<td>30 August, 2017</td>
</tr>
<tr>
<td>Award Start - End Date</td>
<td>1 July, 2016 – 30 June, 2017</td>
</tr>
<tr>
<td>Non-Technical Summary – 500 words or less</td>
<td>Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter. The major objective was to make use of higher-order spatial accuracy in the simulations of an axial compressor, for which there was a reasonable experience base using standard (i.e., 2nd order) spatial accuracy. Thus, one-to-one comparisons could be made, especially with regard to comparison of the numerical results with experimental results in terms of overall performance parameters. The original plan was to use both finite-volume and finite-element methodologies with higher-order spatial accuracy and make comparisons between the two methodologies, as well as with experiment. In the end, only the finite-volume methodology was tested, since it was “ready to use”, at least as applied to rotating machinery. Even so, this was a useful experience as it provided clear evidence that the use of higher-order spatial accuracy improved the agreement with experiment.</td>
</tr>
<tr>
<td>Project Web Page(s)</td>
<td>Please provide the complete URL. None.</td>
</tr>
</tbody>
</table>
### Project Overview

Provide a scientific/technical overview of your research project – hypotheses or scientific aims, methodologies and activities, outcomes, etc.

<table>
<thead>
<tr>
<th>List of Objectives / Aims / Major Milestones Proposed</th>
<th>Cumulative Outcomes / Accomplishments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploring higher-order spatial accuracy using finite-volume methodologies</td>
<td>Comparing WENO and FE to each other and experiment</td>
</tr>
<tr>
<td>The use of this methodology made a noticeable improvement in the accuracy of simulations performed on a multi-stage axial compressor.</td>
<td>The WENO methodology was extensively tested; FE was not for the incompressible flows.</td>
</tr>
<tr>
<td>Use of high-order finite-element analysis (FEA) in rotating machinery flows</td>
<td>Conduting numerical simulations using both WENO and FEA</td>
</tr>
<tr>
<td>Comparing WENO and FEA to each other and experiment</td>
<td>Conduting WENO and FEA on axial compressor</td>
</tr>
<tr>
<td>Comparisons were not made between the two methodologies for the</td>
<td>The WENO methodology was extensively tested; FE was not for the</td>
</tr>
<tr>
<td>reasons/outcome noted above.</td>
<td>reasons/outcome noted above.</td>
</tr>
<tr>
<td>Comparisons were not made between the two methodologies for the</td>
<td>This objective was not realized during the course of this project, since the</td>
</tr>
<tr>
<td>reasons/outcome noted above.</td>
<td>use of high-order finite-element analysis (FEA) in rotating</td>
</tr>
<tr>
<td>The use of this methodology made a noticeable improvement in the accuracy of simulations performed on a multi-stage axial compressor.</td>
<td>Conduting numerical simulations using both WENO and FEA</td>
</tr>
</tbody>
</table>

Accomplishments during this time period. However, a newly awarded grant will allow that effort to be brought to fruition. The intent was also to use high-order finite-element methodologies, but that required some code development efforts that were not fully

In the low-to-moderate-loading numerical results, the influence of wake losses would not be great at these operating conditions. The accuracy captured thus bringing the computed performance more in line with experiment at these conditions. There was little, if any, change

Comparisons were not made between the two methodologies for the reasons/outcome noted above. A relative advantage when applied to wind turbine flow fields, but this effort was first time to try higher-order accuracy for a more complicated axial-flow configuration. This has been shown to improve simulation quality when used in a finite-volume formulation to increase the spatial accuracy where possible. This has been shown to improve simulation quality when used in a finite-volume formulation to increase the spatial accuracy where possible. This has been shown to improve simulation quality when used in a finite-volume formulation to increase the spatial accuracy where possible. This has been shown to improve simulation quality when used in a finite-volume formulation to increase the spatial accuracy where possible. This has been shown to improve simulation quality when used in a finite-volume formulation to increase the spatial accuracy where possible. This has been shown to improve simulation quality when used in a finite-volume formulation to increase the spatial accuracy where possible.
Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered or difficulties that you were impacted from achieving the objectives and milestones approved in your proposal.

As stated above, the second objective was not met. This was due largely to an underestimate of what was required for the development effort. Progress was made toward this goal, but it was not fully completed. Milestones and estimations were underestimated and sometimes not all milestones were met.

Investigating the impact of higher-order spatial accuracy was met. This is a source of external funding that should be useful in aiding the PI as he works toward attaining tenure. This work, in addition to similar efforts from previous years, has led to a PETT grant award that the PI and fellow colleagues will be involved with. This is a source of external funding that should be useful in aiding the PI as he works toward attaining tenure. This work, in addition to similar efforts from previous years, has led to a PETT grant award that the PI and fellow colleagues will be involved with.

As stated above, this is a source of external funding that should be useful in aiding the PI as he works toward attaining tenure. This work, in addition to similar efforts from previous years, has led to a PETT grant award that the PI and fellow colleagues will be involved with.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PI's, and key collaborators:

This work, in addition to similar efforts from previous years, has led to a PETT grant award that the PI and fellow colleagues will be involved with. This is a source of external funding that should be useful in aiding the PI as he works toward attaining tenure.

Students Impacted

Please list students including name, brief description of how they were impacted, what degree or when graduated, and any other relevant details.

None.

collaborators

pl, the co-PI's, and key collaborators

Impact on the career(s) of the PI, the co-PI's, and key collaborators:

This work, in addition to similar efforts from previous years, has led to a PETT grant award that the PI and fellow colleagues will be involved with. This is a source of external funding that should be useful in aiding the PI as he works toward attaining tenure.

Students Impacted

Please list students including name, brief description of how they were impacted, what degree or when graduated, and any other relevant details.

None.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

See above.

What did you do right? What did you learn besides what you achieved whether it met your expectations at the outset of the effort?

See above.

What did you learn besides what you achieved whether it met your expectations at the outset of the effort?

See above.
### Community and Broader Impact

**Consider and discuss the technical and actual or potential societal impacts of your research project.**

**Increased accuracy of computational simulations of axial compressor flows, in conjunction with experimental efforts, should lead to better understanding of the flow physics, which can aid in design and optimization of gas turbine components.**

Increased accuracy of computational simulations of axial compressor flows, in conjunction with experimental efforts, should lead to better understanding of the flow physics, which can aid in design and optimization of gas turbine components.

**Proposal Submissions**

*Heterogeneous HPC for High-Order Stabilized Finite-Elements on Moving and Deforming Domains.*

The proposal was for $422,001 (over two years) from the Engility Corporation.

**EXTERNAL FUNDING**

<table>
<thead>
<tr>
<th>Proposal Submissions</th>
<th>Outreach &amp; Collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Heterogeneous HPC for High-Order Stabilized Finite-Elements on Moving and Deforming Domains.</em></td>
<td><em>Proposals Reduced to practice and when they will be formally disclosed.</em></td>
</tr>
<tr>
<td>The proposal was for $422,001 (over two years) from the Engility Corporation.</td>
<td>New inventions reduced to practice and when they will be formally disclosed.*</td>
</tr>
</tbody>
</table>

**Work Products Reduced to practice:**

Provide a bibliographic entry where appropriate.


**Outreach & Collaboration**

Please list any visitor workshops or other collaborative events did you hold; indicate the location (on campus, etc.).

Participation in the Research Dialogues program held on campus in April, 2017.

None.

**Proposal Submissions**

*Heterogeneous HPC for High-Order Stabilized Finite-Elements on Moving and Deforming Domains.*

The proposal was for $422,001 (over two years) from the Engility Corporation.

**EXTERNAL FUNDING**

<table>
<thead>
<tr>
<th>Proposal Submissions</th>
<th>Outreach &amp; Collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Heterogeneous HPC for High-Order Stabilized Finite-Elements on Moving and Deforming Domains.</em></td>
<td><em>Proposals Reduced to practice and when they will be formally disclosed.</em></td>
</tr>
<tr>
<td>The proposal was for $422,001 (over two years) from the Engility Corporation.</td>
<td>New inventions reduced to practice and when they will be formally disclosed.*</td>
</tr>
</tbody>
</table>

**Work Products Reduced to practice:**

Provide a bibliographic entry where appropriate.


**Outreach & Collaboration**

Please list any visitor workshops or other collaborative events did you hold; indicate the location (on campus, etc.).

Participation in the Research Dialogues program held on campus in April, 2017.

None.

**Proposal Submissions**

*Heterogeneous HPC for High-Order Stabilized Finite-Elements on Moving and Deforming Domains.*

The proposal was for $422,001 (over two years) from the Engility Corporation.

**EXTERNAL FUNDING**

<table>
<thead>
<tr>
<th>Proposal Submissions</th>
<th>Outreach &amp; Collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Heterogeneous HPC for High-Order Stabilized Finite-Elements on Moving and Deforming Domains.</em></td>
<td><em>Proposals Reduced to practice and when they will be formally disclosed.</em></td>
</tr>
<tr>
<td>The proposal was for $422,001 (over two years) from the Engility Corporation.</td>
<td>New inventions reduced to practice and when they will be formally disclosed.*</td>
</tr>
</tbody>
</table>

**Work Products Reduced to practice:**

Provide a bibliographic entry where appropriate.


**Outreach & Collaboration**

Please list any visitor workshops or other collaborative events did you hold; indicate the location (on campus, etc.).

Participation in the Research Dialogues program held on campus in April, 2017.

None.
WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1, 2, … 5 years?

Obviously, the most immediate follow-up will be working on the grant that has been recently awarded. It is also expected to work toward rebuilding the working relationship with NASA-Glen that has stagnated somewhat over the last two to three years. Perhaps this can lead to additional research funding from NASA-Glen, which is heavily involved in research involving flow fields with rotating machinery.

Higher-order spatial accuracy would aid in the simulations of most anything related to aerospace propulsion. This could be applicable to both gas-turbine and rocket propulsion.

The presentation of the conference paper listed above has sparked a renewed interest from personnel at the NASA Glenn Research Center. The PI and colleague Dr. Kidambi Sreenivas met with Dr. Michael Liss, director of the compressor research group. They are interested in the collaboration with researchers at Auburn University; attending camp sessions, etc.

The collaboration is a positive step toward rebuilding the working relationship. The conference paper that was presented at Wright- Patterson Air Force Base in September 2016, is a portion of that meeting was recorded. The conference paper is available online.

The following are additional activities in which you have engaged during the award period.

- Meeting with a sponsor program officer
- Attending a conference building activity
- Participating in a GWSW activity
- Attending a workshop or other sponsor regional workshop

ANY OTHER RELATED RESEARCH

CEACSE Grant with Work in the Next 1, 2, … 5 Years?

Contracts / Awards Received

List any awards or agreements received/executed related to this or previous CEACSE Awards. Include sponsor name, sponsor program name (if applicable).

Sponsored Program Capacity Building Activities

List all capacity building activities in which you have engaged during the award period. Examples may include meetings with a sponsor program officer.
Tell us anything else we should know about this work not described above.

What barriers (if any) do you face to reach these next goals?
**FINANCIAL ACCOUNTING**

<table>
<thead>
<tr>
<th>Financial Report:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Award Amount:</td>
<td>$</td>
</tr>
<tr>
<td>Cumulative Expenditures:</td>
<td>$</td>
</tr>
<tr>
<td>Remaining Award Amount:</td>
<td>$</td>
</tr>
</tbody>
</table>

Please attach the following:

- Final ledger report showing the final accounting for your award.
- Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.
- Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.

<table>
<thead>
<tr>
<th>Supplemental Award Request</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).</td>
<td>No.</td>
</tr>
</tbody>
</table>
## PROJECT OVERVIEW

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.</th>
<th>Dr. Dalei Wu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>Dr. Yu Liang, Dr. Li Yang, Dr. Farah Kandah, Dr. Joseph M. Kizza</td>
<td></td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Identify by type – senior personnel, technicians, graduate students, undergraduate students</td>
<td></td>
</tr>
<tr>
<td><strong>Graduate students:</strong></td>
<td>Mehran Ghafari, Maxwell Omwenga, Stuart Eudaly, Nada Alharbi, Sharmila chackrawathy, Maha Almaimani, Rabhu Bajracharya</td>
<td></td>
</tr>
<tr>
<td><strong>Undergraduate students:</strong></td>
<td>Robert Slaughter, Dakila Ledesma, Christopher Davis, Alaykumar Patel, Suhail Arora, Austin Obynre, Peter Zeglen, Derek Snyder, Morgan Sanborn, Izabella Arredondo</td>
<td></td>
</tr>
<tr>
<td>Project Title</td>
<td>Multiscale Serviceability Analysis and Assessment of Urban Infrastructure</td>
<td></td>
</tr>
<tr>
<td>Date Submitted</td>
<td>08/30/2017</td>
<td></td>
</tr>
<tr>
<td>Award Start - End Date</td>
<td>07/01/2016 – 06/30/2017</td>
<td></td>
</tr>
<tr>
<td>Non-Technical Summary – 500 words or less</td>
<td>Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.</td>
<td></td>
</tr>
</tbody>
</table>

The project was primarily targeted at developing a new multi-scale structural health monitoring system over Big-Data platform (MS-SHM-BD) to monitor and evaluate the serviceability of large-scale civil structures. Under the sponsorship of CEACSE funding, the team has been able to complete the major research goals and tasks of the project. The impacts are:

- Two research seminars on the project were given in SimCenter seminar series by the team faculty in early 2017. Research findings were also presented during UTC Research Dialogues 2017.
- Total 7 graduate students (3 females) and 10 undergraduate students (2 females) have been involved in the project.
- Four research papers have been published, including one book chapter, two journal papers, and one conference paper. A female graduate student is the first author of the conference paper. In addition, two conference papers have been submitted, and two journal papers are under preparation by the team.
- The team has submitted four research proposals to NSF, NIST, and NIHS, with one proposal being funded by NSF (#1647175, $299,884).
Collaborations have been established with researchers from inside and outside UTC. The team submitted research proposals by collaborating with professors and researchers from University of Vermont, University of Cincinnati, University of Tennessee at Knoxville, Old Dominion University, Oak Ridge National Laboratory, and UTC Math Department.

With the help of The Enterprise Center, The team also held meetings with officials and engineers from local organizations, including Tennessee American Water, EPB, Chattanooga Department of Transportation, and Chattanooga Public Works, for experiment planning and demonstration.

Please attach a Quad Chart using the following format as an example:
The objective of the project was to develop a multi-scale structural health monitoring system over Big Data platform to monitor and evaluate the serviceability of large-scale civil structures. Aimed to evaluate the structural health status of bridges and pipelines, a nationwide bridge/pipeline database survey, global structural integrity analysis and component structural reliability analysis were performed by using methodologies of machine learning, signal processing, structural modeling and simulation, fatigue analysis, and Bayesian network.

### Accomplishments & Outcomes

<table>
<thead>
<tr>
<th>List of Objectives</th>
<th>Major Milestones Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>With data acquisition, transmission and integration, bridges/pipelines in the United States will be characterized and zoned to potential damages.</td>
<td>Propensity characterization of the safety level of major bridges/pipelines database survey will be done to obtain a precise description about the specific heavily damaged zones/sections.</td>
</tr>
<tr>
<td>Various data analytics techniques such as missing data handling, variable transformation, and feature extraction were proposed for delivery of urban infrastructure monitoring information.</td>
<td>Bayesian network was applied to generate a compact representation of joint probability distributions as global bridges reliabilty analysis.</td>
</tr>
<tr>
<td>A Hadoop platform based on the CS cluster “Qbert” at the SimCenter has been used for data storage and analytics.</td>
<td>Component reliability analysis results will be synthesized to achieve a holistic characterization of the serviceability of global bridges/pipelines.</td>
</tr>
<tr>
<td>A method for global structural integrity analysis has been developed by using measured structural resonance frequency and computed natural frequency.</td>
<td>Bayesian network was applied to generate a compact representation of joint probability distributions as global bridges reliability analysis.</td>
</tr>
<tr>
<td>Ground penetrating radar (GPR) image processing techniques have been explored.</td>
<td>Bayesian network was applied to generate a compact representation of joint probability distributions as global bridges reliability analysis.</td>
</tr>
<tr>
<td>Two strageties of component reliability analysis, structural reliability analysis and observation-oriented method, have been investigated.</td>
<td>Component reliability analysis results will be synthesized to achieve a holistic characterization of the serviceability of global bridges/pipelines.</td>
</tr>
<tr>
<td>Localized structural component reliability analysis will be done to obtain a precise description about the specific heavily damaged sections.</td>
<td>Bayesian network was applied to generate a compact representation of joint probability distributions as global bridges reliability analysis.</td>
</tr>
</tbody>
</table>
Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

- Proper data for global structural integrity analysis targeted bridges/pipelines were missing. To overcome this challenge, collaboration with researchers from the University of Vermont was pursued to collect the needed data (e.g., GPR images).
- Students involved in this project lacked background knowledge of infrastructure sensing, structural modeling and dynamics theory. To overcome this challenge, collaboration with researchers from the University of Vermont was pursued to provide study materials and interactive workshops.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?
Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

The following students were involved in this project. With the support of this CEACSE project, most of them worked on this project with hourly pay.

Graduate students pursuing PhD degree in Computer Science: Maxwell Omwenga, Mehran Ghafari.
Graduate students pursuing master degree in Computer Science: Sharmila Chackrawathy, Stuart Eudaly, Nada Alharbi, Maha Almaimani, Rabhu Bajracharya.
Undergraduate students pursuing bachelor degree in Computer Science: Robert Slaughter, Dakila Ledesma, Christopher Davis, Alaykumar Patel, Suhail Arora, Austin Obyrne, Peter Zeglen, Derek Snyder, Morgan Sanborn.

Community and Broader Impacts

Consider and discuss the technical and actual or potential societal impacts of your research project. The broader impacts include educational experiences for graduate students and participating municipal utility officials in network-enabled sensing and urban infrastructure monitoring. The research conducted in this project was designed to determine methods of managing civil infrastructure in an urban setting using network-enabled sensing and information processing techniques that are measurable, scalable, and interoperable. These sensing and information processing techniques have been developed to determine methods of managing civil infrastructure in urban settings. This project has been utilized for education to promote educational experiences for graduate students and participating municipal utility officials.

The broader impacts include educational experiences for graduate students and participating municipal utility officials.

Work products reduced to practice; provide a bibliographical entry where appropriate. Please include software, papers, presentations, posters, and creative works. Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factor where appropriate.

Book chapter:


Journal papers:


::
Conference/workshop papers:


Presentations:

• bruk research dialogue: “monitoring and modeling underground infrastructure for smart maintenance and usage,” by dr. dalei wu, feb. 03, 2017.
• bruk research dialogue: “monitoring, mapping and modeling underground infrastructure for smart maintenance,” by d. yuan, feb. 12, 2017.


