Global Supply Chain of Medical Equipment: Vulnerability Assessment, Emergency Response Tool, and Financial Impact Analysis

1. Specific Aim

This proposal will enable the researchers to establish foundations for collaborative work and plan to apply for future funding opportunities within the 2020 calendar year. The aim of this collaborative project is three-fold: 1. Assess the vulnerability across the global supply chain of medical equipment, 2. Develop an emergency response tool, and 3. Measure the impact of change in global supply chains on firms' financial performance.

1.1 Vulnerability Assessment. While researchers had warned that issues such as "90 percent of the latex for sterile gloves [being] produced in Malaysia" or "a significant portion of surgical hand instruments [being] manufactured in Pakistan" are concerning (MRB, 2016, as cited in NASEM, 2018 p. 10), however it was the COVID-19 that exposed the vulnerability of the global supply chains to policy-makers and the general public. Through this research we develop a network model of the global supply chain of medical equipment using a ten-tier[1] supply chain network; comprising five tiers forward and five tiers backward. The Innovation & Entrepreneurship Business Ecosystem Lab (IBIE Lab) housed in North Carolina Central University's School of Business has developed unique data mining capabilities to develop such supply chain networks at the country-level, industry-level, and firm-level. Furthermore, we are capable of locating supply chain network participants by state/province, city, and zip/postal code. Using multidisciplinary network-based modeling we will develop tools to measure supply chain vulnerabilities and fragmentations. In our pilot, we will provide the top countries and firms that can impose the highest interruption to the US global supply chain of medical equipment.

1.2 Emergency Response Tool. On March 27, 2020, the United States' president "ordered General Motors Co. to … ramp up the production of ventilators"[2]. This was more than two months after the first case of COVID-19 was diagnosed in the United States (state of Washington).

Since time is of the essence in fighting pandemics, policymakers need to have access to tools that can instantaneously provide alternative supply chain paths in case of a disruption using multiple network layers. We will develop a rapid response supply chain interruption tool that is capable of identifying alternative supply chain paths in case of disruption in a region, a country, state/province, city, or a collection of firms. In this report, a network visualization of our feasibility study is presented where our algorithm was shown to be capable of correctly identifying auto manufacturing firms, as the only alternative to supply medical equipment when supply chains are ruptured in China (Figure 1). We propose to develop a pilot interface where the users can select certain firms or countries to be removed the global supply chain and our tool can dynamically present alternatives using networking algorithms (c.f. Figure 1).

1.3 Financial Impact. The third aim of this research is to explore the financial consequences of the change in the structure of the global supply chain network; a change that incorporates the elimination of a cluster of firms from the global supply chain networks. This work is focused on the "medical equipment" as a critical industry in response to COVID-19 and as the most likely industry to be subject to upcoming global protectionism policies. In our pilot study, we measure how firms are financially affected as a result of their position across several tiers of intertwined global supply chain pre- and post-elimination of a country from the global supply chain. Our pilot will include scenarios where several countries individually, or a collection of countries are ruptured from the global supply chain of medical equipment industry.

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[1] Tier-1 supplier, supplies to the firm. Tier-2 is suppler of supplier and so on. Same tier system is used for customers.
[2] Wall Street Journal, Trump Orders General Motors to Make Ventilators, March 27, 2020.