New inventions Reduced to Practice and When They Will be Formally Disclosed:

Please list any software prototypes you have developed. If you wish to disclose the location of your current research efforts, please indicate the location (on campus, etc.).
Please list all sponsored program proposals submitted during the reporting period related to this or previous awards.

**External Funding**

Proposal Submissions


- **•** Dr. Wu attended the IEEE INFOCOMM, Atlanta, May 4-12, 2017, meeting with NSF CNS program officers.

Contracts / Awards Received

- **•** Dr. Wu participated in the Global City Team Challenge (GCTC) 2016, sponsored by NSF, Washington DC, October 25-26, 2016, networking with other GCTC Action Cluster team leads.

- **•** The participated in the Global City Team Challenge (GCTC) 2016, sponsored by NSF, Washington DC, October 25-26, 2016, attended on-campus workshops, etc.

Sponsored Program Capacity Building Activities

- **•** Dr. Wu participated in the Grant Writing Workshop cohort, 2017.

- **•** Dr. Wu attended the IEEE INFOCOMM, Atlanta, May 4-12, 2017, meeting with NSF CNS program officers.

- **•** Dr. Wu attended the IEEE INFOCOMM, Atlanta, May 4-12, 2017, meeting with NSF CNS program officers.

- **•** Dr. Wu attended the IEEE INFOCOMM, Atlanta, May 4-12, 2017, meeting with NSF CNS program officers.
What's Next for This Research?

The team will continue conducting in-depth study of the research topics identified in this CEACSE project in the following years. Funding is needed to support students working on the target research in the following years.

The team will continue the collaborations that have been established through this CEACSE project to publish the generated research results, and submit external grant applications.

The teaching load of the PI and Co-PIs is high, leaving insufficient time for conducting research and supervising students.

What barriers (if any) do you face to reach these next goals?

Funding is needed to support students working on the target research in the following years.

The teaching load of the PI and Co-PIs is high, leaving insufficient time for conducting research and supervising students.

What will you pursue (and with whom) in light of the support you've received from CEACSE?

Several smart city and public safety-related projects including connected vehicles, railroad safety, fire fighting, and crime fighting will be pursued by collaborating with UTC faculty and external researchers (Dr. Dryver Huston, Dr. Tian Xiang from University of Vermont; Dr. Guirong Liu from University of Cincinnati; Dr. Zhongguo John Ma and Dr. Husheng Li from University of Tennessee at Knoxville; Dr. Yaohang Li from Old Dominion University; Mr. Richard Lusk from Oak Ridge National Laboratory; The Enterprise Center; and other local organizations).

Tell us anything else we should know about this work not described above.

What other related research will you pursue and with whom in the next 3, 4, or 5 years?

In early next year, a demonstration of field testing will be carried out. In each following year, we will focus on the development of novel machine learning algorithms and Bayesian networks and structural modeling and data analytics. Field experiment is under preparation by interacting with utility officials. In each following year, we will focus on the development of novel machine learning algorithms and Bayesian networks and structural modeling and data analytics. Field experiment is under preparation by interacting with utility officials.
## Financial Accounting

<table>
<thead>
<tr>
<th>Financial Report:</th>
<th>Total Award Amount:</th>
<th>$95,610</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cumulative Expenditures:</td>
<td>$84,580</td>
</tr>
<tr>
<td></td>
<td>Remaining Award Amount:</td>
<td>$11,030</td>
</tr>
</tbody>
</table>

Please attach the following:

- Final ledger report showing the final accounting for your award.
- Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.
- Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.

### Supplemental Award Request

<table>
<thead>
<tr>
<th>Supplemental Award Request</th>
<th>Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).</th>
<th>$10,000</th>
</tr>
</thead>
</table>
APPENDIX B

Awardee Project Reports

Extended from Previous Award periods into FY2017
# PROJECT OVERVIEW

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Joseph M. Kizza</td>
<td></td>
</tr>
<tr>
<td>Co-PI(s)</td>
<td></td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Identify by type – senior personnel, technicians, graduate students, undergraduate students</td>
</tr>
<tr>
<td>Project Title</td>
<td>Harnessing the power of Big Data in Aerial Network Authentication and Medical Analysis and Predictions</td>
</tr>
<tr>
<td>Date Submitted</td>
<td>1/10/15</td>
</tr>
<tr>
<td>Award Start - End Date</td>
<td>6/30/17</td>
</tr>
</tbody>
</table>

**Non-Technical Summary – 500 words or less**

We now live in a world driven by digital data. To put this in perspective, all the digital data created, replicated, and consumed in a single year will about double every two years from now until 2020 based on a recent report of the digital universe [1]. Big data can generate significant financial value across sectors including healthcare, public administration, retail, manufacturing, etc. Advanced analytics has become a key basis of competition, underpinning new waves of productivity growth, innovation, and consumer surplus, which are essential to maintain advantages in the face of global competition. Analytics and data science are central to making “business, the global economy, and our society work better,” according to Steve Mills, senior VP and group executive at IBM, and co-chair of the Big Data Commission. Data science and big data solutions are promising avenues of solving many of our society’s challenges. Data scientists are hard at work developing new algorithms and protocols that will revolutionize the world as we know it today. One of the approaches of using big data to find new solutions to outstanding, sometimes unsolvable, problems, is to revisit these old problems driven by big data concepts with new big data solution techniques. In this study, we will revisit two old problems and try to apply known big and
streaming data solutions to them, and also try to develop new big data algorithms, where possible. The two case studies for this project are: airborne networks authentication using zero knowledge and medical analysis using boosted decision tree algorithms. These two cases are good candidates for big data solutions because their processes generate extensively huge amounts of high velocity and high volume, unstructured and sometimes, in the case of aerial networks, streaming data.

<table>
<thead>
<tr>
<th>Project Web Page(s)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Please provide the complete URL.</td>
<td>None</td>
</tr>
</tbody>
</table>

Please attach a Quad Chart using the following format as an example:

If the escalating rate of system attacks is any measure of system security, we are in for a unprecedented period of system upheaval. Indeed, a dangerous future for all of us who have come to depend on computing systems, big and small. We come to take, as normal, a situation where everyone is vulnerable. We have a security system that makes all users potentially victims of hackers. That is the vulnerability that is ravaging our present-day system and causing the endemic hacking that does not have an end in sight. Unless and until we plug this vulnerability, no system will ever be safe.

The goal of this study is to develop a password-free framework, that does not depend on a user-provided passcode and, consequently, to server-based storage of the pair. If and once there is no storage of user-provided anything, hackers will never break into systems and get away with pasado storage of the pair. If and once there is no storage of user-provided anything, hackers will never break into systems and get away with

The scientific and technical overview of this project is that the current password-based framework inherently has a vulnerability that makes all users potentially victims of hackers. That is the vulnerability that is ravaging our present-day system and causing the endemic hacking that does not have an end in sight. Unless and until we plug this vulnerability, no system will ever be safe.

The goal of this study is to develop a password-free framework that does not depend on a user-provided passcode and, consequently, to server-based storage of the pair. If and once there is no storage of user-provided anything, hackers will never break into systems and get away with pasado storage of the pair. If and once there is no storage of user-provided anything, hackers will never break into systems and get away with

The scientific and technical overview of this project is that the current password-based framework inherently has a vulnerability that makes all users potentially victims of hackers. That is the vulnerability that is ravaging our present-day system and causing the endemic hacking that does not have an end in sight. Unless and until we plug this vulnerability, no system will ever be safe.

The goal of this study is to develop a password-free framework, that does not depend on a user-provided passcode and, consequently, to server-based storage of the pair. If and once there is no storage of user-provided anything, hackers will never break into systems and get away with pasado storage of the pair. If and once there is no storage of user-provided anything, hackers will never break into systems and get away with

The scientific and technical overview of this project is that the current password-based framework inherently has a vulnerability that makes all users potentially victims of hackers. That is the vulnerability that is ravaging our present-day system and causing the endemic hacking that does not have an end in sight. Unless and until we plug this vulnerability, no system will ever be safe.
<table>
<thead>
<tr>
<th>Major Milestones</th>
<th>Proposed Cumulative Outcomes / Accomplishments</th>
</tr>
</thead>
<tbody>
<tr>
<td>To develop a passcode-free framework, that does not depend on user provided passcode and, consequently to develop a password-free framework.</td>
<td></td>
</tr>
<tr>
<td>- Study and develop zero knowledge proofs (ZKP)</td>
<td>- Developed a new ZKP - Feige-Fiat-Shamir ZKP Scheme Revised (Joseph M. Kizza)</td>
</tr>
<tr>
<td>- Multiple paths to the Prover</td>
<td>- Adjacent asynchronous first-hand Verifiers</td>
</tr>
<tr>
<td>- Distinct/Second-hand verification with two</td>
<td>- Distinct/Second-hand verification by two</td>
</tr>
<tr>
<td>- Distinct/Second-hand verification with one</td>
<td>- Distinct/Second-hand verification with one</td>
</tr>
<tr>
<td>- Develop a Simulation</td>
<td>- Distinct/Second-hand verification with two</td>
</tr>
</tbody>
</table>

- The Trust Propagation Algorithm

- To study and develop zero knowledge proofs (ZKP)

- To develop a passcode-free framework, that does not depend on user provided passcode and, consequently to develop a password-free framework.

- Developed a new ZKP - Feige-Fiat-Shamir ZKP Scheme Revised (Joseph M. Kizza)

- Study and develop zero knowledge proofs (ZKP)
Add rows as needed.

Challenges & Strategies Used to Address / Overcome:

IMPACT & OUTCOMES

We tried to do an airborne entity authentication based on a cluster of servers and this did not come out right. We were unable to move the entity fast enough.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

The most difficult problems we are encountering are:

(1) Time window. Perhaps this is still the biggest challenge we have to overcome.
(2) To find a way to design an entity (e.g. device) request – request, request authentication scheme – based on a request-response, trust-propagation, nearest neighbor and majority vote algorithms and send back an authentication to an entity seeking authentication and authorization in a given time window. That will respond to the nearest neighbor response algorithms in a timely manner.

Discuss any changes or outcomes that you encountered, particularly if you were impacted from achieving the objectives and milestones approved in your proposal.

Your expectations at the outset of this effort?

Discuss any areas where you did not meet goals; negative results are important too and should be explained and documented. Also, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?
Impact on the career(s) of the PI, the co-PIs, and key collaborators

The impact of this project has been really great. I was able to meet with and work with scientists from the US Air Force Research Lab in Rome, New York. Over the last couple of years, I have met with and collaborated with several other scholars. The experience has been rewarding.

Work products


Students Impacted

Starting with fall 2015 through fall 2016, I hired Mr. Jenner Dai, then an MS student to work on this project with me. Now Mr. Dai is a PhD student and still working under me for his PhD thesis research based on this work. In 2017, I hired Mr. Eshin Jhann to work on this project with me. He is finishing with fall 2017 through fall 2016.

Please list students including nome, major, and degree, if applicable, with a description of how they were impacted. Note degree sought of whom graduated and any other relevant details.

Community and Broader Impacts

If this were to work, and I am sure it will, its impact will be phenomenal as we know it today, something of the past.

Please consider and discuss the technical and actual or potential societal impacts of your research project.

New inventions reduced to practice and when they will be formally disclosed.

New inventions reduced to practice: provide a bibliographical entry where appropriate.

Work products reduced to practice; provide a bibliographical entry where appropriate.

If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to share some or all of the invention disclosures, please indicate where and how you plan to share them.

If you filed any publications that are technical or non-tecchnical, please indicate where and how you plan to share them.

Students Impacted

Collaborators

Impact on the career(s) of the PI, the co-PIs, and key collaborators

The impact of this project has been really great. I was able to meet with and work with scientists from the US Air Force Research Lab in Rome, New York. Over the last couple of years, I have met with and collaborated with several other scholars. The experience has been rewarding.
Proposal Submissions

Based on this research work, I have submitted several funding proposals including:

• Title of Project: Strengthening the National Cyber Security Workforce; Source of Support: NSF CyberCorps; Total Award Amount: $1,897,076 (Co-PI; PI: Li Yang).

• Title of Project: EAGER: Curbing Crimes in Urban Areas Using Emerging Computing Technologies; Source of Support: NSF CyberCorps; Total Award Amount: $780,832 (Co-PI; PI: Li Yang).

• Title of Project: US Ignite: Focus Area 1: Improving Safety in Urban Neighborhoods Using Cyber Physical Systems; Source of Support: NSF CyberCorps; Total Award Amount: $596,551 (Co-PI; PI: Dr. Farah Kandah).

• Title of Project: NRT-DESE: Data in the City: A Unified and Comprehensive Platform for Education and Research on Data Science and Engineering to Push Revolutionary Urbanization; Source of Support: NSF CyberCorps; Total Award Amount: $2,770,725 (Co-PI; PI: Mina Sartipi).

• Title of Project: Data in the Gig City: A Unified and Comprehensive Platform for Education and Research on Data Science and Engineering to Push Revolutionary Urbanization; Source of Support: NSF CyberCorps; Total Award Amount: $2,692,076 (Co-PI; PI: Mina Sartipi).

• Title of Project: US Ignite: Focus Area 1: Improving Safety in Urban Neighborhoods Using Cyber Physical Systems; Source of Support: NSF CyberCorps; Total Award Amount: $596,551 (Co-PI; PI: Dr. Farah Kandah).

• Title of Project: NRT-DESE: Data in the City: A Unified and Comprehensive Platform for Education and Research on Data Science and Engineering to Push Revolutionary Urbanization; Source of Support: NSF CyberCorps; Total Award Amount: $2,770,725 (Co-PI; PI: Mina Sartipi).

I am planning to write more proposals from this work. In fact, according to ResearchGate, my publication “Feige-Shamir ZK-Scheme Revisited”, based on this work has been cited three times in the last year alone.

Please list any workshops, conferences, or other collaborative events that you held/indicate the location (on campus, etc.).
Contracts / Awards Received

This work is becoming more applicable in the developing Internet of Things (IoT) authentication.

What's Next for This Research?

Attended several on-campus workshops including those in CECS.
- NSF Review Panel - Smart & Connected Community
- NSF Other Related Activities

During the two years of the award, I have attended several capacity building activities including:
- Attending an NSF/EPSCoR-sponsored regional workshop. Participating in a GWSW activities training on-campus workshops.
- Embracing new insights gained during the award period. Examples may include meeting with a sponsor program officer.

Building Activities

None

Contracts / Awards Received

None

Sponsored Program Capacity Building Activities

Federal, state, 
industry, etc.

What other related research
next 1, 2, ... 5 years?

CEACSE grant with work in the

How will you follow up your
CEACSE grant with work in the

WHAT'S NEXT FOR THIS RESEARCH?

Attended several on-campus workshops including those in CECS.
- NSF Review Panel - Smart & Connected Community
- NSF Other Related Activities

During the two years of the award, I have attended several capacity building activities including:
- Attending an NSF/EPSCoR-sponsored regional workshop. Participating in a GWSW activities training on-campus workshops.
- Embracing new insights gained during the award period. Examples may include meeting with a sponsor program officer.

Building Activities

None

Contracts / Awards Received

None

Sponsored Program Capacity Building Activities

Federal, state, 
industry, etc.

What other related research
next 1, 2, ... 5 years?

CEACSE grant with work in the

How will you follow up your
CEACSE grant with work in the

WHAT'S NEXT FOR THIS RESEARCH?

Attended several on-campus workshops including those in CECS.
- NSF Review Panel - Smart & Connected Community
- NSF Other Related Activities

During the two years of the award, I have attended several capacity building activities including:
- Attending an NSF/EPSCoR-sponsored regional workshop. Participating in a GWSW activities training on-campus workshops.
- Embracing new insights gained during the award period. Examples may include meeting with a sponsor program officer.

Building Activities

None

Contracts / Awards Received

None

Sponsored Program Capacity Building Activities

Federal, state, 
industry, etc.

What other related research
next 1, 2, ... 5 years?

CEACSE grant with work in the

How will you follow up your
CEACSE grant with work in the

WHAT'S NEXT FOR THIS RESEARCH?

Attended several on-campus workshops including those in CECS.
- NSF Review Panel - Smart & Connected Community
- NSF Other Related Activities

During the two years of the award, I have attended several capacity building activities including:
- Attending an NSF/EPSCoR-sponsored regional workshop. Participating in a GWSW activities training on-campus workshops.
- Embracing new insights gained during the award period. Examples may include meeting with a sponsor program officer.

Building Activities

None

Contracts / Awards Received

None

Sponsored Program Capacity Building Activities

Federal, state, 
industry, etc.

What other related research
next 1, 2, ... 5 years?

CEACSE grant with work in the

How will you follow up your
CEACSE grant with work in the

WHAT'S NEXT FOR THIS RESEARCH?

Attended several on-campus workshops including those in CECS.
- NSF Review Panel - Smart & Connected Community
- NSF Other Related Activities

During the two years of the award, I have attended several capacity building activities including:
- Attending an NSF/EPSCoR-sponsored regional workshop. Participating in a GWSW activities training on-campus workshops.
- Embracing new insights gained during the award period. Examples may include meeting with a sponsor program officer.

Building Activities

None

Contracts / Awards Received

None

Sponsored Program Capacity Building Activities

Federal, state, 
industry, etc.

What other related research
next 1, 2, ... 5 years?

CEACSE grant with work in the

How will you follow up your
CEACSE grant with work in the

WHAT'S NEXT FOR THIS RESEARCH?

Attended several on-campus workshops including those in CECS.
- NSF Review Panel - Smart & Connected Community
- NSF Other Related Activities

During the two years of the award, I have attended several capacity building activities including:
- Attending an NSF/EPSCoR-sponsored regional workshop. Participating in a GWSW activities training on-campus workshops.
- Embracing new insights gained during the award period. Examples may include meeting with a sponsor program officer.

Building Activities

None

Contracts / Awards Received

None

Sponsored Program Capacity Building Activities

Federal, state, 
industry, etc.

What other related research
next 1, 2, ... 5 years?

CEACSE grant with work in the

How will you follow up your
CEACSE grant with work in the

WHAT'S NEXT FOR THIS RESEARCH?

Attended several on-campus workshops including those in CECS.
- NSF Review Panel - Smart & Connected Community
- NSF Other Related Activities

During the two years of the award, I have attended several capacity building activities including:
- Attending an NSF/EPSCoR-sponsored regional workshop. Participating in a GWSW activities training on-campus workshops.
- Embracing new insights gained during the award period. Examples may include meeting with a sponsor program officer.

Building Activities

None

Contracts / Awards Received

None

Sponsored Program Capacity Building Activities

Federal, state, 
industry, etc.

What other related research
next 1, 2, ... 5 years?

CEACSE grant with work in the

How will you follow up your
CEACSE grant with work in the

WHAT'S NEXT FOR THIS RESEARCH?