2. Research Strategy
2.1 Motivation for Research
The supply chain and logistics associated with emergency response and pandemics have been a subject of several studies over the past few decades. In geographically limited emergencies "logistics issues" especially as it relates to low-tech equipment such as Protective Personal Equipment (PPE) are "straight forward" as they can be "purchased inexpensively" and the main issue is the availability of "multiple size and type" of PPE (Willis, 2006, pp: 64). However, in the case of widespread natural disaster relief operations (such as COVID-19), including "catastrophic epidemic outbreak[s]" there exist explicit consensus in the literature that geographically expansive supply chain interruptions should be expected as a result of "disruption in the distribution and transportation" (Syahrir, Suparno and Vananyl, 2015) as well as manufacturing limits. Kumar and Havey (2013), Dasaklis, Pappis, and Rachaniotis (2012) and Peng, Peng, and Chen (2014) have made important contributions in this area. Syahrir et al. (2015) in their review of literature on health care and disaster supply chain have highlighted that most research in this area is focused on exploring supply chain in "normal operating conditions", however, there is a gap in the literature on studying supply chains in "abnormal" situation, or what Ivanov (2020) refers to as "special" situations when he calls for research related to COVID-19. These abnormal or special cases –such as COVID-19– not only cause global supply chain disruptions but also cause suspension in manufacturing (Retaildive, 2020, as cited in Ivanov, 2020) Syahrir et al. (2015) in their work on the "healthcare supply chain" describe that supply chains in the healthcare sector have certain complexities as they require timely procurement of various "medical needs such as medical equipment, medicines, anti-virus, vaccine, etc." One of the characteristics of the medical equipment and medicine is that for certain raw materials, parts, and equipment across the tiers of supply chain few countries have an elevated, out-sized, role in maintaining the continuous functioning of the global supply chain. For example, "90 percent of the latex for sterile gloves is produced in Malaysia" and "a significant portion of surgical hand instruments are manufactured in Pakistan." (MRB, 2016, as cited in NASEM, 2018 p. 10). In a business environment with high dependencies across borders the current intertwined global supply chain network is ripe to cause "serious repercussions worldwide" stemming "from any of the destabilizing factors known as the "four P's: powerful weather, pandemic, port closures, and political instability" (NASEM, 2018, p. 10). The 2018 NASEM report on the global medical supply chain further explains the focus on operational efficiency programs such as implementing just in time inventory management. This report highlights that there is a gap in action. The COVID-19 exposed a special risk of global supply chains; a risk with high magnitude, short-term as well as long-term consequences (Ivanov, 2020).

These developments motivated us to create a team of researchers from North Carolina Central University, UNC-Chapel Hill and Arizona State University to explore three aspects of the global supply chain of medical equipment, namely, vulnerability assessment, emergency response tool, and financial impact analysis. After discussing the current state of the global supply chain of medical equipment and the interruptions imposed by COVID-19 a discussion of our proposed research project is presented along with a sample feasibility study.

2.2 State of Global Supply Chain in the Medical Equipment Industry
The global supply chain and production of medical equipment have experienced significant transformations over the past few decades. Jha (2019) describes four recent trends in the medical equipment domain which can further explain the vulnerability of the industry's supply chain in global pandemics. The first trend is the separation of Original Equipment Manufacturers (OEMs) of the medical devices from sales, inventory management, and distribution of medical equipment. For example in the United States, Group Purchasing Organizations (GPOs) have control and power and control over distribution channels and activities. The second trend is the role of governments, which varies from one country to another. In many countries, governments enforce price caps and product standards in their market. The third trend is reduced brand differentiation as a result of increased

similarity of quality and performance of devices manufactured by different manufacturers in developing countries. For example, a device manufactured in India by MNCs according to Jha (2019) has comparable performance to one manufactured in more complex and technologically advanced facilities. Finally, the use of advanced supply chain management and private equity firms has further standardized and consolidated the industry at the global level.

These very same trends which were celebrated up until 2019 (c.f. Jha, 2019), have now become points of concern and contention for individuals, firms, and governments around the world. A recent survey from National Association of Manufacturers (NAM) conducted in early 2020 (NAM report, 2020) from US manufacturers revealed 35% respondents reported facing supply chain disruptions as early as February/March of 2020, while 53% reported expecting changes in their operations as a result of COVID-19. 78% of respondents reported uncertainty about the financial impact of supply chain disruption on their business; this latter information highlights the magnitude of interruptions on the business environment. While this research is being conducted in the early months of this pandemic, future research can provide a far more comprehensive assessment of the scope and magnitude of the supply chain disruption at the national and global scale.

2.3 COVID-19 and the Global Supply Chain of Medical Equipment

Ivanov (2020) describes three reasons why epidemic outbreaks are special cases of supply chain risk. These reasons are uncertainty about scale and duration of the disruption, ripple effects of disruption among people and supply chain actors, and disruption in operational infrastructure (Ivanov, 2020). Unlike the other pandemics of the past including Ebola, MERS, and SARS, the COVID-19 is more likely to impose long-term, far-reaching, changes to global supply chains as a result of "rising protectionism" and the upcoming "global financial crisis" (Salvatore, 2020). Javaid, Haleem, Vaishya, Bahl, Suman, and Vaishin (2020) their study on the fourth industrial revolution (Industry 4.0) and medical equipment manufacturing, provided evidence that even before the recent pandemic there had been explicit interests and actions toward reshoring manufacturing. The advancements in redistributed manufacturing (Hannibal and Knight, 2018) can further facilitate the localization of manufacturing in a post-COVID-19 political and business environment.
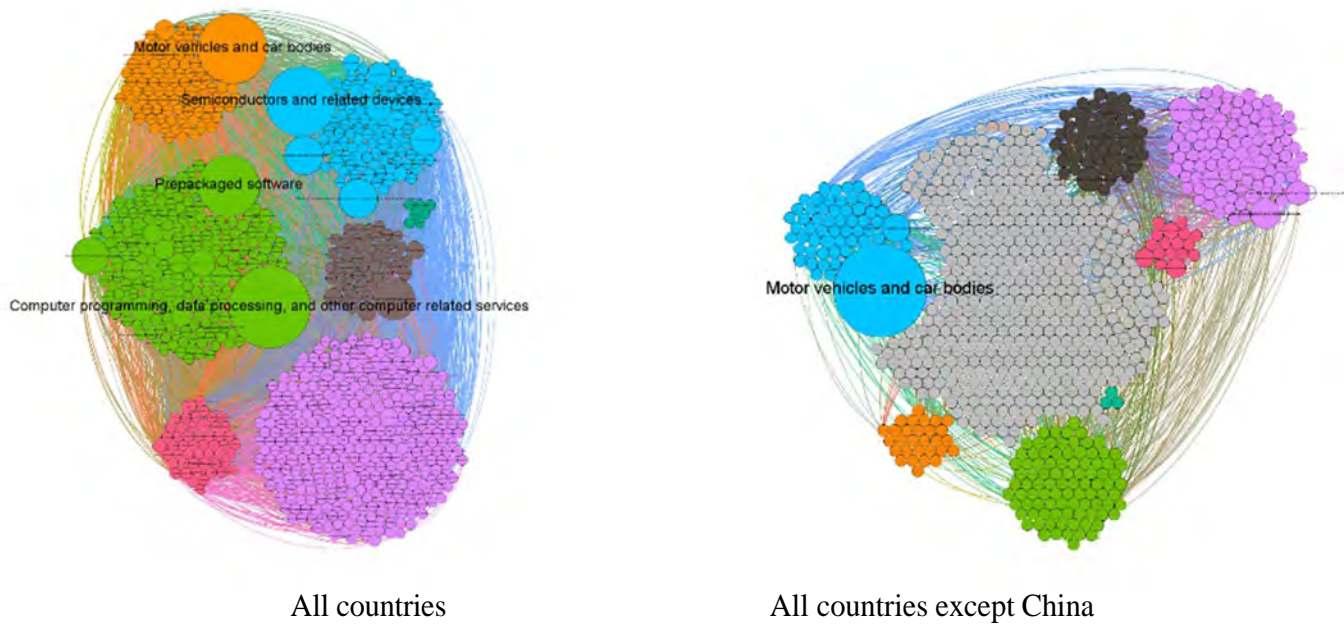
The root of vulnerability in the medical equipment supply chain originated before the 2019 epidemic. In addition to the global nature of supply chains (Ivanov, 2020), Shokrani, Loukaides, Elias, and Lunt (2020) argue that two other factors have contributed to the vulnerability of the global supply chain of medical equipment "due to the global coronavirus (COVID) pandemics". The first factor is that the manufacturing of medical equipment in advanced economies have become more "focused on manufacturing low-volume, high-value, [and] high-margin products" over the past few decades. The second factor contributing to the increased supply chain vulnerability to such interruptions is the dominant supply chain management practices promoting leanness and high-volume efficiency across the global supply chains.