Attended several on-campus workshops including those in CECS.
- NSF Review Panel - Smart & Connected Community
- NSF Other Related Activities

During the two years of the award, I have attended several capacity building activities including:
- Attending an NSF/EPSCoR-sponsored regional workshop. Participating in a GWSW activities training on-campus workshops.
- Embracing new insights gained during the award period. Examples may include meeting with a sponsor program officer.

Building Activities

None

Contracts / Awards Received

None

Sponsored Program Capacity Building Activities

Federal, state, 
industry, etc.

What other related research
next 1, 2, ... 5 years?

CEACSE grant with work in the

How will you follow up your
CEACSE grant with work in the

WHAT'S NEXT FOR THIS RESEARCH?

Attended several on-campus workshops including those in CECS.
- NSF Review Panel - Smart & Connected Community
- NSF Other Related Activities

During the two years of the award, I have attended several capacity building activities including:
- Attending an NSF/EPSCoR-sponsored regional workshop. Participating in a GWSW activities training on-campus workshops.
- Embracing new insights gained during the award period. Examples may include meeting with a sponsor program officer.

Building Activities

None

Contracts / Awards Received

None

Sponsored Program Capacity Building Activities

Federal, state, 
industry, etc.

What other related research
next 1, 2, ... 5 years?

CEACSE grant with work in the

How will you follow up your
CEACSE grant with work in the

WHAT'S NEXT FOR THIS RESEARCH?

Attended several on-campus workshops including those in CECS.
- NSF Review Panel - Smart & Connected Community
- NSF Other Related Activities

During the two years of the award, I have attended several capacity building activities including:
- Attending an NSF/EPSCoR-sponsored regional workshop. Participating in a GWSW activities training on-campus workshops.
- Embracing new insights gained during the award period. Examples may include meeting with a sponsor program officer.

Building Activities

None

Contracts / Awards Received

None

Sponsored Program Capacity Building Activities

Federal, state, 
industry, etc.

What other related research
next 1, 2, ... 5 years?

CEACSE grant with work in the

How will you follow up your
CEACSE grant with work in the

WHAT'S NEXT FOR THIS RESEARCH?

Attended several on-campus workshops including those in CECS.
- NSF Review Panel - Smart & Connected Community
- NSF Other Related Activities

During the two years of the award, I have attended several capacity building activities including:
- Attending an NSF/EPSCoR-sponsored regional workshop. Participating in a GWSW activities training on-campus workshops.
- Embracing new insights gained during the award period. Examples may include meeting with a sponsor program officer.

Building Activities

None

Contracts / Awards Received

None

Sponsored Program Capacity Building Activities

Federal, state, 
industry, etc.

What other related research
next 1, 2, ... 5 years?

CEACSE grant with work in the

How will you follow up your
CEACSE grant with work in the

WHAT'S NEXT FOR THIS RESEARCH?

Attended several on-campus workshops including those in CECS.
- NSF Review Panel - Smart & Connected Community
- NSF Other Related Activities

During the two years of the award, I have attended several capacity building activities including:
- Attending an NSF/EPSCoR-sponsored regional workshop. Participating in a GWSW activities training on-campus workshops.
- Embracing new insights gained during the award period. Examples may include meeting with a sponsor program officer.

Building Activities

None

Contracts / Awards Received

None

Sponsored Program Capacity Building Activities

Federal, state, 
industry, etc.

What other related research
next 1, 2, ... 5 years?

CEACSE grant with work in the

How will you follow up your
CEACSE grant with work in the

WHAT'S NEXT FOR THIS RESEARCH?

Attended several on-campus workshops including those in CECS.
- NSF Review Panel - Smart & Connected Community
- NSF Other Related Activities

During the two years of the award, I have attended several capacity building activities including:
- Attending an NSF/EPSCoR-sponsored regional workshop. Participating in a GWSW activities training on-campus workshops.
- Embracing new insights gained during the award period. Examples may include meeting with a sponsor program officer.

Building Activities

None

Contracts / Awards Received

None

Sponsored Program Capacity Building Activities

Federal, state, 
industry, etc.
Tell us any thing else we should know about this work not described above.

The possibilities and potential of this work if it is successful are overwhelming.

What barriers (if any) do you face to reach these next goals?

Funding. If I were to get funds to hire a post-doc who will work along with a few undergraduate and graduate students, this work would move faster.
# Financial Report:

<table>
<thead>
<tr>
<th>Total Award Amount:</th>
<th>$50,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative Expenditures:</td>
<td>$</td>
</tr>
<tr>
<td>Remaining Award Amount:</td>
<td>$</td>
</tr>
</tbody>
</table>

Please attach the following:

- **Final ledger report showing the final accounting for your award.**
- **Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.**
- **Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.**

## Original Budget

<table>
<thead>
<tr>
<th>Category</th>
<th>Year 1</th>
<th>Total</th>
</tr>
</thead>
</table>

### A. Personnel

1. **Graduate Students** (2 students supported for a year - $20,762 for one student where $8,762 is in state tuition waiver and 12,000 is stipend in AY)  
   - Year 1: $41,524  
   - Total: $41,524
2. **Faculty** (1.5 month summer support)  
   - Year 1: $15,900  
   - Total: $15,900

### B. Equipment

- 10 Raspberry Pi B+ (B Plus) Complete Starter Kit -- Includes Quick Start Guide - @ at $59.99 + tax  
  - Year 1: $653.89  
  - Total: $653.89

### C. Benefits (rate is 20%)

- Year 1: $3,180  
- Total: $8,829

### D. Total Direct Costs

- Year 1: $61,257.89  
- Total: $66,906.89

## Extension Budget:

<table>
<thead>
<tr>
<th>Category</th>
<th>Year 1</th>
<th>Total</th>
</tr>
</thead>
</table>

### A. Faculty, summer pay

- Year 1: $6000  
- Total: $6000

### B. Ungraduated Students

- 2 graduate students @$12/hr for 15/wk for 9m  
  - Year 1: $3240  
  - Total: $3240

### C. Benefits (rate is 20%)

- Year 1: $848  
- Total: $848

### D. Travel

- Year 1: $1,425.52  
- Total: $1,425.52
### How Budget was used:
(see attached file).

The funded granted to me, including an extension, were very useful to me and helped me to expand my research work. With more funding, mostly sought externally, I hope you achieve my set goals.

Thank you for funding me for the last two years.
Joseph M. Kizza

<table>
<thead>
<tr>
<th>Supplemental Award Request</th>
<th>Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>E. Total Direct Costs</th>
<th>$13,713.52</th>
<th>$13,713.52</th>
</tr>
</thead>
</table>

**PROJECT OVERVIEW**

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farah Kandah, PhD</td>
<td></td>
</tr>
<tr>
<td>Co-PI(s)</td>
<td>None</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Identify by type – senior personnel, technicians, graduate students, undergraduate students</td>
</tr>
<tr>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Project Title</td>
<td>A Robust Network Design in Cognitive Radio Networks</td>
</tr>
<tr>
<td>Date Submitted</td>
<td>May 30, 2014</td>
</tr>
<tr>
<td>Award Start - End Date</td>
<td>July 1, 2014 – June 30, 2017</td>
</tr>
</tbody>
</table>

**Non-Technical Summary – 500 words or less**

This project’s aim was to improve the communications and the connectivity in wireless networks. In supporting the SimCenter mission, our team worked in the area of urban systems and public safety with an aim of maintaining an effective emergency communications and connectivity among different levels of users to support the network in handling different types of traffic. For instance, in an emergency situation, communications among first responders in the scene and communications between field personnel and control centers must be handled smartly and efficiently to avoid any delay or interruption that might result in delaying the response or containing the situation.

**Project Web Page(s)**

Please provide the complete URL.

*Please attach a Quad Chart using the following format as an example:*

THEC Center for Excellence in Applied Computational Science & Engineering

**Technology Area of Interest:** Wireless Networks

**Proposal Title:** A Robust Network Design in Cognitive Radio Networks

### Operational Capability to be provided:

Our overall goal is to address the challenges in wireless network that would degrade the communication performance and develop a new practical and theoretical approach for routing and communication robustness in CRNs.

### Proposal Technical Approach:

- Evaluate the behavior of CRNs under high traffic demand.
- Combining the full spectrum knowledge and the local spectrum knowledge to create an adaptable connectivity in the network that will lead to high satisfied ratio among the network users.
- Evaluate the proposed scheme to show the network enhancements.

### Equipment to be used:

- All the experiments will be simulated and run on the lab computers.
- An upgrade to the lab computers is required to speed up the run of the simulation.
- A set of Raspberry Pi models will be purchased to be used to configure a testbed to be used to run our experiments.

### Deliverables:

- Quarterly reports describing the status of the project.
- The Code and the manual will be posted on GitHub and will be provided upon request.
**Project Overview**

Provide a scientific / technical overview of your research project — background of scientific aims, methodologies and activities, outcomes, etc.

---

**ACCOMPLISHMENTS & OUTCOMES**

<table>
<thead>
<tr>
<th>List of Objectives / Aims / Major Milestones Proposed</th>
<th>Cumulative Outcomes / Accomplishments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhancing the behavior of CRN</td>
<td>Evaluating the proposed scheme to show the enhancement provided to the network</td>
</tr>
<tr>
<td>Provide a wide understanding of the spectrum to different users in the network</td>
<td></td>
</tr>
<tr>
<td>Evaluate the performance of the network with different types of traffic and how the primary users and the secondary users perform in these situations</td>
<td></td>
</tr>
<tr>
<td>With this, we were able to manage the network more efficiently and eventually avoid interruptions in the secondary users' transmissions due to the return of the primary users</td>
<td></td>
</tr>
<tr>
<td>Evaluating the proposed scheme to show the enhancement provided to the network</td>
<td></td>
</tr>
<tr>
<td>Provide a wide understanding of the spectrum to different users in the network</td>
<td></td>
</tr>
<tr>
<td>Enhancing the behavior of CRN</td>
<td></td>
</tr>
</tbody>
</table>

---

**Challenges & Strategies Used to Address / Overcome:**

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

Some challenges that we encountered was trying to run the simulation. Some of the cases required high computing powers which end up requiring us to seek high computing powers. With the help of the Simcenter Supercomputers, we were able to run our simulation and get the results.

---

In this project we investigated the cognitive radio technology and its ability in supporting the network in emergency and critical situations. We focused on successful transmission taking into consideration the primary users, secondary users, and the connection between the two. We were able to provide an enhancement in the network by creating a dynamic shared environment between the primary and the secondary users. With the help of the Simcenter Supercomputers, we were able to run our simulation and get the results.

In this project we investigated the cognitive radio technology and its ability in supporting the network in emergency and critical situations. We focused on successful transmission taking into consideration the primary users, secondary users, and the connection between the two. We were able to provide an enhancement in the network by creating a dynamic shared environment between the primary and the secondary users. With the help of the Simcenter Supercomputers, we were able to run our simulation and get the results.
What didn’t work? What did you disprove or learn from the parts that didn’t meet your initial concept at the proposal?

Describe any areas where you did not meet goals; negative results are important too and should be explained and documented.

Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?

We were planning to build an actual testbed that can be used to run actual experiments to support our simulations. We started our research in this area but it required a lot of time to learn about the equipment and the software to be used. We currently continue our investigation in this area and intend to build the testbed in the near future.

IMPACT & OUTCOMES

Consider and discuss the technical and/or potential societal impacts of your research project.

The high mobile and wireless demand among network users and the ability to dynamically handle networking traffic efficiently and smartly utilizing the spectrum will support future network communication in different fields.

Students Impacted

Two students worked on this project:

- Jesse Whitehead was the first student to work on this project. During his research he learned a lot about wireless networks and using simulations. Currently, he is working at BlueCross BlueShield as he graduated in 2016 with a Master degree in Computer Science.

- Steven Schmitt continued the work on this project. He finished his undergraduate degree in 2016 and is currently enrolled in the Master program at UTC. He is working at BlueCross BlueShield as he graduated in 2016 with a Master degree in Computer Science.

Collaborators

This research helped the PI understand how CRN works and how it manages traffic between primary and secondary users. The research will be used to introduce students to this technology in the coming semesters. This research will be used to introduce students to this technology in the coming semesters.

Community and Broader Impacts

Consider and discuss the technical and actual or potential societal impacts of your research project.

The high mobile and wireless demand among network users and the ability to dynamically handle networking traffic efficiently and smartly utilizing the spectrum will support future network communication in different fields and will have a wide broader impact on many generations to come.

The high mobile and wireless demand among network users and the ability to efficiently and smartly utilize the spectrum will support future network communication in different fields and will have a wide broader impact on many generations to come.
Work products reduced to practice

Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.

- Critical Situations.
- NSF CAREER: Adopted Networking Design to Improve the Network Performance in Crowded and Workshop scenarios.

Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed for invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well.

If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our intellectual property rights.


Outreach & Collaboration

- We will be seeking new collaborations with the police department and the City of Chattanooga.
- Please list any visitors, workshops, or other collaborative events you held to promote the location (on campus, etc.).

External Funding

Proposal Submissions

- NSF CAREER: Adopted Networking Design to Improve the Network Performance in Crowded and Workshop scenarios.

We will accept the proposal with the police department and the City of Chattanooga.

New Inventions Reduced to Practice and When They Will be Formally Disclosed:

Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed for invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well.


Please include software, papers, presentations, posters, and creative works. Include referred journal, refereed conference, non-refereed conference, and workshops.

Appropriate bibliographic entry where applicable: provide a

Work products reduced to practice
## Contracts / Awards Received

List any awards or agreements received related to this or previous CEACSE awards. Include sponsor name, program name, project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non-Disclosure Agreement, Material Transfer Agreement, etc.).

<table>
<thead>
<tr>
<th>Sponsor Name</th>
<th>Program Name</th>
<th>Project Title</th>
<th>Award Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSF CyberCorps</td>
<td>Collaborative Research: Building Security Education Capacity</td>
<td>Building Security Education Capacity</td>
<td></td>
</tr>
</tbody>
</table>

## What's Next for This Research?

Our next step in this research is to investigate different techniques in how to improve the network performance in Cognitive Radio as well as defining security threats against the network.

Our next step in this research is to investigate different techniques in how to improve the network performance in Cognitive Radio as well as defining security threats against the network.

What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?

We will focus our future research to create robust autonomous and aerial vehicle networks through the development of next-generation Cognitive Radio algorithms that can advance the next generation of cyber-physical systems in understanding adverse threats and targeted cyberattacks. Our next step in this research is to investigate different techniques in how to improve the network performance in Cognitive Radio as well as defining security threats against the network.

The PI participated in the Grant Writing Workshop held at the College of Engineering and Computer Science.

**NSF CyberCorps:** Collaborative Research: Building Security Education Capacity through Project.

**Contracts / Awards Received:**

- NSF CyberCorps: Collaborative Research: Building Security Education Capacity through Project.
- <other awards>

Tell us anything else we should know about this work.
What barriers (if any) do you face to reach these next goals? Seeking more funds to support our future research and train new students to conduct research and use our developed systems.
FINANCIAL ACCOUNTING

Financial Report:

<table>
<thead>
<tr>
<th>Total Award Amount:</th>
<th>$45,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative Expenditures:</td>
<td>$44,034.54</td>
</tr>
<tr>
<td>Remaining Award Amount:</td>
<td>$965.46</td>
</tr>
</tbody>
</table>

Please attach the following:

- Final ledger report showing the final accounting for your award.
- Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.
- Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.

Supplemental Award Request

Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).

Final Ledger report:

<table>
<thead>
<tr>
<th>SOURCES OF FUNDS</th>
<th>Current Month</th>
<th>Budget</th>
<th>Cumulative Actuals</th>
<th>Remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gifts, Grants &amp; Receipts</td>
<td>$5,573.28</td>
<td>$45,000</td>
<td>$44,034.54</td>
<td>$44,034.54</td>
</tr>
<tr>
<td>Sponsored Projects Billings</td>
<td>$5,573.28</td>
<td>$45,000</td>
<td>$44,034.54</td>
<td>$44,034.54</td>
</tr>
<tr>
<td>TOTAL SOURCES OF FUNDS</td>
<td>$11,146.56</td>
<td>$45,000</td>
<td>$44,034.54</td>
<td>$44,034.54</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>USSES OF FUNDS</th>
<th>Current Month</th>
<th>Budget</th>
<th>Commitments</th>
<th>Cumulative Actuals</th>
<th>Remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL COSTS</td>
<td>$45,000</td>
<td>$44,034.54</td>
<td>$965.46</td>
<td>$965.46</td>
<td></td>
</tr>
</tbody>
</table>

In accordance with university policy, I have reviewed the charges shown in this ledger and either verified their accuracy and appropriateness to this fund or identified and reported discrepancies for correction through proper channels.

Responsible Person

Date: ____________________
### Line Item Budget:

**R041302182**
**THEC CEACSE 15 Kandah Cognitive Radio Networks**

<table>
<thead>
<tr>
<th>Category</th>
<th>Original Budget</th>
<th>Final Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Senior Personnel</strong> - List each individual separately. Include details on how the budgeted amount was calculated. Specify Summer Pay or Release Time and the percent of effort budgeted.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. PI</td>
<td>$11,748.00</td>
<td>$11,748.00</td>
</tr>
</tbody>
</table>

**EXAMPLE:** Dr. X will work 1 summer month on this project. 9-month salary is $90,000 for 9 months x 1 summer month = $10,000

<table>
<thead>
<tr>
<th><strong>B. Other Personnel</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Graduate Students</td>
<td>$12,087.49</td>
<td>$11,688.00</td>
</tr>
<tr>
<td>2. Undergraduate students</td>
<td>$1,912.51</td>
<td>$1,500.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>C. Fringe Benefits</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>actual rate (full time faculty)</td>
<td>$3,041</td>
<td>$2,284.00</td>
</tr>
<tr>
<td>9% of salary (part time staff &amp; students)</td>
<td>$183.00</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>D. Equipment</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>only items over $5000 are considered equipment</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>E. Travel</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Domestic (conferences, etc.)</td>
<td>$1,861</td>
<td>$1,220.00</td>
</tr>
<tr>
<td>b. Foreign</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>F. Other Direct Costs</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Materials and Supplies</td>
<td>$3,100</td>
<td>$5,127.00</td>
</tr>
<tr>
<td>(Note: items under $5000, such as computers, and other materials related to the activities of the project go here)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Publication Costs / Documentation/Dissemination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Consultant Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Note: if you include an external project evaluator, other individuals outside of the UT system, etc., you include them here</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Tuition</td>
<td>$10,080</td>
<td>$10,080.00</td>
</tr>
<tr>
<td>5. Subawards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Other (Contractual &amp; Special Services)</td>
<td>$1,170</td>
<td>$1,170.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>G. Total Direct Costs</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$45,000.00</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL FUNDS REQUESTED** $45,000.00
## PROJECT OVERVIEW

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farah Kandah, PhD</td>
<td></td>
</tr>
<tr>
<td>Co-PI(s)</td>
<td>--------</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Identify by type – senior personnel, technicians, graduate students, undergraduate students</td>
</tr>
<tr>
<td>Project Title</td>
<td>Quality of Service Assurance using GENI</td>
</tr>
<tr>
<td>Date Submitted</td>
<td>May 1, 2013</td>
</tr>
<tr>
<td>Award Start - End Date</td>
<td>July 1, 2013 – June 30, 2017</td>
</tr>
</tbody>
</table>

### Non-Technical Summary – 500 words or less

Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.