2.4 Data Collection and Analysis

We use S&P Global Market Intelligence (S&P Global) to have access to financial records of the firms. S&P Global provides access to various financial, industrial, geographical and operational data about firms. Additionally, we will use our unique data mining techniques to develop the global supply chain of firms in the medical equipment sector. We will use various network analytics algorithms and econometrics tools to achieve our aims. Figure 1 displays our feasibility study simulation of a major disruption to the global supply chain. This is the network of the global supply chain of medical equipment at the industry-level. The figure on the left displays the global supply chain before an interruption. The figure on the right illustrates the effect of removing all Chinese industries from the network. The result indicates that in response to such disruption only the "motor vehicle and car bodies" sector can revive the supply chain in the short-term. As mentioned previously our simulation

correctly predicted an alternative supply chain path that was mandated in the United States in 2020 to address the need for ventilators.

Figure 1: Medical Equipment Supply Chain Industries: With and Without China[3]

All countries   All countries except China

3. Budget

The main cost associated with this project is access to the database. We access proprietary supply chain and financial data through S&P Global. This database will be made available to all faculty. While S&P Global provides access to large and complex data we still require to perform a significant amount of computation to mine the supply chain network data. Hence, we also require computers (hardware and software) capable of computing large and complex networks along with supplies.

We also allocated a budget for travel to attend conferences and/or workshops; considering the COVID-19 the budget is expected to be used to attend virtual conferences/workshops. As the field of network analytics is a new area we require to hire highly skilled consultants for designing optimization models, and new algorithms. We have support from top-notch researchers in the areas of network science and supply chain at UNC-Chapel Hill and Arizona State University to support us in this endeavor. We have also added budgets for books, a website that displays our pilot projects, and any required cloud services.

$ 22,000	S&P Global
$ 4,000	Supplies, computer hardware/software)
$ 1,000	Workshop/Conference
$ 2,000	Consulting/RA
$ 1,000	Books, website, cloud service
$30,000	Total

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3   The node colors identify clusters in the supply chain network. The node sizes illustrate eigenvector centrality.

References

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NASEM (National Academies of Sciences, Engineering, and Medicine); Health and Medicine Division; Board on Health Sciences Policy. Impact of the Global Medical Supply Chain on SNS Operations and Communications: Proceedings of a Workshop. Washington (DC): National Academies Press (US); 2018 Jul 18. References. Available from: https://www.ncbinlm.nih.gov/books/NBK525656/

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Attachments

Letters of Support

NIH Biosketches

May 31, 2020

Dear Dr. Kumar.

Re: NIH COVID Grant Application, Dr. Kayvan Lavassani

Please accept this letter of recommendation for Dr. Kayvan Lavassani's application for a NIH COVID Grant.

I have been associated with North Carolina Central University for the past two decades. I have also known Dr. Lavassani for the past nine years or so and can therefore vouch for his qualifications. I am the Chair of the Department of Accounting in the School of Business at NCCU School of Business. Dr. Lavassani serves as a full-time faculty member in the Department of Management at NCCU. Dr. Lavassani is the founding editor of the Journal of Business Ecosystems QBE) and director of the Innovation & Entrepreneurship Business Ecosystem Lab (IEBE Lab). As a business faculty member he has published numerous peer-reviewed articles. He has also served as a member of search committee for the tenure-track faculty searches for the Department of Accounting.

I have reviewed both the grant application and a summary of the study on which he and Dr. Boyd of UNC, Chapel Hill are collaborating, and it appears to meet the criteria for the grant, as well as serve the mission of the University.

Thank you for your consideration. I will be happy to amplify these comments, if you so desire.

Best regards,

Raghavan (Raj) J. Iyengar

Professor and Chair

Department of Accounting

May 31, 2020

Dear Professor Lavassani:

I am writing this letter of support to indicate my intention and interest to support your project related to disruption risks and vulnerabilities in global supply chains of medical equipment.

I am an Eminent Scholar at Ira. A. Fulton Schools of Engineering at Arizona State University. I have authored or coauthored over 40 peer-reviewed research articles in the areas of supply chain risk and resilience, operations and supply chain management, and teclmology and i1movation management. I have also published one book and three book chapters.

Fulton Schools of ENGINEERING

School of Sustainable Engineering and the Built Environment

Mahour M. Paras!,Ph.D.
Eminent Scholar

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My current research is at the intersection of supply chain risk and resilience management and i1movation management; this research is supported by several grants from the National Science Foundation (NSF) and VentureWel l. More specifically, I examine how firm innovativeness enhances an organization's resilience and its response to supply chain disruptions. I am a member (by invitation only) of the International Supply Chain Risk Management Network (ISCRiM), which is a network of researchers and practitioners engaged in analyzing, developing, and disseminating best practices associated with managing supply chains and their associated risks.

I have delivered over 20 invited talks at domestic and international universities focusing on supply chain risks and management of the teclmological innovation process. My research and scholarly works have earned me awards from the Academy of Management, the American Society for Quality, and the Decision Sciences Iristitute (DSI), including the DSI 2016 Best Application Paper Award, the 2016 Highly Commended Paper award (International Journal of Quality & Reliability Management), and the 2015 Highly Commended Paper award (Iriternational Journal of Logistics Management).

I believe your proposal on disruption risks and vulnerabilities in global supply chains of medical equipment in very tin1ely and addresses one of the major challenges that we have been facing in the US and across the world during COVID-19 pandemic. A more detailed and nuanced understanding of the global network of medical equipment is deemed necessary. Thus, the fmdings of your proposed study have important theoretical and practical implications that can infonn scholars and practitioners alike, which ultin1ately enhances the robustness and responsiveness of the global supply chain of medial equipment.

Your proposal on disruption risks and vulnerability global supply chain of medical equipment has my keen support.

Sincerely,

Mahouy§lrast, Ph.iy()

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To whom it may concern,

TIIis letter is to confirm my support of the team lead by Kayvan Lavassani for the project "Global Supply Chain of Medical Equipment: Vulnerability Assessment, Emergency Response Tool, and Financial Impact Analysis." Kayvan and I have already worked together on the preliminary results presented in this paper, and I have contributed a number of core ideas for how to understand the supply chain vulnerability in concrete, relevant ways. My intent is to work with him on all three aspects of the grant, providing support in temls of network modeling, tracking supply chain dynamics, and connecting the results to existing ideas about how networks operate. I understand that the period of this award is for six months and plan to assign an appropriate amount of time to this collaboration to ensure that we accomplish the goals of the grant. I will participate as a co-author on the core publications and promote the research tlu·ough speaking engagements. I understand that this grant is intended as a stepping stone for future funding opportunities and intend help Kayvan obtain additional funding at appropriate times and develop the results of this work according to our anticipated success at obtaining that future funding.

This project goes well with my overall research interests and program, which lies at the intersection of applied network modeling and theoretical data science. I have cultivated relationships where I add value to projects in a variety of fields, ranging from neuroscience to explosives design to genealogy. These collaborations indirectly strengthen my theoretical work and allow me to approach particular applications (such as the CUJTent supply chain work) in creative ways that might not occur to domain specialists such as Kayvan. I look forward to working with him on this project.