This project started with a focus on supporting real-time applications using the Global Environment and Networking Innovation to improve the quality of service over networks. To support the SimCenter efforts in the field of Urban System, our team worked on developing a collaborative emergency system with the ability to provide real-time reports with ample information to emergency responders to make accurate decisions about the incidents. The broader impact of this project is its ability to provide a panoramic view of the incident to give the responders ample information leading to better decision making regarding the resources needed to control the incident before heading to the scene. Moreover, with high mobile penetration around the country and successfully using it with mobile carriers to be provided free as an emergency app on their platforms, will give a national wide boarder impact for generation to come.
Please attach a Quad Chart using the following format as an example: http://www.usamraa.army.mil/pages/baa_paa/fy06quaddirections_jsto_baa.pdf.

THEC Center for Excellence in Applied Computational Science & Engineering
Technology Area of Interest: Computer Networks
Proposal Title: Quality of Service Assurance using GENI

Operational Capability to be provided:

Our overall goal is to enhance the currently adopted emergency reporting system, by capturing audio, video and text messaging data, quickly analyzing it and reporting it with adequate and precise amount of information about the incident with enough lead time to enable the dispatcher and the response team to make accurate decisions leading to the shortest elapsed time delay to efficiently contain the situation.

Proposal Technical Approach:

- Data gathering entity: this entity consists of a set of fixed cameras for audio/video data gathering, and users’ smart devices for crowdsourced (audio/video/text) data gathering. The focus here is to carry the task of monitoring the area of interest and feed the gathered data to the system.

- Networking/Communication entity: this entity focuses on data transmission and communication to facilitate data and information transmission in real-time while avoiding any delays that might occur due to bandwidth limitations or traffic congestion.

- Reporting/Notifying entity: this entity will focus on reporting the incident to the dispatcher based on the collected data.

Equipment to be used:

Task 1: IP cameras and Smart Phone devices will be used to provide the data to the system.
Task 2: GENI and SDN Openflow framework will be used to facilitate the communication and traffic monitoring.
Task 3: GENI will be used to develop a cloud based dashboard.

Deliverables:

- Quarterly reports describing the status of the project.
- The Code and the manual will be posted on GitHub and will be provided upon request.
**Project Overview**

Provide a scientific/technical overview of your research project – hypothesis or scientific aims, methodologies and activities, outcomes, etc.

Our goal started with developing a multi-path routing scheme to enhance the network performance, thus ensuring a better quality of service taking into consideration the network delay and the throughput optimization to assure a near real-time data transmission.

We studied ways of improving the ability of the network in supporting real-time transmissions through avoiding transmission delays and minimizing communication errors to address the challenges and possibilities of error and misunderstanding common in verbal descriptions of incidents.

**List of Objectives / Aims / Major Milestones**

- Improve data capture at the incident scene to decrease the time of making description between the time of reporting and the clarity of the description. This will address description of the incidents.
- Improved speed up the reporting of incidents, and misunderstanding common in verbal description of the incidents.
- Improve and speed up the reporting of anomalies.
- Improve network survivability.
- Improve the network performance in handling the traffic and balance the load in the network.
- To automate the network utilization process, we developed a dynamic and adaptable network design over software-defined network that allows the network to dynamically handle the traffic and balance the load.
- To improve the network utilization, we developed a dynamic and adaptable network design over software-defined network that allows the network to dynamically handle the traffic and balance the load.
- This objective was achieved by developing a multi-path routing scheme that smartly distributes the network traffic to utilize the resources more efficiently.
- A mobile app was developed to allow users to capture and video stream the incidents in real-time to the dispatcher dashboard.
- A cloud based application was developed over GENI that allow users to capture and video stream the incidents in real-time to the dispatcher dashboard.
- To view concurrent streams about the incidents and be able to allocate to video stream the incident in a dashboard that allows the dispatcher to view concurrent streams about the incidents and be able to allocate video stream the incident to the dispatcher dashboard.
- Dynamic disjoint multipath scheme was designed to support the reliability and the survivability of the network.

**Cumulative Outcomes / Accomplishments**

- Improve the network performance in handling the traffic and balance the load in the network.
- Support the reliability and the survivability of the network.

We studied ways of improving the ability of the network in supporting real-time transmissions through avoiding transmission delays and minimizing communication errors to address the challenges and possibilities of error and misunderstanding common in verbal descriptions of incidents.

Our goal started with developing a multi-path routing scheme to enhance the network performance, thus ensuring a better quality of service taking into consideration the network delay and the throughput optimization to assure a near real-time data transmission.

To achieve the desired performance, Dynamic disjoint multipath scheme was designed to support the reliability and the survivability of the network.
Challenges & Strategies Used to Address / Overcome:

Discuss any challenges or barriers that you encountered, particularly if you were impeded from achieving the objectives and milestones approved in your proposal.

To address the challenges in dynamically handling the network traffic, we considered traffic engineering and traffic pattern recognition through monitoring the network statistics in real-time, such as drop rate, throughput requirement, and network capacity. With this, we were able to automatically control the network switches to update the flow in the network to handle any failure issues due to a hardware/software failure or a network attack.

Different techniques that allow us to virtualize the controller in the network to avoid a single point of failure to allow the network to handle more traffic. We maintained a single controller to control the network and update the flow in the network switches, we are still investigating different schemes to allow the network to adapt to the traffic demand and support the network survivability in case of an attack. We developed schemes to allow the network to adapt to the traffic demand and support the network survivability in case of an attack. We are still looking into enhancing our developed schemes to allow the network to handle more traffic and manage traffic in real-time or close to real-time. The challenge was to ensure the network could handle the demand and we are still looking into enhancing our developed schemes to allow the network to handle more traffic.

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators:

This project was a great help for the PI in learning different techniques in traffic engineering and software, and how to use software to manage the traffic in the network more efficiently. The PI will continue his work in this field and investigate new techniques to help advance his research capacity and apply the concepts learned in different fields in computer networks.

Collaborators:

What didn’t work? What did you disprove or learn from the parts that didn’t meet your initial concept at the proposal?

Describe any areas where you did not meet goals; negative results are important too and should be explained and documented. Mostly, what did you learn besides what you achieved whether it met your expectations at the outset of this effort?

Maintaining the reporting and managing traffic in real-time or close to real-time was a challenge and we are still looking into enhancing our developed schemes to allow the network to handle more traffic.

As we maintained a single controller to control the network and update the flow in the network switches, we are still investigating different schemes to allow the network to adapt to the traffic demand and support the network survivability in case of an attack.

What didn’t work? What did you disprove or learn from the parts that didn’t meet your initial concept at the proposal?

We were able to automatically control the network switches to update the flow in the network to handle the demand and support the network survivability in case of an attack.

To address the challenges in dynamically handling the network traffic, we considered traffic engineering and traffic pattern recognition through monitoring the network statistics in real-time, such as drop rate, throughput requirement, and network capacity. With this, we were able to automatically control the network switches to update the flow in the network to handle any failure issues due to a hardware/software failure or a network attack.

Maintaining the reporting and managing traffic in real-time or close to real-time was a challenge and we are still looking into enhancing our developed schemes to allow the network to handle more traffic.

As we maintained a single controller to control the network and update the flow in the network switches, we are still investigating different schemes to allow the network to adapt to the traffic demand and support the network survivability in case of an attack.

What didn’t work? What did you disprove or learn from the parts that didn’t meet your initial concept at the proposal?

We were able to automatically control the network switches to update the flow in the network to handle the demand and support the network survivability in case of an attack.

To address the challenges in dynamically handling the network traffic, we considered traffic engineering and traffic pattern recognition through monitoring the network statistics in real-time, such as drop rate, throughput requirement, and network capacity. With this, we were able to automatically control the network switches to update the flow in the network to handle any failure issues due to a hardware/software failure or a network attack.

What didn’t work? What did you disprove or learn from the parts that didn’t meet your initial concept at the proposal?

We were able to automatically control the network switches to update the flow in the network to handle the demand and support the network survivability in case of an attack.

To address the challenges in dynamically handling the network traffic, we considered traffic engineering and traffic pattern recognition through monitoring the network statistics in real-time, such as drop rate, throughput requirement, and network capacity. With this, we were able to automatically control the network switches to update the flow in the network to handle any failure issues due to a hardware/software failure or a network attack.
**Students Impacted**

Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

Three students worked on this project:

- **Dustin Howerton** perused his undergraduate degree in Computer Science. Mr. Howerton graduated in 2016. Working on this project, Mr. Dustin learned a great amount of programming languages that served him well in finding a job after his graduation.

- **Steven Schmitt** worked on this project and he finished his undergraduate degree in 2016 and is currently enrolled in the Master program at UTC. Mr. Schmitt focused his research on Software Defined Network and he is currently working on building an SDN testbed to be used as a platform. He worked on developing the multi-path scheme used in this project. During his degree, he worked on developing the multi-path scheme used in this project. He is currently working on building an SDN testbed to be used as a platform. He is currently working on building an SDN testbed to be used as a platform. He is currently working on building an SDN testbed to be used as a platform.

- **Jesse Whitehead** graduated in 2016 with a Master degree in Computer Science. During his degree, he worked on developing the multi-path scheme used in this project. He is currently working at Blue Cross Blue Shield of Chattanooga.

---

**Community and Broader Impacts**

Consider and discuss the technical and actual or potential societal impacts of your research project.

The high mobile penetration around the country and successfully using our app with mobile carriers to be provided free as an emergency app on their platforms, will give a national wide border impact for Blue Cross Blue Shield of Chattanooga.

**Work Products Reduced to Practice**: Provide a bibliographical entry where appropriate.

**Softwarre, papers, presentations, posters, and creative works**

Indicate Refereed Journal, Refereed Conference, Non-refereed Conference for each publication listed. For journal publications, indicate the impact factors where appropriate.

- **Dustin Howerton**, "Video Streaming over GENI" ACM Southeast Conference 2015 – Poster


- **Dustin Howerton**, "Video Streaming over GENI" ACM Southeast Conference 2015 – Poster

---

**References**

- **Dustin Howerton**, "Video Streaming over GENI" ACM Southeast Conference 2015 – Poster


- **Farah Kandah** and **Steven Schmitt**, "Towards a Smart, Dynamic, and Adaptable Network Design Using Virtual Slicing over Software Defined Network". IEEE Consumer Communications and Networking Conference (CCNC) (Under review)

- **Steven Schmitt** and **Farah Kandah**, "Mitigating Denial of Service Attacks using Traffic Pattern Recognition over Software Defined Network". IEEE Consumer Communications and Networking Conference (CCNC) (Under review)
New inventions reduced to practice and when they will be formally disclosed; Please consider and include new software products that are subject to copyright but also methods and systems are potentially patentable. If you filed invention disclosures, patent or copyright applications during the period of performance, please indicate so here as well. If you wish to open source a software prototype data set, please state so; we will follow up with you with a disclosure process and guidance on how to proceed effectively for UTC and our research program, including required steps prior to doing so, and how properly to credit ownership to the UT system.

Outreach & Collaboration

Please list any visitors, workshops, or other collaborative events did you hold? Indicate the location (on campus, etc).

We are in the process of seeking collaborations with Clemson University and the Department of Transportation at Chattanooga.

EXTERNAL FUNDING

Proposal Submissions

Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.

- DOD Early Career program: Software Defined Network Utilization to Improve the Network Performance in Collaborative Virtual Labs.
- CRISP: Using Internet Technology to Connect Captive Chimpanzees.
- Cyber Research Institute (CRI), Simulation of Trust and Distrust Propagation in Airborne Networks Authentication.

Contracts / Awards Received

List any awards or agreements received / executed related to this or previous CEACSE awards. Include sponsor name, sponsor program name (if applicable), project title, and award amount. If it is a non-funding agreement, identify by type (e.g., Data Use Agreement, Non Disclosure Agreement, Material Transfer Agreement, etc.).

- NSF CyberCorps: Collaborative Research: Building Security Education Capacity through POGIL.
Sponsored Program

Capacity Building Activities

List all capacity-building activities in which you have engaged during the award period. Examples may include meeting with a sponsor program officer, attending an NSF/NIH/other sponsor regional workshop, participating in GWSW activities, attending on-campus workshops, etc.

The PI participated in the Grant Writing Workshop held at the College of Engineering and Computer Science.

WHAT'S NEXT FOR THIS RESEARCH?

How will you follow up your CEACSE grant with work in the next 1, 2, … 5 years?

Our next step in this research is to investigate different techniques in the software-defined networking field that allow us to enhance the network performance in handling traffic smartly as well as investigating different ways in supporting the network survivability against single point of failure due to operational failures in software/hardware failures or network attacks.

WHAT'S NEXT FOR THIS RESEARCH?

What barriers (if any) do you face to reach these goals?

Seeking more funds to support our future research and train new students to conduct research and use our developed systems.

WHERE ARE YOU IN THIS RESEARCH?

Tell us anything else we should know about this research.

We will focus our future research to create robust autonomous and aerial vehicle networks through the development of cybersecurity layers that can advance the next generation cybersecurity workforce in standing against threats that target the safety of human lives.

What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?

We will focus our future research to create robust autonomous and aerial vehicle networks through the development of cybersecurity layers that can advance the next generation cybersecurity workforce in standing against threats that target the safety of human lives.

Seeking more funds to support our future research and train new students to conduct research and use our developed systems.
FINANCIAL ACCOUNTING

Financial Report:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Award Amount:</td>
<td>$65,000</td>
</tr>
<tr>
<td>Cumulative Expenditures:</td>
<td>$64,953.40</td>
</tr>
<tr>
<td>Remaining Award Amount:</td>
<td>$46.60</td>
</tr>
</tbody>
</table>

Please attach the following:

- Final ledger report showing the final accounting for your award.
- Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.
- Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.

Supplemental Award Request

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned).</td>
<td>No</td>
</tr>
</tbody>
</table>

Final Ledger:

<table>
<thead>
<tr>
<th>Sources &amp; Uses of Funds</th>
<th>Current Month</th>
<th>Budget</th>
<th>Cumulative Actuals</th>
<th>Remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sources of Funds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gifts, Grants &amp; Bequests-Receipts</td>
<td>1,899.11</td>
<td>45,000</td>
<td>64,953.40</td>
<td>19,953.40</td>
</tr>
<tr>
<td>TOTAL SOURCES OF FUNDING</td>
<td>1,899.11</td>
<td>45,000</td>
<td>64,953.40</td>
<td>46.60</td>
</tr>
<tr>
<td>Uses of Funds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL COSTS</td>
<td></td>
<td>45,000</td>
<td>64,953.40</td>
<td>46.60</td>
</tr>
</tbody>
</table>

In accordance with university policy, I have reviewed the charges shown on this ledger and either verified their accuracy and appropriateness to this fund or identified and reported discrepancies for correction through proper channels.

Responsible Person

Date: ________________
## Line Item Budget:

<table>
<thead>
<tr>
<th>Category</th>
<th>Amount Requested</th>
<th>Original Budget</th>
<th>Remaining Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Senior Personnel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>List each individual separately. Include details on how the budgeted amount was calculated. Specify Summer Pay or Release Time and the percent of effort budgeted.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. PI</td>
<td>$18,198.00</td>
<td>$18,198.00</td>
<td></td>
</tr>
<tr>
<td><strong>EXAMPLE:</strong> Dr. X will work 1 summer month on this project. 9-month salary is $90,000 for 9 months x 1 summer month = $10,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>B. Other Personnel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Graduate Students</td>
<td>$2,000.00</td>
<td>$2,207.00</td>
<td></td>
</tr>
<tr>
<td>2. Undergraduate students</td>
<td>$29,231.00</td>
<td>$29,963.00</td>
<td></td>
</tr>
<tr>
<td><strong>C. Fringe Benefits</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>actual rate (full time faculty)</td>
<td>$5,575.00</td>
<td>$4,862.00</td>
<td></td>
</tr>
<tr>
<td>9% of salary (part time staff &amp; students)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>D. Equipment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>only items over $5000 are considered equipment</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>E. Travel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Domestic (conferences, etc.)</td>
<td>$3,200.00</td>
<td>$2,713.00</td>
<td></td>
</tr>
<tr>
<td><strong>G. Other Direct Costs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Materials and Supplies</td>
<td>$2,548.00</td>
<td>$2,809.00</td>
<td></td>
</tr>
<tr>
<td>(Note: items under $5000, such as computers, and other materials related to the activities of the project go here)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Publication Costs / Documentation/Dissemination</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Consultant Services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Note: if you include an external project evaluator, other individuals outside of the UT system, etc., you include them here</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Tuition</td>
<td>$2,568.00</td>
<td>$2,568.00</td>
<td></td>
</tr>
<tr>
<td>5. Subawards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Other (Contractual &amp; Special Services)</td>
<td>$1,680.00</td>
<td>$1,680.00</td>
<td></td>
</tr>
<tr>
<td><strong>H. Total Direct Costs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL FUNDS REQUESTED</strong></td>
<td>$65,000.00</td>
<td>$65,000.00</td>
<td></td>
</tr>
</tbody>
</table>
Numerical Simulation of Airflow in the Small Human Airways

Submitted to:

Tennessee Higher Education Commission Center of Excellence in Applied Computational Science and Engineering at the University of Tennessee at Chattanooga

Principal Investigators:
Dr. Abdollah (Abi) Arabshahi
Jamasp Azarnoosh
Dr. Kidambi Sreenivas
The University of Tennessee at Chattanooga
SimCenter: National Center for Computational Engineering
701 East M.L. King Boulevard
Chattanooga, TN 37403
Numerical Simulation of Airflow in the Small Human Airways

By

Dr. Abdollah(Abi)Arabshahi, Jamasp Azarnoosh and Dr. Kidambi Sreenivas

The University of Tennessee at Chattanooga, Chattanooga, TN, 37403

ABSTRACT

This study compares the effect of the extra-thoracic airways on the flow through the lower airways by carrying out computational fluid dynamics (CFD) simulations of the airflow through the human respiratory tract. In order to facilitate this comparison, two geometries were utilized. The first was a realistic nine-generation lower airway geometry derived from computed tomography (CT) images, while the second included an additional component, i.e., an idealized extra-thoracic airway (ETA) coupled with the same nine-generation CT model. Another aspect of this study focused on the impact of breathing transience on the flow field. Consequently, simulations were carried out for transient breathing in addition to peak inspiration and expiration. Physiologically-appropriate regional ventilation for two different flow rates was induced at the distal boundaries by imposing appropriate lobar specific flow rates. The scope of these simulations was limited to the modeling of tidal breathing at rest. The typical breathing rates for these cases range from 7.5 to 15 breaths per minute with a tidal volume of 0.5 Liter (L). For comparison, the flow rates for constant inspiration/expiration were selected to be identical to the peak flow rates during the transient breathing. Significant differences were observed from comparing the peak inspiration and expiration with transient breathing in the entire airway geometry. Differences were also observed for the lower airway geometry. These differences point to the fact that simulations that utilize constant inspiration or expiration may not be an appropriate approach to gain better insight into the flow patterns present in the human respiratory system. Consequently, particle trajectories derived from these flow fields might be misleading in their applicability to the human respiratory system.

1 Introduction

There are hundreds of millions of people worldwide who suffer from chronic respiratory diseases such as asthma and chronic obstructive pulmonary disorder (COPD), obstructive sleep apnea syndrome (OSAS), pulmonary hypertension, etc. (Alwan A. et al., 2008-2013). Air pollution is directly connected to these illnesses because of the deposition of particulate pollutants in the lungs. These toxic pollutant particles have the potential to induce these diseases. Particle deposition is mainly affected by the flow field within the respiratory system. These effects are very prominent in the extra-thoracic airway (ETA). An investigation reported that 80–95% of an inhaled aerosol dose is
deposited in the ETA (Gonda, 1992). A detailed analysis of the airflow mechanisms within the human respiratory system could lead to a better understanding of the deposition of toxic aerosols during breathing and help with health risk assessments. Complex airflow patterns in the airways, while effective at removing inhaled toxic elements, hinder the delivery of therapeutic materials delivered through inspiration. Over the past 20 years, computational fluid dynamics (CFD) has been established as a powerful tool for the study of these complex flow patterns and its application to improvements in aerosolized medication delivery. Even with these advances, the complex flow patterns in these airways are still understood only at a relatively rudimentary level.

2 Literature Review

The flow through the human respiratory tract has been studied extensively, both experimentally and via numerical simulations. Studies regarding the lower airways typically use a laminar profile at the trachea, which is the point of delineation between the ETA and the lower airways. However, various studies conducted using ETA models, have clearly shown that the flow exiting the ETA is very likely turbulent. The inherent complexity of flows through the ETA can lead to regions which are laminar, transitional or fully turbulent. Attempts to study flows (experimental or computational) through the ETA are stymied because of the wide variability in ETA geometries depending on age, disease, etc. One approach to the problem of variability is to create an idealized ETA geometry which contains all the basic physiological elements that are present in the real geometry. (Yu et al., 1998) used a teaching model as the basis of the geometry for the ETA while (Stapleton et al., 2000) utilized an idealized version of an ETA based on CT scans. The so called Alberta ETA geometry (Johnstone et al., 2004) has been studied extensively using both experimental (Heenan et al., 2003), (Johnstone et al., 2004) and computational (Ball et al., 2008a, b) approaches. Ball et al. (Ball et al., 2008a) used various turbulence models to simulate the flow through this geometry and compared their results to experimental data. They (Ball et al., 2008b) also used a Lattice Boltzmann method (LBM) to study the details of the flow field while Kleinstreuer and Zhang (Kleinstreuer, C., & Zhang, Z., 2010) used an LES approach.

The framework for the study of the airflow through the lung and human pulmonary airways was laid by (Weibel, 1963) and (Horsfield et al., 1971). Xu et al. (Xu et al., 2006) simulated constant inspiration and expiration of the airflow through a CT-based geometry. De Backer et al. (De Backer et al., 2008) carried out numerical simulation of constant inspiration through CT-based lower airways. Lin et al. (Lin et al., 2007) compared the effects of an ETA by simulating the flow through a CT-derived model of the upper respiratory tract and the lower airways with the corresponding the lower airway geometry only. They concluded that a curved sheet-like turbulent laryngeal jet in the entire airway geometry, with turbulence intensity exceeding 10 to 20% in the trachea, could significantly affect airway flow patterns as well as tracheal wall shear stress. These simulations were limited to constant inspiration only. In an earlier study, the effects of inhalation transience through CT-based human airway geometry were explored by Gruetzemacher (Gruetzemacher, 2014), where he obtained solutions for a full breathing cycle. As is the norm in these types of simulations, a uniform velocity profile was imposed at the trachea (for the constant inspiration case) and lobar specific flow rates
were imposed at the distal airways (for the full breathing cycle). An interested reader
directed to Gruetzemacher (Gruetzemacher, 2014) for more details.

Numerical studies provide detailed information of airflow patterns that is very
difficult to obtain using in vivo observations or in vitro experiments. Earlier studies had
mostly focused on constant inspiration, although some of them did consider a full
breathing cycle or constant expiration. The geometries utilized in most of these studies
were limited to either the ETA or the lower airway only. For instance, (Zhang, Z., &
Kleinstreuer, C., 2002) compared both the peak inspiration and expiration velocity
profiles for the Womersley number (\( \lambda \)) 0.93 and found good agreement with those of
instantaneously equivalent constant inspiration/expiration cases. This paper focuses on
the effects of the ETA on the lower airway (and vice versa) for a full breathing cycle and
compares the results of transient simulations with simulations corresponding to constant
inspiration and expiration. To the best of the authors’ knowledge, these comparisons have
not been carried out, by any researcher, for the entire (combined ETA/lower) geometry.

3 Methods

3.1 The idealized ETA and CT-based pulmonary airway geometry

The computational ETA geometry utilized in this study is based on the so-called
Alberta ETA model from University of Alberta. This geometry represents a mean of the
dimensions of the upper airway which mimics the complete ETA from the oral cavity to
the trachea of an adult human. The overall height (including the inlet nozzle) and width
of this geometry are 160.4 and 110 mm, respectively. Licensing issues prevented the
actual geometry from being used in this paper. The geometry utilized in this study has
been reconstructed based on the descriptions and cross-sections available in the literature,
for instance, (Heenan et al., 2003), (Johnstone et al., 2004) and (Zhang, Y., & Finlay, W.
H., 2005). The geometry was created using SolidWorks, a 3D Computer Aided Design
(CAD) modeling package. Figure 1 shows the dimensions and the anatomical names
which include the most important airflow structures in the sagittal plane of the ETA.
Traverse cross-sectional views of the airway passage of all thirteen cross-sections are
depicted in Figure 1c.
The various regions of the ETA are geometrically very different which is revealed in the complexity of the model. The oral cavity features different radii of curvature along the sagittal and coronal (frontal) planes. In the posterior of the oral cavity, the cross sectional shape converges to a somewhat half elliptical shape, and is then extended by the uvula. The shape remains elliptical within the pharynx before the glottal region. The epiglottis protrudes into the pharynx volume, thus the airflow must travel around it before entering the trachea and then on to the main bronchi and subsequently the lungs.

As can be seen from Figure 1, the local area increases from the inlet to the oral cavity and then decreases through the oro-pharynx (cross-sections 2-8). There is a sudden change in the local area from oro-pharynx to pharynx (cross-sections 8-9). Thus, the bulk velocity decreases, consequently reducing the Reynolds number. The existence of epiglottis (cross-sections 11 and 12) in the pharynx causes this region of the model to be more complicated.

The ETA geometry was scaled to match with the CT-based lower airways model of Gruetzmacher (Figure 2a) to provide the entire airway geometry (Figure 2b and c).
Both geometries were meshed using Pointwise version 17.3. The surface mesh was entirely structured, as this helped reduce the number of surface nodes compared to utilizing an unstructured surface mesh. The volume mesh was generated using an off-wall spacing ranging from 0.01 to 0.05 mm such that an average $y^+$ of around unity was obtained. The volume mesh utilized the T-Rex feature of Pointwise (T-Rex: Automated Boundary Layer Meshing, 2010). This resulted in the extrusion of regular layers of tetrahedra from boundaries, which are recombined to obtain prism elements off the walls. A minimum of 7 prism layers were utilized in this study. Two different meshes were generated for the entire airway geometry. The different meshes were generated so as to maintain adequate viscous resolution for the two different flow rates considered in this study. The first mesh (low flow rate) contained 7,886,440 nodes and 31,157,333 control volumes while the mesh for the high flow rate had 8,491,553 nodes and 32,788,751 control volumes. In order to assess the impact of the ETA on the flow through the lower airways, a mesh for the lower airways was also generated. This mesh contained 3,142,780 nodes and 18,035,344 control volumes.

3.2 Flow solver

The in-house flow solver, Tenasi (Hyams et al., 2011) was used in this study to simulate both inspiration/expiration and a full respiratory cycle. The baseline flow solver in Tenasi employs a node centered, finite volume, implicit scheme with high resolution fluxes based on Roe averaging and a Newton subiteration procedure for time accuracy. The linear system at each Newton subiteration is solved using a Symmetric Gauss–Seidel algorithm. For the cases considered here, Tenasi solves the artificial-compressibility form of the incompressible Navier-Stokes equations. Tenasi has been validated in a previous study for steady and unsteady flow through idealized and CT-based geometries (Gruetzemacher, 2014). LES is sufficient to resolve the large-scale eddies of turbulent turbulent
flow without using any turbulence model, however, this is inappropriate to resolve smaller scales of turbulent motions i.e. length scales smaller than the grid spacing. Therefore, these small unresolved length scales are modeled by a SGS turbulence model. In this study, the Wall-Adapting Local Eddy-viscosity (WALE) model (Ducros et al., 1998) is used for the SGS stresses. The SGS tensor \( \tau_{ij} \) is given by

\[
\tau_{ij} = - \rho \langle \nu_{i,j} \rangle
\]  

(1)

Subgrid scale modeling is based upon an eddy-viscosity assumption. The eddy viscosity model is defined as

\[
\nu = \bar{\nu}
\]

(2)

where \( \bar{\nu} \) denotes a time-average.

The eddy viscosity appearing in the SGS term of the WALE model \( \tau_{ij} \) is defined as

\[
\nu_{ij} = \frac{1}{3} \tau_{ij} - \bar{\nu}
\]

(3)

where \( \tau_{ij} \) for incompressible flow and \( \bar{\nu} \).

This model was used because it resulted in good predictions of the wall stress and turbulent intensities as reported by Ducros et al., 1998.

To investigate turbulent characteristic of the flow, the turbulence kinetic energy (TKE) and turbulence intensity were used. The TKE can quantified by the mean of the turbulence normal stresses which is defined as

\[
\frac{1}{2} D_{ij} D_{ij} = \frac{1}{2} \tau_{ij} \tau_{ij}
\]

(4)

For steady laminar flow TKE is zero while the large value of TKE represents the existence of the turbulent flow phenomena.

The turbulence intensity is

\[
I = \frac{1}{2} |D_{ij}| = \frac{1}{2} |\tau_{ij}|
\]

(5)

where \( |D_{ij}| \).

The cases presented here are solved using a Large Eddy Simulation (LES) formulation with the Wall-Adapting Local Eddy-viscosity (WALE) model (Ducros et al., 1998) being used for the subgrid stresses.
3.3 Numerical Solution

The computations utilized a quadratic reconstruction approach, and were solved in unsteady (time-accurate) mode utilizing 80 Newton subiterations to ensure second order temporal accuracy. Dual-time-stepping was used to enhance stability of the iterative solution process with a Courant-Friedrichs-Lewy (CFL) number in the range of 0.015 to 0.025.

Two breathing rates (7.5 and 15 breaths per minute) corresponding to the range of typical human breathing at rest were considered in this study. The transient breathing cases were simulated for one breathing cycle and utilized 7,968 iterations resulting in different time steps ( ). Table 1 summarizes the various parameters that were used in these simulations. The Womersley number (Womersley, 1955) shown in the table is the ratio of the transient inertial force to the viscous force and is a significant nondimensional parameter in the study of transient flows. It is defined as , where R is the radius of the trachea, the kinematic viscosity and where is the breathing rate. The Reynolds number is defined as , where D is the average diameter of the trachea and is largest of the velocities imposed at the distal boundaries.

The constant inspiration and expiration simulations corresponded to the peak inspiration and expiration for the two breathing rates considered here (hereinafter referred to as ). They were carried out for 8,000 iterations and the resulting solutions were time-averaged over the last 3,000 time steps.

Table 1: Parameters for the breathing cycles considered in this study

<table>
<thead>
<tr>
<th>Breathing Rate</th>
<th>Re</th>
<th>(seconds)</th>
<th>T (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5 breaths/minute</td>
<td>4.72</td>
<td>875</td>
<td>8</td>
</tr>
<tr>
<td>15 breaths/minute</td>
<td>6.68</td>
<td>1750</td>
<td>4</td>
</tr>
</tbody>
</table>

3.4 Boundary conditions

Humans have two lungs which consist of five lobes. Three lobes on the right and two on the left, i.e., right superior (RS), right middle (RM), right inferior (RI), left superior (LS), and left inferior (LI) bronchus. For the transient breathing cases, a sinusoidal waveform velocity profile was imposed at the distal lobar boundaries, i.e., while the pressure was allowed to float. To enforce the appropriate velocities at lobar boundaries an expression for velocity as a function of the lobar volume was written (Gruetzemacher, 2014), i.e., where is area at the appropriate distal boundary and is 0.105, 0.045, 0.125, 0.1 and 0.125L corresponding to the RS, RM, RI, LS and LI, respectively (Horsfield et al., 1971). The velocity used for the inspiration/expiration cases matched the flow conditions at peak inspiration and expiration of the transient breathing cases, i.e. at phase angle of and , respectively. At the inlet boundary, a pure Dirichlet boundary condition was used to keep static pressure fixed at standard atmospheric pressure while the velocities were allowed to float.
4 Results and Discussion

A discussion of the results obtained for the geometries are presented in this section. Firstly, the ETA geometry was validated with experimental data and computational (LBM) simulation for a flow rate of 10 l/min using the SST turbulence model and LES which resulted in four simulations, i.e., simulations for coarse and fine mesh for each technique. A comparison of constant inspiration/expiration with the first transient breathing cycle was carried out for each flow rate. Two LES simulations were performed for 30 l/min so that a comparison between the two flow rates could be carried out. Similarly, the simulations of the entire airway geometry are presented for constant inspiration/expiration and full transient breathing cycles resulted in six simulations.

4.1 The Idealized Upper Airway Geometry (the ETA geometry)

The comparison of LES simulation with PIV data and LBM is presented in the first part of the simulation of the ETA geometry. The local coordinate system used here is the same as the one used by Johnstone et al. and Ball et al. (Dubief, Y., & Delcayre, F., 2000). As depicted in Figure 3, the coordinate system is defined in the sagittal plane. x is defined along the direction of the probe, y is perpendicular to the x-direction (in the direction of the flow) and z is perpendicular to the sagittal plane. The origin of the coordinate system is on the superior (inlet and cross-sections 1 to 4) or posterior wall (cross-sections 5 to 7) in the sagittal plane of the ETA (Figure 4). Note that these cross-sections are the measuring locations that were used by Johnstone et al.

As mentioned before, the geometry utilized in this study is not the original geometry and has been reconstructed based on available papers in the literature. Therefore, some deviations from the geometry used in the experiments can be expected. The investigation was carried out by comparing the results of the LES simulation with hot-wire anemometry data (Heenan AF, Matida E, Pollard A, Finlay W.H., 2003), as well as direct numerical simulation i.e., LBM (Ball, C. G., Uddin, M., & Pollard, A., 2008b), at seven cross-sections (see Figure 4) for the flow rate 10 l/min.
Simulations were carried out for two grids (coarse and fine grid as summarized in Table 2), but for comparison solutions of the coarse mesh were utilized, because no significant differences were observed between these two grids.

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Low flow rate</th>
<th>High flow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nodes</td>
<td>Number of volume elements</td>
</tr>
<tr>
<td>The upper airway</td>
<td>Coarse</td>
<td>4,990,450</td>
</tr>
<tr>
<td></td>
<td>Fine</td>
<td>9,744,653</td>
</tr>
<tr>
<td>The lower airway</td>
<td></td>
<td>3,142,780</td>
</tr>
<tr>
<td>The entire airway</td>
<td></td>
<td>7,886,440</td>
</tr>
</tbody>
</table>

The contour plot of the time-averaged LES solution in central sagittal plane for flow rates of 10 and 30 l/min are shown in Figure 5. Generally, the same structure of the flow can be observed for both flow rates. The difference is in the strength of the flow that is clearly visible in the length of laryngeal jet within the trachea. Therefore, the comparisons of time-averaged velocity profiles and flow structures through the ETA with experimental and computational results (LBM solutions) were carried out only for 10 l/min.
Figure 5. Contour plot of the central sagittal plane of the ETA, colored with the velocity magnitude, for flow rate 10 and 30 l/min

The values of the local Reynolds number, i.e., and local bulk velocities at the inlet and all seven cross-sections (see Figure 4) were compared against the PIV [4] and LBM (Ball, C. G., Uddin, M., & Pollard, A., 2008b) in Table 3. The most differences of the local Reynolds number can be found at cross-section 2 and 5 with 8% and cross-section 6 with 10.5%. This shows a reasonable agreement of the reconstructed geometry with the original experimental geometry.

Table 3. Comparison of the local Reynolds number and local bulk velocity between PIV data, the LBM and LES solutions at the inlet and seven cross-sections

<table>
<thead>
<tr>
<th>Sections</th>
<th>PIV results (Johnstone et al.)</th>
<th>LBM solution (Ball et al.)</th>
<th>LES solution (Coarse mesh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Re</td>
<td>Re</td>
<td>Re</td>
</tr>
<tr>
<td>Inlet</td>
<td>674</td>
<td>0.587</td>
<td>0.58632</td>
</tr>
<tr>
<td>1</td>
<td>483</td>
<td>0.291</td>
<td>0.31851</td>
</tr>
<tr>
<td>2</td>
<td>480</td>
<td>0.275</td>
<td>0.31151</td>
</tr>
<tr>
<td>3</td>
<td>716</td>
<td>0.542</td>
<td>0.55048</td>
</tr>
<tr>
<td>4</td>
<td>1052</td>
<td>1.178</td>
<td>1.35403</td>
</tr>
<tr>
<td>5</td>
<td>699</td>
<td>0.623</td>
<td>0.68282</td>
</tr>
<tr>
<td>6</td>
<td>1073</td>
<td>1.368</td>
<td>1.61969</td>
</tr>
<tr>
<td>7</td>
<td>805</td>
<td>0.778</td>
<td>0.85325</td>
</tr>
</tbody>
</table>
Figure 6 illustrate the comparison of SST and LES solutions of coarse and fine mesh from *Tenasi* along with experimental results for flow rate 10 l/min. The overall agreement between the various solutions is quite similar, though there are some significant differences. For cross-section 2, the fine grid LES solution has much better agreement with experimental data than either the coarse grid LES or both the SST solutions, though all the solutions over predict the peak velocity at that cross-section. Overall, the fine grid LES solution has better agreement with the experimental data, while the sensitivity of the RANS (SST) solutions to grid density does not seem to be that high.
Cross-Sections 3

Cross-Sections 4

Cross-Sections 5
4.2 Transient Breathing Cycle and Constant Inspiration/Expiration

Simulations of the ETA geometry were performed for two flow rates summarized Table 4. Two simulations corresponding to constant inspiration/expiration and one for four full breathing cycles were carried out. This resulted in a total of three simulations per flow rate. The constant inspiration/expiration cases were conducted at two Reynolds
numbers, i.e., 875 and 1750, analogous to peak flow conditions in the full breathing cases, i.e., the Womersley numbers of 4.72 and 6.68, respectively.