Best regards,

Zachary M. Boyd
Postdoctoral research associate
Department of Mathematics
University of orth Carolina at Chapel Hill

NSF BIOGRAPHICAL SKETCH

NAME: Lavassani, Kayvan
ORCID: 0000-0003-1662-3299

POSITION TITLE & INSTITUTION: Associate Professor, North Carolina Central University

(a) PROFESSIONAL PREPARATION

INSI'ITUTION	LOCATION	MAJOR / AREA OF SI'UDY	DEGREE (if applicable)	YEAR yyyy
National (Beheshti) University of Iran	Tehran, Tehran	Economics	BS	2001
Carleton University	Ottawa, Ontario	Business	MBA	2003
Carleton University	Ottawa, Ontario	Management and Supply Chain	PHD	2011

(b) APPOINTMENTS

2018 -   Associate Professor, North Carolina Central University, Durham, NC
2011 - 2018   Assistant Professor, North Carolina Central University, Durham, NC
2008 - 2011   Instructor, Carleton University, Ottawa

(c) PRODUCTS

Products Most Closely Related to the Proposed Project

1. Lavassai KM, Movahedi B. Achieving Higher Supply Chain Performance via Business Process Orientation. Business Process Management Journal 2018; 24(3):671-694. Available from: https://www.emerald.com/insight/content/doi/10.1108/BPMJ-07-201   6-0140/full/html

2. Lavassani KM, Movahedi B. Coopetition and Sustainable Competitiveness in Business Ecosystem: A Networks Analysis of the Global Telecommunications Industry. Transnational Corporations Review. 2017; 9(4):281-308. Available from: https://www.tandfonline.com/doi/abs/1 0.1080/19186444.2017.1 401207?journa!Code=rncr20

3. Lavassani K. Applications Driven Information Systems: Beyond Networks toward Business Ecosystems. Internationa!Journal of lnnovation in the Digital Economy. 2017; 8(1):61-75. Available   from: https://www.igi-globalcom/article/applications-driven-information-systems/165404

4. Movahedi B, Lavassani K, Kumar U. Operational Excellence through Business Process Orientation: An Intra- and Inter-Organizational Analysis. The TQM Journal 2016; 28(3):467-495. Available   from: https://www.emerald.com/insight/content/doi/10.1   108/TQM-12-2013-0147/full/html

5. Lavassani K, Movahedi B, Parry G. Broadband Internet Adoption Challenge: An Investigation of Broadband Utili7.ation in the United States. Transforming Government: People, Process and Policy. 2014; 8(4). Available from: https://www.emerald.com/insight/content/doi/10.1108/TG-11-2013-0050/full/html

Other Significant Products, Whether or Not Related to the Proposed Project

(d) SYNERGISTIC ACTIVITIES

1. Founding editor of the Journal of Business Ecosystems (IBE): The IBE promotes and di<iseminates study and understanding of business modeJs at different leve1s of analysis. While the journal encourages submission of rigorous conceptual and qualitative studies, the main orientation of the journal is to attract empirical and quantitative studies using the innovative statistical teclmique to measure and analyze complex systems. The journal follows the holistic view of the ecosystem as described by Ludwig von BertaJanffy (1968) within the General System Theory (GST). The term ecosystem in the title of the journal is presented in the plural form to illustrate the dynamic role of multiple actors and multiple Jayers of networks in the complex and intergraded global business environment.

    htt,ps://www .igi-globalcomljournaVjournal -business-ecosystems

2. Founder and Director of the Innovation & Entrepreneurship Business Ecosystem Lab (IEBE Lab): IEBE Lab conducts research on deveJoping global and regional business ecosystem networks using data mining and big data network analytics. Using our unique data mining and networks analytics teclmiques, IEBE Lab, is capable of constructing complex Single-tier, or Multi-tier networks of people, and firms at the Iocai national and global scale in any industry for: 1- Supply Chain Networks (Single-Tier & Multi-Tier) 2- Strategic Alliance Networks (Single-Tier & Multi-Tier) 3- University-Industry Partnership Networks (Single-Tier & Muhi-Tier), and 4- Board of Directors Membership Networks (Single-Tier & Muhi-Tier)

3. Networks Analytics Research: Dr. Lavassani has previously developed large scale global networks of business ecosystems in the Pharmaceutical industry, Auto manufacturing industry, and Telecormnunications industry. Some of these networks have over 6.5 million connections/edges. Most recently following COVID-19 pandemic and the global supply chain ruptures, Dr. Lavassani ic; leading a team of researchers at NCCU with collaboration with schoJars in UNC-Chapel Hill, and Arizona State University on the multi-tier study of Global supply chain Network risk and security assessment in the Medical Equipment Manufacturing sector (SIC 5047). Dr. Lavassani has published over 50 papers in journa1s and proceedings.

BIOGRAPHICAL SKETCH
Provide the following information for the Senior/key personnel and other signi.fi.C2llt contributors.
Follow this format for each perscm. DO NOT EXCEED FIVE PAGES.

NAME: Raghavan (Raj) J Iyengar

eRA COMMONS USER NAME (credential, e.g., agency login): Raghavan_Iyengar

POSITION 1TILE: Professor and Chair, Department of Accounting

EDUCATION/TRAINING *(Begin with baccalazmate or other initial professional education, such as nursing, include postdoctoral training and residenry training if applicable. Add/ delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicabk)*	Completion Date MM/YYYY	FIELD OF STUDY
University of Bombay, India	M.Com	05/1980	Cost Accounting
Saint Mary's University, Canada	MBA	05/1986	Finance
University of :Maryland, College Park, MD	PhD	12/1995	Accounting

A. Personal Statement

Over the past twenty five years, I have formulated, investigated, analyzed, critiqued, and reviewed many empirical projects. Experience gained on many of these projects would stand me in good stead to successfully execute the proposed research project. I have a broad background in statistics, multivariate data analysis and econometrics using diverse statistical packages. My research primarily investigates the economic effects of managerial decision making. I have also served as a team member for the 2009 Business and International Education award (P153A090054) for $177,240 from the US Department of Education.

My work has been published in top-tier accounting, finance and management journals. I have documented the pay-performance sensitivity in all-equity firms; the effect of CEO duality in firm performance; the moderating role of board independence in duality-performance relationship. I have also reviewed and critiqued many manuscripts in the area of accounting and management The following publications give a brief glimpse of my published research studies:

1. "The Dynamic Relationship Between CEO Duality and Firm Performance: The Moderating Role of Board Independence" *Journal '!(Business Research,* 2016, 69(10), 4269-4277. With A. Duru and E. Zampelli. http://www.sciencedirect.com/science/article/pii/S01 48296316300698
2. "Performance Choice, Executive Bonuses and Corporate Leverage" *Journal ef Corporate Finance.* 2012, 18, 1286-1305. With A. Duru and E. Zampelli.
3. "Self-Selection, Endogeneity, and the Relationship between CEO Duality and Firm Performance." *Strategic Management Journal.* 2009, *30(10),* 1092-1112. With E. Zampelli http://onlinelibrary.wiley.com/doi/1 0.1002/smj.776/abstract
4. "Auditor Independence, Executive Pay, and Firm Performance." *Accounting and Finance,* 2008, *48(2),* 259-278. With E. Zampelli.

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5. "The Shielding of CEO Compensation from the Effects of Strategic Expenditures." *Contenpomry AccoHnting & sermh,* 2002, *19(2),* 175-193. With A. Duru, and A. Thevaranjan.
http: / /onlinelib.racy.wile.y.com/doi/10.1 506/UM8O-NYJ6-IKGT-GH5W/abstract

6. "Return on Investment and Corporate Capital Expenditures: Empirical Evidence." *JoHrnal of AccoHnting and Public Po/iry,* 1996, *15(4),* 305-325. With L.A. Gordon.