4.2.1 Inspiration

Peak inspiration in a breathing cycle solutions occurs at a phase angle of at $t = 2s$ and $t = 1s$ for and , respectively. The comparison was made between peak inspiration with corresponding constant inspiration for both flow rates (i.e., Re = 875 and Re = 1750). Volumetric fluxes were computed at the inlet and outlet of the ETA. The deviation of flow rates from the targeted values was found no more than 0.05%.

The flow structure of a transient breathing cycle in both flow rates is depicted against the time-averaged solution in the central sagittal plane of the ETA in Figure 7. Even though the flow features in the oral cavity as well as the oro-pharynx are observed to be laminar, unsteadiness can be seen in the transient breathing cases for both flow rates, especially for the higher flow rate where unsteadiness was much more pronounced. This figure shows that the flow rate is not the main cause of the turbulent flow through the trachea. Because of the Dean-like instabilities caused by the curvature of the oro-pharynx, and the complicated structure of the pharynx and the larynx, the airflow became transitional and eventually fully turbulent through the trachea. Fully turbulent flows in both flow rates are clearly visible in the figures.

From the time-averaged solutions the same flow pattern was observed in both flow rates. The only difference is in the strength of the airflow as the velocity values doubled for the higher flow rate. This is clearly visible in the laryngeal jet and the size of the recirculation bubble in the trachea.
Figure 7. Central sagittal cross-section of the ETA, illustrating velocity magnitude during inspiration. Peak transient breathing and time-averaged solutions of both flow rates.
The secondary flow at three cross-sections of the ETA (see Figure 4) is illustrated in Figure 8, to have a better insight into the flow regime during inspiration. Cross-sections 5, 6 and 7 were selected because significant changes in the flow features occur through the pharynx, the larynx and more importantly the trachea. The comparison of these three critical cross-sections between transient breathing and constant inspiration are discussed in the following.

Cross-section 5 is located in the pharynx (see Figure 4) upstream of the larynx. Clear differences can be observed in the cross-flow pattern between transient breathing and the time-averaged solution of both flow rates. Unsteadiness in the high flow rate case was much more pronounced compared to the low flow rate. This shows the effects of the flow rate in this region. Transient solution of the high flow rate illustrated strong unsteadiness of the flow pattern in the oro-pharynx, before entering the pharynx. As was previously mentioned, this is due to the Dean-type instabilities in oro-pharynx.

The complicated flow regime in the pharynx causes the flow to be turbulent in the larynx and consequently in the trachea. The presence of the turbulent flow is clearly visible in iso-surface of Q-criterion in Figure 9. Unsteadiness in both transient breathing solutions can be observed at cross-section 6. In this location, the turbulent feature is clearly visible in the transient breathing solution of the high flow rate, whereas the low flow rate shows less turbulent features.

The cross-section in the trachea, cross-section 7, illustrates the fully turbulent flow for both the low and high flow rates. This highly turbulent flow phenomenon is much more prominent for the higher flow rates. Figure 9 illustrates this flow phenomenon through the larynx and the trachea.
Figure 8. Secondary flows of the low and the high flow rate during inspiration in the ETA. Cross-sections 5, 6 and 7 of the low and high flow rates from the top and bottom, respectively
Figure 9. Iso-surface of Q-criterion colored by velocity magnitude for . Oblique (45°) view, coronal view and sagittal view of the pharynx and larynx from left to right. The geometry is in gray.

The values of the Reynolds number at all seven cross-sections of interest in Figure 4 are summarized in Table 4. The largest differences between Reynolds numbers for the constant inspiration and peak transient breathing for the low Womersley number was found to be no more than 4% and appeared at cross-section 7. As the flow rate is doubled i.e., higher Womersley number, the differences of the Reynolds numbers are almost doubled as well. Similarly, cross-section 7 has the highest discrepancy in Reynolds number with approximately 8.8% for higher Womersley number.

Cross-section 6 has the highest value of Reynolds number in both flow rates among all the cross-sections considered here. This illustrates the effects of complexity of the geometry on the flow field in this region.
Table 4. Reynolds numbers of constant and transient breathing cycle during inspiration at all seven traverse cross-sections of the ETA

<table>
<thead>
<tr>
<th>Sections</th>
<th>Low flow rate</th>
<th>High flow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Re (Constant inspiration)</td>
<td>Re (Transient breathing)</td>
</tr>
<tr>
<td>1</td>
<td>713.597</td>
<td>728.061</td>
</tr>
<tr>
<td>2</td>
<td>733.432</td>
<td>736.446</td>
</tr>
<tr>
<td>3</td>
<td>964.419</td>
<td>956.027</td>
</tr>
<tr>
<td>4</td>
<td>1438.58</td>
<td>1423.414</td>
</tr>
<tr>
<td>5</td>
<td>1121.371</td>
<td>1127.912</td>
</tr>
<tr>
<td>6</td>
<td>1617.872</td>
<td>1665.383</td>
</tr>
<tr>
<td>7</td>
<td>1284.596</td>
<td>1338.778</td>
</tr>
</tbody>
</table>

4.2.2 Expiration

Peak expiration in breathing cycle solutions occurs at a phase angle at and for and , respectively. The comparison was made between peak expiration with corresponding constant expiration for both flow rates (i.e. Re = 875 and Re = 1750).

Velocity contour plot of the central sagittal plane of the ETA during expiration for both flow rates are displayed in Figure 10. Similar to inspiration, the flow pattern of the time-averaged solution of both flow rates is approximately identical; the only difference is in the strength of the flow. The third backward facing step during inspiration has a role of a forward facing step during expiration. As with inspiration, the jet-like flow was formed in the opposite direction during expiration. A small recirculation zone appeared at posterior wall of trachea. Unsteadiness in jet-flow was observed in transient breathing of both flow rates. These effects are more significant for higher flow rate. Critical changes in the flow regime occurred right after jet-flow in the larynx. For both flow rates, the flow is unsteady and highly three-dimensional.

Cross-sections 2, 3, 4 and 5 were considered for investigation of the flow structure during expiration. These locations were selected to have a better understanding of the flow phenomena in the pharynx and the oral cavity. As can be seen in the central sagittal plane of both flow rates in Figure 10, fully turbulent flow is clearly visible in the pharynx, oro-pharynx and consequently in the oral cavity. Secondary flows at the four cross-sectional planes of interest in the ETA are shown in Figure 11. The flow pattern of the time-averaged solutions of the low and the high flow rates are approximately similar at each cross-section. Again, the difference is in the strength of the flow. The flow pattern of transient breathing solutions at all these four cross-sections shows the presence of the turbulent flow in both flow rates. This can also be seen in the iso-surface of the Q-criterion of the low flow rate in Figure 12. This reveals that the flow regime during expiration is much more complicated than inspiration with high level of turbulent flow in the pharynx and the oral cavity.
Figure 10. Central sagittal cross-section of the ETA, illustrating velocity magnitude during expiration. Peak transient breathing and time-averaged solutions of both flow rates.
Figure 11. Secondary flows of the low and the high flow rate during expiration in the ETA. Cross-sections 5, 6 and 7 of the low and high flow rates from the top and bottom, respectively.
The values of the Reynolds number for both flow rates during expiration are summarized at all seven cross-sections in Table 5. Reynolds numbers in either flow rates suggested higher values at all locations, except cross-section 7, compared to inspiration in Table 4. This confirms the earlier statement about the complexity of the flow during expiration. In both flow rates, significant differences of Reynolds number between transient breathing and constant expiration can be observed in many cross-sections, especially at locations 2 and 5. Highly turbulent flow was found through the pharynx, oro-pharynx and the oral cavity. Hence, discrepancies of the Reynolds numbers are not surprising at these locations.

Table 5. Reynolds numbers of constant and transient breathing cycle during expiration at all seven traverse cross-sections of the ETA

<table>
<thead>
<tr>
<th>Sections</th>
<th>Low flow rate</th>
<th>High flow rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Re (Constant expiration)</td>
<td>Re (Transient breathing)</td>
</tr>
<tr>
<td>1</td>
<td>945.102</td>
<td>1043.254</td>
</tr>
<tr>
<td>2</td>
<td>895.443</td>
<td>1089.182</td>
</tr>
<tr>
<td>3</td>
<td>1100.579</td>
<td>1196.479</td>
</tr>
<tr>
<td>4</td>
<td>1482.123</td>
<td>1589.581</td>
</tr>
<tr>
<td>5</td>
<td>1276.371</td>
<td>1594.169</td>
</tr>
<tr>
<td>6</td>
<td>1641.512</td>
<td>1604.205</td>
</tr>
<tr>
<td>7</td>
<td>1077.172</td>
<td>1156.734</td>
</tr>
</tbody>
</table>
4.3 The Entire Airway Geometry

Final simulations were carried out for the entire airway geometry in addition to the lower airways geometry. For each flow rate, two simulations (constant inspiration and expiration) and one full breathing cycle simulation were carried out. This resulted in 6 simulations per flow rate and a total of 12 simulations. The constant inspiration/expiration cases were conducted at two Reynolds numbers, i.e., 875 and 1750, analogous to peak flow conditions in the full breathing cases, i.e., the Womersley numbers of 4.72 and 6.68, respectively. Five cross-sections of interest in the lower airways, shown in Figure 7, were selected for analysis. These cross-sections are representative of the airflow entering each lobar bronchus. Volumetric fluxes were computed at each of the cross-sections. The deviation of flow rates from the targeted values were found no more than 0.045% and 2% in lower airways and the entire airway geometry, respectively.

4.3.1 Inspiration

Peak inspiration in breathing cycle solutions occurs at a phase angle of at t = 2s and t = 1s for and , respectively. Sagittal sections of the oro-pharynx, the pharynx, the larynx and the trachea during inspiration for transient breathing cases and constant inspiration (time averaged as well as instantaneous) are depicted in Figure 14. As can be seen, highly turbulent flow occurs in the trachea. The level of the turbulence intensity can be gauged by comparing the flow fields between the instantaneous and time-averaged cases. This is characteristic of the turbulence generated by the effect of the epiglottis and structure of the larynx and very similar to the results of other researchers (Johnstone et al., 2004), (Ball et al., 2008b). The laryngeal jet is clearly visible in the solutions shown in Figure 14, with its strength increasing with increasing flow rate.
The strength of the flow field between the low and high flow rates can be seen by comparing the time-averaged solutions. The recirculation bubble in the posterior region of the high flow rate is bigger, compared to low flow rate. Hence, for high flow rate greater turbulence level and also more unsteadiness are expected downstream of the trachea. This flow regime with high turbulence intensity has a critical impact on the flow features in the downstream of the lower airway. Iso-surface of Q-criterion for is provided in Figure 15 to have a better insight into this flow phenomenon through the entire airway. In this figure, the presence of highly turbulent flow can be observed through the pharynx, the larynx and the trachea. There is no significant turbulence features in daughter branch or other generations. The feature of turbulence can be seen in the zeroth generation, i.e. the trachea, caused by the complex flow formed by the ETA. These effects can be recognized by comparing the flow pattern at five cross-sections of interest (see Figure 4).
Figure 15. Iso-surface of Q-criterion colored by velocity magnitude for during inspiration. a) Front view b) sagittal view of the entire airway geometry. The geometry is in grey.

The effect of the ETA on the flow through the lower airways can be gauged by comparing the solutions obtained for the entire airway geometry with one obtained for the lower airways only in Figure 16. This figure illustrates cross-sectional coronal view of velocity magnitude, limited to 2 m/s, for for the lower airway and the entire geometry. Noticeable differences can be observed between the solutions. A quasi-steady laminar flow occurs in the lower airway, while the entire airway geometry does not show similar flow phenomenon through the trachea and both primary bronchi. Figure 17 provides a better inside into of turbulence features through both airway geometries.
Figure 16. Cross-sectional plane of velocity magnitude is limited to 2 m/s for during inspiration

Figure 17 shows the TKE and turbulence intensity of the entire airway solutions and the lower airway. From the TKE contour in the entire airway, high turbulent flow appeared within the trachea and low level of turbulence decreases within the generations. Conversely, the TKE is almost zero throughout the lower airway geometry.

Turbulence intensity is also zero in the lower airway, whereas turbulence intensity can be spotted in different regions of the entire airway. High turbulence intensity can be found in stagnation points, as can be seen in the first bifurcation and second bifurcation of the right daughter branch. Note that high turbulence intensity is expected in other stagnation points that cannot be seen in this figure. The turbulence intensity is high in the central portion of the trachea downstream of the larynx as well as two sheet-like features near both sides of the wall within the trachea.
Figure 17. Cross-sectional coronal plane of the first generation of pulmonary airway, illustrating TKE and turbulence intensity for high flow rate during inspiration. The entire airway and the lower airway geometry are on the left and right, respectively. The values limited to 0.3 m²/s² and 0.5, respectively

The flow in the lower airway geometry with practically zero turbulence intensity suggests quasi-steady laminar flow, while the entire airway geometry displays high levels of turbulence through the trachea as well as both primary bronchi. The high-speed laryngeal jet causes this characteristic of the airflow within the trachea and results in high turbulence levels. However, the level of turbulence intensity reduces significantly
through the generations. This suggests that the flow through the lower airways is quasi-turbulent and is not significantly affected by the high-speed laryngeal jet.

Secondary flow velocity vectors, colored by velocity magnitude, are shown at various cross-sections (depicted in Figure 13) in Figure 18. The results shown here include that obtained for the entire airway geometry as well as the lower airways geometry. In this figure, only the high flow rate results are shown. This is strictly due to the page number limitation, though the qualitative nature of the comparison is similar between the high and low flow rate cases.

As can be seen from Figure 18, clear differences are visible in the cross-flow velocity vector patterns for the RS, RM and the LI bronchi, while the differences are less pronounced for the other two locations. However, differences in velocity magnitude (the colors in 10) can be seen at these two locations (RI and LS). In the RS, the differences between the two transient breathing solutions are quite clear. The transient breathing entire airway geometry solution shows the presence of two distinct vortices, while the corresponding lower airways solution has three well defined vortices. The differences between the time-averaged solutions are even more pronounced, with the entire airway geometry showing the presence of a single vortex, while two well defined vortices can be seen in the lower airways solution. Another comparison that can be made is between the time-averaged and transient breathing solutions. Comparing these for the entire airway geometry, one can see that there are two vortices for the transient breathing case, while there is a single vortex for the time-averaged case. The presence of the second vortex towards the bottom of the cross-section pushes the other vortex against the edges of the cross-section, effectively squishing it. This also leads to the presence of a higher velocity region down the left side of the cross-section that is absent in the full breathing cycle case. Similar differences can be observed by comparing the time-averaged and transient breathing solutions for the lower airways only. The differences in the secondary flow for the RM are more pronounced compared to the RS bronchus. Similar to the RS, the number of vortices present seems to go up by one when comparing the corresponding time-averaged and transient breathing solutions. The time-averaged lower airways solution has a cloverleaf like pattern, with the fourth vortex being fairly weak. A comparison of the full breathing cycle solutions for the entire airway geometry with the lower airways only case indicates the presence of a vortex towards the top of the cross-section (for the lower case), which is clearly missing from the entire airway geometry.
Only subtle differences are visible in the cross-flow velocity vector patterns between the solutions for the RI, LS, and LI bronchi. Differences are present in the velocity magnitude at all these stations. A possible explanation for these differences could be the distance to these cross-sections from the entrance to the trachea, i.e., the farther you get away from the exit of the ETA, the lesser its effect will be. This is because the low Reynolds number of the flows through the lower airways which tends to damp out most of the turbulent content with increasing residence time.

4.3.2 Expiration

The secondary flow for the expiration case at all cross-sections of lobar bronchus is shown in Figure 19. Again, for the reasons mentioned earlier, only the high flow rate
results are shown here. Compared to the inspiration case, only subtle differences are observed between the various solutions. The flow features for all cases are remarkably similar, with the only difference arising in the magnitudes of the velocity between the various cases. This is not surprising given that the flow is now travelling in a direction opposite to the inspiration case, making the ETA downstream of the lower airways. The effect of the ETA will be felt at best as a slight increase in flow resistance, but the overall flow features are not affected by the presence of the ETA.

The most significant differences between the time-averaged and full breathing cycle solutions for the entire airway geometry are seen in the LI and LS cross-sections, where there are some changes to the cross-flow velocity vector patterns. In the transient breathing solution (LI), an additional vortex appears at the bottom right side that does not exist in time-averaged solution. Furthermore, the velocity magnitude for the time-
averaged solution was about 10% lower than the transient breathing one. The maximum velocity (time-averaged) for the RI bronchus was approximately 4.2% lower than the breathing cycle case, while this difference was much more significant in the LS, with 18%. Moreover, in the LS bronchus of the lower airway, prominent differences can be seen in the velocity magnitude of the time-averaged solutions which is approximately 14% less than the transient breathing solution.

The turbulence intensity in the lower airway and the entire airway solutions are provided in Figure 20 to gain insight into the flow regime that exists in the zeroth generation (trachea) and the first generation. The turbulence intensity in both geometries revealed the existence of the turbulent flow during expiration. The level of the turbulence in the lower airway was more pronounced compared to the entire airway solution. This shows the importance of the ETA and its effects on the flow regime within the first bifurcation and the trachea. Higher turbulence intensity appeared in the right primary bronchus of both geometries, with the lower airway having higher values compared to the entire airway geometry.

![Figure 20](image.png)

Figure 20. Cross-sectional coronal plane of the first generation of pulmonary airway illustrating turbulence intensity for high flow rate during expiration. The entire airway and the lower airway geometry on the left and right, respectively. The value of turbulence intensity limited to 0.2

It can be seen from Figure 20 that the turbulence intensities are dropping near the trachea. This is consistent with what is seen in Figure 21, which shows a visualization of the turbulent structures present in the ETA, as the turbulent structures are mostly absent in the region of the thorax. However, once the flow passes the glottis, significant turbulent structures appear. This is not surprising given that it is the glottis which causes the laryngeal jet to form during inspiration and the same geometry results in turbulence being generated during expiration.

The changes in the velocity flow field observed in Figure 19 and the turbulence generated in the ETA during expiration could influence particle deposition patterns as
one goes through a breathing cycle. Particle inspiration and deposition was not carried out as part of this research; it is however planned as a continuation.

Figure 21. Iso-surface of Q-criterion colored by velocity magnitude for . Behind view, sagittal view and right oblique (45°) of the ETA from left to right. The geometry is in grey.

5 Conclusions

Computational simulations have been carried out using Tenasi for two different breathing conditions. These computations utilized either an entire geometry or only the lower airways geometry. This allowed for an assessment of the impact of the ETA on the flow through the lower airways.

In the lower airway, irrespective to the presence of the ETA, it was observed that expiratory flows (constant or cyclic breathing) had more fluctuations and unsteadiness compared to inspiratory flows. Conversely, the existence of the ETA increased the levels of turbulence during inspiration. The flow through the ETA is highly unsteady and has significant levels of turbulence in either inspiration or expiration. This manifests itself as differences in velocity distributions at the various lobar planes considered for analysis. These differences could have a significant impact on drug delivery and point to the need for including the ETA geometry in any lower airways simulations.

The impact of constant inspiration/expiration compared to a full breathing cycle was also analyzed by comparing the results of the simulations between peak inspiration/expiration obtained using both the approaches. Significant differences were observed in the simulations pointing to the fact that a constant inspiration/expiration approach might not be sufficient to develop and understanding of these complex flow phenomenon.

References


Physics Based Prediction of Stability and Control Characteristics Using Sensitivity-Enhanced Reduced Order Models

Submitted to:
Tennessee Higher Education Commission Center of Excellence in Applied Computational Science and Engineering at the University of Tennessee at Chattanooga

Principal Investigators:
Dr. Abdollah (Abi) Arabshahi
Jaber J. Hasbestan
Dr. James Newman III

The University of Tennessee at Chattanooga
SimCenter: National Center for Computational Engineering
701 East M.L. King Boulevard
Physics Based Prediction of Stability and Control Characteristics Using Sensitivity-Enhanced Reduced Order Models

By

Dr. Abdollah(Abi)Arabshahi, Jaber J. Hasbestan and Dr. James Newman III

The University of Tennessee at Chattanooga, Chattanooga, TN, 37403

ABSTRACT

Least squares spectral element methods formulate the partial differential equation (PDE) as an optimization problem. One of the advantages of this method is that the boundary conditions can be implemented by adding a penalty equation to the cost function and hence be imposed in a weak sense with little effort. In this study a discontinuous methodology is utilized; that is, each element has its own set of degrees-of-freedom. This formulation possesses a greater sparsity pattern in the Jacobian matrix, and has a smaller bandwidth when compare to the continuous counterpart. However, these attributes come at the expense of an increased number of degrees-of-freedom on a given discretization. In the current work, the conventional discontinuous approach is modified to convert the equations to a matrix free system where there is no need for assembling the global system. The continuity in the formulation between two neighboring elements is imposed in a weak sense with a penalty equation added to the original PDE in each element. This penalty term minimizes the integral of the square root of the difference between the unknown state-vectors on each edge for neighboring elements. The conventional discontinuous approach evaluates this integral at the current time iterate. Using the aforementioned approach, assembly of the system is required and is not matrix free. It is shown in this study that by modifying this equation it is possible to obtain a matrix free system. Additionally each element becomes independent from other elements, and the direct solution for each element possible. The system matrix obtained by this least squares method is symmetric positive definite and can be effectively solved by Cholesky decomposition. This solution procedure is well suited for parallelization using P threads and CUDA. This is due to the fact that there is now no need for any communication, and each element only reads the data from the neighboring elements, while solving for its own unknowns. Another advantage of the matrix free approach is that adaptation is easily implemented by only introducing the new state-vectors into the data structures and updating the neighbor connectivity. The value of the cost function in the formulation may be used to select the elements to be refined. Each tagged element is then divided by h-refinement. This results in a nonconformal mesh. Utilization of a
nonconformal mesh alleviates the need for increasing the resolution in unnecessary locations. To require conformality of the mesh, the extent of refinement and the number of degrees-of freedom are increased. In the current work, quintic quadrilateral elements are used in the simulations, and a C++ vector class is used for updating mesh refinement data structures.

INTRODUCTION

Least squares spectral element method has been used in the past for the solution of the flow problems. This method is based on the conversion of the PDE to an unconstrained optimization problem. This approach has several advantages over the other two methods popularly used in Computational Fluid Dynamic (CFD) analysis, namely, Discontinuous Galerkin and Petrov-Galerkin methods. In this methodology the weighted integral statement is used therefore secondary variables are not present in the discrete equations. In fluid dynamics, the corresponding equations do not contain boundary integrals and thus flux evaluation is not necessary. When applied to nonlinear governing equations of fluid flow, it leads to symmetric positive definite systems. By proper implementation of the boundary conditions of the system, symmetry is preserved. The value of the cost function at each element can be used to detect the elements for refining purposes. In this study P5 spectral element is used for the analysis. This element is shown in Figure 1.

![Figure 1. P5 ELEMENT IN COMPUTATIONAL DOMAIN](image)

BRIEF LITERATURE REVIEW

Least squares finite element methods have received sporadic attention in the past decade [1–5]. The least squares finite element method has been previously applied to low Mach number flows by Sheng-Tao et al. [6]. This method for viscous incompressible flow provides sufficient dissipation and has been shown to be inherently stable [7]. Celikkale et. al. [8] show that conservation is recovered by this approach when used
along with adaptation. Application of this method to nonconforming grids has been studied by Sert et al. [9]. Akargun et al. [10] has applied h-refinement to capture discontinuities in an unstructured finite element grid. Ponanza et al [7, 11] has utilized the least squares method for the Euler and Navier-Stokes equations in primitive variables. Conventional Discontinuous version is also Garrisma et al [12] has demonstrated the use of Newton linearization for the Euler equations using the conservative variables as the primary unknowns. Discontinuous least-squares formulation is first introduced by Aziz et al [13] for a two-domain transmission problem, for which mathematical analysis and numerical results were given by Cao and Gunzburger [14]. Application of the discontinuous least-squares finite element formulation has been also demonstrated by Gerritsma and Proot [15] in the for a first-order one-dimensional model problem, and by Heinrichs [16] for one dimensional singular perturbation model problem.

CONTINUOUS LEAST SQUARES SPECTRAL ELEMENT METHOD

For spectral element methods the band-width of the Jacobian (or Stiffness) matrix becomes very large. Every node that is in common between two elements will depend on all the nodes from those element. When written in compressed row format this means that ‘ja’ will include plenty of nodes. This effect varies almost quadratically in two dimensional spaces and cubically in three dimensional space with the order of interpolation polynomial. This dependency actually is beneficial in terms of convergence speed. However, error propagation is also more pronounced due to the same reason. The Least Squares formulation would lead to symmetric Jacobian matrix so only half of this matrix need be stored. And the memory requirement is reduced for this type of formulation. Preconditioned conjugate gradient method can be effectively used to solve the linear system. The penalty function for the method is as follows

\[ I = \int R(i)^2 dS, i = 1, \ldots, n \]  \hspace{1cm} (1)

where n is the number of equations.

DISCONTINUOUS LEAST SQUARES SPECTRAL ELEMENT METHOD

In discontinuous approach, each element has its own set of degrees of freedom. Now there are no nodes in common. And each node at the edge is only dependent on the edge nodes from the neighboring element and the nodes inside the elements. This effectively reduces the bandwidth of the Jacobian matrix. In the realm of the least squares spectral element method the continuity can weakly be imposed by adding the following penalty function

\[ I = \int R(i)^2 dS + \lambda \int (q - q^*)^2 dl, i = 1, \ldots, n \]  \hspace{1cm} (2)
where \( n \) is the number of equations and \( dl \) stands for the line integral and \( q^* \) is the unknowns state vector along the edge of the neighboring element. The penalty term basically enforces this integral to be minimized and hence enforces the continuity in a weak sense.

**CONVERSION TO MATRIX FREE SYSTEM**

The discontinuous least squares spectral element method can easily be converted to matrix free system by modifying the penalty term. Matrix free means the assembling stage of the regular finite element analysis is eliminated and the Jacobian matrix is only formed for each element. Now, instead of evaluating the \( q^* \) at time step \( n+1 \), it is evaluated at time step \( n \), making the system semi-implicit. For higher order system using a preconditioner is inevitable for conventional discontinuous or continuous FEM methods. Conversion to matrix free eliminates the storage of the Jacobian matrix as well as the corresponding preconditioner.

**ADAPTIVE H-REFINEMENT AND NONCONFORMAL GRID**

Adaptive refinement is crucial in improving the resolution at desired locations in flow in an economic way. For conformal structured grids (i.e. quad elements), local adaptation of one element will lead to adaptation of all the neighboring elements all the way up to the boundaries. This increases the cost of the calculations unnecessarily. On the other hand, if one removes the requirement of conformity on the grid generation process the constraint of the matching points from both sides on the neighboring surfaces will also be eliminated. This in turn, can make the mesh generation process using quad elements less burdensome for practical geometries.

**Non-Conformal Mesh Refinement**

Except for linear elements, both h-refinement and p-refinements lead to hanging nodes. The modified mesh will include different number of nodes from different sides. Hence form the so-called non-conformal mesh. An example of this is demonstrated in Figure 2. In this study, refinement of the P5 quad elements are accomplished by dividing the element by four new elements. The elements are generated using the midpoints of each edge and the centroid of the element. The one located at the bottom left holds the element number of the element before refinement and the three new elements are labeled in increasing order in counter clockwise rotation. To keep the order of accuracy in curved elements P2 is used to approximate the geometry inside each refined element. P2 requires specification of the central point as well. The coordinates of this point can be easily calculated using the iso-parametric representation of the original element. Having calculated this, one can easily calculate the coordinates using P2 interpolation polynomials. A sample of such a mesh is shown in the Figure 2. This representation of geometry by an order higher than one enables us to generate smooth interior mesh.
Virtual Edge Construction

In the Discontinuous Least Squares Spectral Element (DLSSEM) method the continuity across the elements are enforced weakly using a penalty function. At each non-conformal edge, a virtual edge is constructed and the continuity is enforced between this virtual edge and the current edge. There are two types of non-conformal edges. One that has several neighbors, and one that only has one neighbor but shares that edge with some other elements. At first a virtual edge is constructed at each edge and then jump through this face is minimized. To find the location of the Gaus points in neighboring nonconformal edges Newton solver is used. While integrating the continuity penalty parameter the following procedure is implemented to obtain $q^*$. Consider two abutting element ‘a’ and ‘b’,

1) Given the Gaus point location for element ‘a’ in the natural coordinates calculate the location of the Gaus point in the physical space, i.e. $X_p$ and $Y_p$

$$X_p^a = \sum X_i^a \Phi_i$$
$$Y_p^a = \sum Y_i^a \Phi_i$$  \hspace{1cm} (3)

2) Identify which neighbor holds that points (as now each element can have multiple neighbors)

3) Using the coordinates of the neighbor form the isoparametric representation of the neighboring edge, i.e.,

$$X_p^a = \sum X_i^b \Phi_i(\xi, \eta)$$
$$Y_p^a = \sum X_i^b \Phi_i(\xi, \eta)$$  \hspace{1cm} (4)
4) Solve the above nonlinear equation using a Newton method for
5) Interpolate the unknown vector at that location for the element
6) Assume this value as \( q^* \)
7) Loop over for the next Gauss point

GOVERNING EQUATIONS

In this study, the Euler and Laminar Navier-Stokes equations are numerically solved using the matrix free DLSSEM. Conversion to laminar flow follows redeclaration of the PDE in first order form. This will eliminate the need for computing the second order derivatives at the expense of introducing more independent variables.

Euler Equations In Conservative Form In Two Dimensions

Conservative formulation is a necessity to capture the location of the discontinuities (i.e. shocks) in the flow.

\[
\frac{\partial Q}{\partial t} + \frac{\partial F}{\partial x} + \frac{\partial G}{\partial y} = 0 \quad (5)
\]

Performing chain rule, one will get the linearized form as follows:

\[
\frac{\partial Q}{\partial t} + A \frac{\partial Q}{\partial x} + B \frac{\partial Q}{\partial y} = 0 \quad (6)
\]

At this point one can assume that the coefficients appearing at the nonlinear terms are known from the previous iteration. This assumption will lead to the Picard linearization. In other words, a nonlinear convective term at iteration \( (n+1) \) is approximated in the following manner:

\[
Q^{n+1} \frac{\partial Q^{n+1}}{\partial x} = Q^n \frac{\partial Q^{n+1}}{\partial x} \quad (7)
\]

The alternative way is to use Newton linearization. This approach is illustrated as follows. Consider the conservative variable \( Q^{n+1} \) at iteration \( n+1 \), \( Q^{n+1} = Q^n + \Delta Q \).

Consider \( Q^{n+1} \frac{\partial Q^{n+1}}{\partial x} \) to be a sample convective term,

inserting the above mentioned relation into this nonlinear equation will give:

\[
(Q^n + \Delta Q) \frac{\partial (Q^n + \Delta Q)}{\partial x} = Q^n \frac{\partial Q^n}{\partial x} + Q^n \frac{\partial \Delta Q}{\partial x} + \Delta Q \frac{\partial Q^n}{\partial x} + \Delta Q \frac{\partial \Delta Q}{\partial x} \quad (8)
\]
By neglecting the higher order terms it follows, 
\[ \Delta Q \frac{\partial \Delta Q}{\partial x} \]

\[ (Q^n + \Delta Q) \frac{\partial (Q^n + \Delta Q)}{\partial x} \approx Q^n \frac{\partial Q^n}{\partial x} + \Delta Q \frac{\partial Q^n}{\partial x} + Q^n \frac{\partial \Delta Q}{\partial x} \] (9)

Inserting back the relation for \( \Delta Q \) yields;

\[ Q^n \frac{\partial Q^n}{\partial x} + \Delta Q \frac{\partial Q^n}{\partial x} + Q^n \frac{\partial (Q^{n+1} - Q^n)}{\partial x} \] (10)

by rearranging, and plugging back \( \Delta Q + Q^n = Q^{n+1} \) in

\[ Q^{n+1} \frac{\partial Q^{n+1}}{\partial x} = Q^{n+1} \frac{\partial Q^n}{\partial x} + Q^n \frac{\partial Q^{n+1}}{\partial x} - Q^n \frac{\partial Q^n}{\partial x} \] (11)

The Euler equations are linearized using this method. For more detail see [12]. The only disadvantage of using this type of linearization is the generation of rational polynomials, for which the number of Gauss points required for exact integration cannot be decided beforehand. Albeit it might suffice to evaluate these terms approximately for most of the problems. Here, the conservative form of the equations are used. However, the primitive variables used as primary variables in the solution procedure. Using the transformation between the primitive and conservative variables i.e. \( Q = Mq \) the following is achieved,

\[ M \frac{\partial q}{\partial t} + L_1 \frac{\partial q}{\partial x} + L_2 \frac{\partial q}{\partial y} = 0 \] (12)

Using the Newton linearization on the nonlinear terms in \( L_1 \frac{\partial q}{\partial x} + L_2 \frac{\partial q}{\partial y} \) the equation takes the following form;

\[ M \frac{\partial q}{\partial t} + L_0 q + L_1 \frac{\partial q}{\partial x} + L_2 \frac{\partial q}{\partial y} = f \] (13)

At the convergence \( L_0 q = f \) the equation reduces to the original form. This fact can be used as a verification of the derivations of \( L_0 \) and \( f \). These coefficients are presented in appendix A. The point is the equations are not multiplied by \( M^{-1} \), and hence the conservative property is preserved at each time step. The change in the conservative variables are calculated at each iteration. The other advantage is that using this technique, neither of the coefficients contain any rational polynomials, now the number of nodes can be specified for exact integration of each term as each term is a polynomial itself. The third advantage noted in the verification procedure is the method used here provides better up-winding and dissipation, in comparison to the direct linearization of the conservative Euler equations with conservative variables as primary variables used in [12]. This is noticed in the grid convergence study in the method of manufactured solution. In addition, it also reduces the burden of chain rule differentiation.
when viscous terms are involved.

**Laminar Navier-Stokes Equations in Conservative Form**

The continuous version for the Least Squares Spectral Element (LSSEM) method is given in [17]. The nondimensional form of the laminar Navier-Stokes equations in first order form are given as,

\[
R_1 = \frac{\partial p}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y}
\]

\[
R_2 = \frac{\partial (\rho u)}{\partial t} + \frac{\partial (\rho u^2 + p)}{\partial x} + \frac{\partial (\rho uv)}{\partial y} - \frac{\partial \tau_{xx}}{\partial x} - \frac{\partial \tau_{xy}}{\partial y}
\]

\[
R_3 = \frac{\partial (\rho v)}{\partial t} + \frac{\partial (\rho uv)}{\partial x} + \frac{\partial (\rho v^2 + p)}{\partial y} - \frac{\partial \tau_{yx}}{\partial x} - \frac{\partial \tau_{yy}}{\partial y}
\]

\[
R_4 = \frac{\partial (\rho E)}{\partial t} + \frac{\partial ((\rho E + p)u)}{\partial x} + \frac{\partial ((\rho E + p)v)}{\partial y}
\]

\[
- \frac{\partial (\tau_{xx}u + \nu \tau_{xy} - q_x)}{\partial x} - \frac{\partial (\tau_{xy}u + \nu \tau_{yy} - q_y)}{\partial y}
\]

\[
R_5 = \tau_{xx} - \frac{2}{3} \mu \frac{M_\infty}{Re_\infty} \left( 2 \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} \right)
\]

\[
R_6 = \tau_{xy} - \frac{\mu}{Re_\infty} \left( \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right)
\]

\[
R_7 = \tau_{yy} - \frac{2}{3} \mu \frac{M_\infty}{Re_\infty} \left( 2 \frac{\partial v}{\partial y} - \frac{\partial u}{\partial x} \right)
\]

\[
R_8 = q_x + k \frac{M_\infty}{Re_\infty Pr_\infty Ec_\infty} \left( - \frac{p}{\rho^2 R} \frac{\partial p}{\partial x} + \frac{1}{\rho R} \frac{\partial p}{\partial x} \right)
\]

\[
R_9 = q_y + k \frac{M_\infty}{Re_\infty Pr_\infty Ec_\infty} \left( - \frac{p}{\rho^2 R} \frac{\partial p}{\partial y} + \frac{1}{\rho R} \frac{\partial p}{\partial y} \right)
\]

where the temperature gradients in the heat fluxes have been written in terms of pressure and density using the equation of state.

The free stream Reynolds number, Prandtl number and speed of sound are defined as $Re_\infty$, $Pr_\infty$, and $c_\infty$, respectively.

**Grid Generation For Higher Order Spectral Elements**

Commercial grid generation softwares generate P1 elements. It is more convenient to try to generate higher order meshes from the mesh generated by these
softwares. The most conventional way is to linearly interpolate the points for the higher order elements, at the locations required by the tensor product of the GLL (Gauss-Legendre-Lobatto) points in the nodal spectral element method.

Geometry Snapping For Higher Order Elements

To be able to maintain the order of accuracy, the geometry under study should be modeled at least with the same order of accuracy. This requires the snapping of the Legendre points on the elements at the boundaries to the solid boundaries based on the arc-length. This is done by using a parametric curve distribution for NACA0012 airfoil in this study. In order to maintain the quality of the mesh, linear elasticity equations are used to deform the mesh according to the locations of the points obtained from the geometry [18]. These equations are formulated at the same order of the flow solver to take advantage of the already developed code [19]. Galerkin FEM [20] is used for the analysis. One should notice that, this procedure introduces some error for elements as it moves the interior nodes without regard to their new Gaus-Legendre-Lobatto (GLL) points. This issue is more noticeable in bigger elements. For those types of situations, it is better to regenerate the interior points inside the element using Trans-Finite Interpolation (TFI) [21] method to remove the error generated during the process.

PARALLELIZATION USING MULTIPLE THREADS

This methodology leads to a pleasingly parallel algorithm which is very suitable for multi-thread programming. The shared data between the threads is read-only, hence the iteration takes place without any need for synchronization or blocking communication. It is worth noting that this method is designed for shared memory paradigm therefore running this in serial is extremely inefficient and slow. Very appealing for CUDA due to the power of launching thousands of threads. However, one needs to have access to the hardware. A simpler version can be easily implemented using C++ OPENMP library. The latter is used for parallelization in this study.

VERIFICATION WITH METHOD OF MANUFACTURED SOLUTION (MMS) ON NONCONFORMAL GRID

This method is widely used to verifying the numerical solution procedure. In this procedure one assumes a predefined field for the independent variables. These variables certainly do not satisfy the original equations. Therefore plugging these into the original PDE will lead to a source term. Adding this source term to the equations, one will try to recover the known results by solving the new PDE. The solution is presented in Figure 3 for comparison.

NUMERICAL RESULTS

Several standard test cases are used to demonstrate the ability of this method. The analysis includes flow over a smooth geometry i.e. a cylinder at subsonic flow. The second test case is NACA0012 in subsonic and transonic flows conditions. This geometry
is included to account for the effect of the geometric and solution singularities on the method. The next test case is supersonic flow over a five degree ramp and the final case is low mach number laminar flow around a circular cylinder. Three level adaptation is applied to the cases unless stated otherwise.

Subsonic Inviscid Flow Around a Cylinder

The flow around a cylinder is simulated at M=0.3 and AOA=0.0. The results for this case is presented in Figure 5. The initial mesh and the final mesh consist of 24 and 228 elements, respectively. The solutions for these two cases are presented in Figure 6 for comparison. In order to preserve symmetry, symmetric adaptation is enforced. Since the path the optimization takes till the convergence is not necessarily symmetric, without enforcing this condition, the solver will perform adaptation in an asymmetric way which is not desirable for the case under study here.

Subsonic Inviscid Flow over NACA0012 Airfoil

The flow condition for this case is set as M=0.5 and AOA=2.0 degrees. The final result at the end of adaptation is presented in Figure 7. The initial mesh and the final adapted mesh are presented in Figure 8. The initial mesh is the same for both subsonic and transonic cases and consists of 266 elements. The number of elements for this case at the end of adaptation is 554.

Transonic Inviscid Flow over NACA0012 Airfoil

The flow condition for this case is set as M=0.8 and AOA=0.0 degrees. The solution to this problem is presented in Figure 9 and the final mesh is presented in Figure 10. The number of elements for initial and final meshes are 266 and 2078, respectively.

Supersonic Inviscid Flow over Ramp

Flow over a 5:0 degree ramp for M=2.0 and AOA=0.0 is presented. The grid is adapted for four levels. The corresponding solution fields are presented in Figure 11. The improvement of the adaptation over the initial solution is demonstrated in Figure 12. Four level adaptation is used for this case. Initial mesh has 30 elements. This numbers increases to 786 at the end of adaptation.

Laminar Viscous Flow over Cylinder

Flow over unit diameter circular cylinder at M=0.2 and AOA=0.0 and Re=20, is presented. Once again, three level adaptation is carried out. The initial and final meshes have 178 and 374 elements and are shown in Figure 13. This flow is indeed low speed and may be considered as incompressible. The solution is presented as a validation with incompressible flow. The variation in density is very small as expected for this flow condition.
Figure 3. VERIFICATION OF THE NUMERICAL METHOD USING THE METHOD OF MANUFACTURED SOLUTIONS
Figure 4. GRID FOR THREE LEVEL ADAPTATION FOR FLWO AROUND A CYLINDER
Figure 5. FLOW AROUND A UNIT DIAMETER CYLINDER M=0.3 AND AOA=0.0
Figure 6. FLOW AROUND A UNIT DIAMETER CYLINDER M=0.3 AND AOA=0.0
Figure 7. FLOW AROUND A NACA0012 AIRFOIL FOR M=0.5 AND AOA=2.0
Figure 8. FLOW AROUND A NACA0012 AIRFOIL FOR M=0.5 AND AOA=2.0
Figure 9. FLOW AROUND A NACA0012 AIRFOIL FOR M=0.8 AND AOA=0.0
Figure 10. FLOW AROUND A NACA0012 AIRFOIL FOR $M=0.8$ AND $AOA=0.0$
Figure 11. FLOW OVER RAMP M=2.0 AND AOA=0.0
Figure 12. FLOW OVER RAMP M=2.0 AND AOA=0.0
Figure 13. FLOW AROUND A UNIT DIAMETER CYLINDER $M=0.2$ AND $AOA=0.0$
Re=$20$
VALIDATION

1) The validation here is presented for the supersonic case. Given the deflection angle of the ramp and the free stream Mach number, one can easily calculate the shock angle using theoretical aerodynamics [22]. For the problem under consideration here, this angle is found to be 34.3 degrees. The “y” location of the shock at the outlet boundary is approximately 2.04, therefore the shock angle calculated here numerically is 34.1 degrees, which shows that they are in good agreement.

2) The second case is the flow at M=0.5 and AOA=1.25, the results are compared to finite volume results of Vassberg and Jameson [23]. Cp for both cases are compared in Figure 14.

![Figure 14. COMPARISON OF PRESSURE COEFFICIENT](Image)

CONCLUSIONS

A pleasingly parallel Matrix Free Least Squares Spectral Element method with h-refinement is developed for steady-state Euler and Laminar Navier-Stokes equations. In this approach, unlike the regular contentious methods, continuity between the elements are enforced in a week sense. A simple modification of this penalty function enables us to obtain a pleasingly parallel algorithm suitable for any shared memory programming paradigm such as CUDA or P threads. It also makes the adaptation procedure extremely easy to implement. The method is not very efficient for transonic flows as due to the
presence of the discontinuity and using the strong form of the equations. However, that property is inherited from the least squares formulation and is present even in continuous solution. The method is not numerically economical for solving transonic problems due to excessive dissipation, this is a well known characteristic of the least squares finite element methods and is not a result of the solution algorithm presented here. Another important point to mention is that, adaptation is dependent on the design of the detector function and the final adapted mesh is not unique. The unsteady adaptation using this methodology will be subject matter of another study and will be reported by the authors.

REFERENCES

Appendix A: Coefficients from Newton Linearization of Euler Equations

\[ L_0(0,0) = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \]
\[ L_0(0,1) = \frac{\partial p}{\partial x} \]
\[ L_0(0,2) = \frac{\partial p}{\partial y} \]
\[ L_0(0,3) = 0.0 \]
\[ L_0(1,0) = 2 \frac{\partial u}{\partial x} u + \frac{\partial v}{\partial y} u + \frac{\partial u}{\partial x} v \]
\[ L_0(1,1) = 2 \frac{\partial u}{\partial x} \rho + \frac{\partial v}{\partial y} \rho + 2 \frac{\partial p}{\partial x} u + \frac{\partial p}{\partial y} v \]
\[ L_0(1,2) = \frac{\partial v}{\partial y} \rho + \frac{\partial p}{\partial x} u \]
\[ L_0(1,3) = 0.0 \]
\[ L_0(2,0) = 2 \frac{\partial v}{\partial y} v + \frac{\partial u}{\partial x} v + \frac{\partial v}{\partial x} u \]
\[ L_0(2,1) = \frac{\partial v}{\partial y} \rho + \frac{\partial p}{\partial x} v \]
\[ L_0(2,2) = 2 \frac{\partial v}{\partial y} \rho + \frac{\partial u}{\partial x} \rho + 2 \frac{\partial p}{\partial y} v + \frac{\partial p}{\partial x} u \]
\[ L_0(2,3) = 0.0 \]
\[ L_0(3,0) = \frac{1}{2} (3u^2 + v^2) \frac{\partial u}{\partial x} + \frac{1}{2} \frac{\partial v}{\partial y} (u^2 + 3v^2) + uv(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}) \]
\[ L_0(3,1) = \frac{\partial p}{\partial x} (3u^2 + v^2) + \rho \frac{\partial v}{\partial y} u + \frac{\partial u}{\partial y} v + \rho (3 \frac{\partial u}{\partial x} u + \frac{\partial v}{\partial x} v) + \gamma \frac{\partial p}{\partial x} \frac{\partial p}{\partial x} u + \frac{\partial p}{\partial y} v \]
\[ L_0(3,2) = \frac{\partial p}{\partial y} (u^2 + 3v^2) + \rho \frac{\partial u}{\partial y} u + \frac{\partial v}{\partial y} v + \rho (3 \frac{\partial v}{\partial x} v + \frac{\partial u}{\partial x} u) + \gamma \frac{\partial p}{\partial y} \frac{\partial p}{\partial x} u + \frac{\partial p}{\partial x} v \]
\[ L_0(3,3) = \gamma \frac{\partial p}{\partial x} \]
PROJECT OVERVIEW

<table>
<thead>
<tr>
<th>Lead PI</th>
<th>List personnel as you would like for them to appear in a formal report – e.g., Dr. John Smith / John Smith, PhD, etc. Nesli Alp, Ph.D., PE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-PI(s)</td>
<td>Endong Wang, Ph.D., CPC</td>
</tr>
<tr>
<td>Other Personnel</td>
<td>Identify by type – senior personnel, technicians, graduate students, undergraduate students</td>
</tr>
<tr>
<td>Project Title</td>
<td>Energy Performance of Residential Buildings Using Simple-Normalization Based Two-Stage Data Envelopment Analysis</td>
</tr>
<tr>
<td>Date Submitted</td>
<td>07/01/2015-06/30/2017</td>
</tr>
<tr>
<td>Award Start - End Date</td>
<td>Please provide a non-technical summary of your project that addresses the major objectives, accomplishments, and outcomes of your project. Discuss impacts of the project in terms of scholarly contributions to the field, scholarly outputs, student and community impacts, etc. Address how your project advanced or supported the mission of the SimCenter.</td>
</tr>
<tr>
<td>Non-Technical Summary – 500 words or less</td>
<td>Residential energy performance assessment, i.e. how efficiently a house is consuming energy compared to its peers, plays an essential role in judging whether the house structure needs to be retrofitted. Many aspects regarding design, materials, climate and occupancy can influence the performance of a house. Thus, the identification of key components that result in energy waste is of critical importance to ensure an effective retrofitting investment without wasting money. However, existing performance evaluation tools on the market often fail to provide the desired information to make valid decisions for effective investments in retrofitting projects. One major challenge associated with current models is that they cannot differentiate the energy effects of various energy factors. Our project proposed a new method based on data envelopment analysis (DEA) to reliably isolate the impacts of energy factors by classifying them into climate factors, management factors and scaling factors. We applied the developed model to a case region in Iowa. The results showed that the model can be useful in accurately providing in-depth information to decision-makers for building retrofitting. The developed method can be used by owners, property managers, policy makers to draw more reliable decisions in building energy efficiency area. The proposed project expands the research coverage of SimCenter to residential energy efficiency.</td>
</tr>
</tbody>
</table>
Identifying detailed meta-factors of building energy performance is of importance for creating effective residential building energy-retrofitting strategies. Compared to other benchmarking methods, nonparametric generalized energy performance indices, nonparametric DEA (data envelopment analysis) is capable of discriminating scale factors from management factors to generate more detailed indicators to better guide retrofitting practices. An improved two-stage DEA energy benchmarking method includes first-stage meta DEA which integrates the common degree day metrics for neutralizing noise energy effects of exogenous climatic variables and censored Tobit regression for advanced efficiency analyses.

A simple-normalization of degree-day based two-stage DEA approach is developed for benchmarking building energy performance to assist in achieving informed decisions for effective residential retrofitting.

<table>
<thead>
<tr>
<th>List of Objectives / Aims / Major Milestones Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed Cumulative Outcomes / Accomplishments</td>
</tr>
</tbody>
</table>
Challenges & Strategies Used to Address / Overcome:

Discuss any changes or differences from your original proposal for achieving the objectives and milestones approved in your proposal.

Building energy data are rare. No physical lab space or equipment to do onsite experiments.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

More fundamental research may need to be done to understand residential energy performance.

What didn't work? What did you disprove or learn from the parts that didn't meet your initial concept at the proposal?

IMPACT & OUTCOMES

Impact on the career(s) of the PI, the co-PIs, and key collaborators

This project helped the PI and Co-PI to strengthen their research in this area by participating in academic seminars.

Students Impacted

Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

Emil Jada – MS Engineering Management

Mawazo Fortunas – MS Engineering Management

IMPACT & OUTCOMES

Students Impacted

Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

Emil Jada – MS Engineering Management

Mawazo Fortunas – MS Engineering Management

More fundamental research may need to be done to understand residential energy performance.

IMPACT & OUTCOMES

Students Impacted

Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

Emil Jada – MS Engineering Management

Mawazo Fortunas – MS Engineering Management

More fundamental research may need to be done to understand residential energy performance.

IMPACT & OUTCOMES

Students Impacted

Please list students including name, brief description of how they were impacted, what degree sought or when graduated, and any other relevant details.

Emil Jada – MS Engineering Management

Mawazo Fortunas – MS Engineering Management

More fundamental research may need to be done to understand residential energy performance.
Consider and discuss the technical and potential societal impacts of your research project. The results of this project have already drawn attention from academia with discussions and citations. The results will definitely benefit industry professionals for their retrofitting activities when adopted.

Science and Math teachers from Hamilton County and other neighboring counties attended the hands-on energy workshops at UTC in June 2017.

We are currently helping an underrepresented community by fixing and renovating their houses in a small scale.

THEC ITQ Workshop for High School Science and Math Teachers in Tennessee – June 19-23, 2017
Proposal Submissions

Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.

Exton:

1. NSF ITEST PROPOSAL
   - Integrated Efficient Environmental Sustainability Modeling of Built Environments
   - Requested budget: $20,000
   - Submitted: October 2016
   - Funded

2. Alfred P. Sloan Foundation
   - Building Energy Efficiency Analysis
   - Requested budget: $73,911
   - Submitted: September 2016
   - Not funded

3. CRISP
   - 3D Printing Technology for Sustainable Construction
   - Requested budget: $40,000
   - Submitted: November 2016
   - Funded

4. ORAU travel grant
5. TDOT research ideas

Nesli:

1. NSF ITEST PROPOSAL
   - Exploring Clean Energy through hands-on learning (EXCEL)
   - Requested budget: $1,170,501
   - Submitted: August 2016
   - PI: Nesli Alp
   - Co-PI: Endong Wang
   - Not funded

2. THEC Improving Teachers Quality (ITQ) PROPOSAL
   - Exploring Clean Energy through hands-on learning (EXCEL)
   - Requested budget: $73,911
   - Submitted: September 2016
   - PI: Nesli Alp
   - Funded

3. Tennessee Board of Architecture and Engineering Examiners (TBAE) Special Grant
   - Submitted: October 2016
   - Requested budget: $20,000
   - PI: Nesli Alp
   - Funded

4. NSF ITEST PROPOSAL
   - Exploring Clean Energy through hands-on learning (EXCEL)
   - Requested budget: $1,170,501
   - Submitted: August 2016
   - PI: Nesli Alp
   - Funded

5. NSF-China—Open-Block Oriented Designing Methods and Strategy

6. NSF-China—Open-Block Oriented Designing Methods and Strategy

Please list all sponsored program proposals submitted during the reporting period related to this or previous CEACSE awards.
5. NSF Advanced Technological Education (ATE) PROPOSAL - Developing an Industry-Responsive Mechatronics AAS to BAS Pipeline for Engineering Technicians

Requested Budget: $586,997
PI: Nesli Alp
Waiting for the result

2. Tennessee Board of Architecture and Engineering Examiners (TBAEE) Special Grant

Requested Budget: $20,000
PI: Nesli Alp
Funded
Submitted: October 2016

Activities Attended:
- NIH Workshop (on campus)
- Thermal Sensing Workshop (Georgia)
- THEC Improving Teachers Quality (ITQ) EXCEL Program: Exploring Energy through hands-on learning
- Additive Manufacturing Workshop (Knoxville, TN)

Activities Endong Attended:
- 1. NIH Workshop (on campus)
- 2. Thermal Sensing Workshop (Georgia)
WHAT'S NEXT FOR THIS RESEARCH?

What other related research will you pursue (and with whom) in light of the support you've received from CEACSE?

Tell us anything else we should know about this work not described above.

What barriers (if any) do you face to reach these next goals?

We will continue to work on this research area and collaborate with other faculty.

How will you follow up your CEACSE grant with work in the next 1, 2, ... 5 years?
## FINANCIAL ACCOUNTING

<table>
<thead>
<tr>
<th>Financial Report:</th>
<th>Total Award Amount:</th>
<th>$91,000.00</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cumulative Expenditures:</td>
<td>$81,104.54</td>
</tr>
<tr>
<td></td>
<td>Remaining Award Amount:</td>
<td>$2,895.46</td>
</tr>
</tbody>
</table>

Please attach the following:

- Final ledger report showing the final accounting for your award.
- Line item budget spreadsheet comparing your original, approved budget to how funds were actually expended.
- Updated budget narrative describing how funds were expended and how expense contributed to the achievement of project goals, objectives, and milestones.

## Supplemental Award Request

Have you or do you anticipate applying for a supplemental award for any portion of the remaining balance? If so, please include the amount requested (or planned). $