B. Positions and Honors

Positions and Employment

Chair, Department of Accounting, North Carolina Central University, USA. (01/2015-Present).
Lead Professor of Accounting, North Carolina Central University, USA. (08/2012-12/2014).
Professor of Accounting (Tenured), North Carolina Central University, USA. (07/2008-Present).
Associate Professor (Tenured), North Carolina Central University, USA. (08/2001-06/2008)
Associate Professor (Tenured), Catholic University of America, USA. (08/2000-07/2001)
Assistant Professor, Catholic University of America, USA. (08/1994-07/2000)
Lecturer, Victoria University of Wellington, New Zealand. (07/1987-08/1988)
Sessional Lecturer, Memorial University of Newfoundland, Canada. (01/1986 - 05/1987)

Honors

- Fulbright Specialists Roster (FSR) Candidate, Council for International Exchange of Scholars. (06/15/2010).
- Dean's Awa.rd for Excellence in Research, North Carolina Central University. (2004).
- Best Research Paper Award, *AccoHnting &searchJournal* (2001).
- University Fellowship and Achievement Scholarship, Saint Mary's University, Canada. (1985).
- All-India Merit Rank Holder, The Institute of Chartered Accountants of India. (01/1979).
- College First, Bachelor of Law (General), Jitendra Chauhan College of Law, University of Bombay, 1979.
- All-India Merit Rank Holder, The Institute of Cost and Works Accountants of India. (1978).
- National Merit Scholar, Government of India. (1977).

C. Contributions to Science

"The Dynamic &lationship Between CEO D11t1li'J and Firm Performance: The Moderating Role of Board Independence "

The above research was motivated by the fact that all prior studies examined duality from the lens of static analysis. In this paper, we examined the dynamic relation between proxies of corporate governance and firm perfonnance. We employed system Generalized Method of Moments (GMM) to estimate a dynamic model of the relationship between CEO duality and operating firm perfonnance. We also examine the performance effect of the interaction between duality and board independence in a dynamic framework. Our findings were consistent with arguments advanced by both agency theorists and some management scholars that though duality might reduce firm perfonnance through managerial entrenchment, it can provide benefits to the firm in the presence of board vigilance.

'Performance Choice, Exee11tive Bo1Z11ses and Corporate Leverage"

Theory suggests that both executive stock options and bonus compensation affect managerial incentives to manage firm risk. In this study we extended prior research by investigating the causal relation between the structure of CEO bonus compensation and leverage decisions. Specifically, we explored two hypotheses regarding the relation between accounting-based perfottnance choice in bonus plans and leverage decisions, one from the perspective of efficient contracting, the other from the perspective of managerial opportunism. Using empirical methods consistent with theoretical literature that suggests the two decisions are jointly determined we found that a hlghly levered firm is more likely to choose a return on asset (ROA) based perfonnance measure upon which to base managerial bonuses. The results do not support the hypothesis that managers whose bonus compensation is based on return on equity (ROE) type performance measures increase leverage in order to increase ROE and, in turn, the size of their bonuses. Overall, our findings provide empirical support for the efficient contracting argument that the use of accounting information in executive incentive contracts is motivated by the objective of reducing the agency costs of debt.

'The Shie/dirg of CEO Compensation from the Effects of Strategic Expendit11res •"

This study investigated whether and why compensation committees shield CEO compensation from income-decreasing effects of strategic expenditures. We documented that firms do shield recurring strategic expenditures such as research and development and advertising expenditures. We also found that firms shield research and development expenditures more than advertising expenditures. Our results were consistent with prior findings that suggest that compensation committees shield CEOs from nonroutine transactions such as restructuring charges and extraordinary losses. Using a two-task principal-agent framework, we showed that such shielding improves the efficiency of the contract by making the shielded income measure more congruent with the principal's objectives.

D. **Additional Information: Research Support and/or Scholastic Performance**

RESEARCH ACTIVITIES/FELLOWSHIPS/GRANTS / CONTRACTS

Grant

Team member for the 2009 Business and International Education (BIE) Award (Award # P153A090054) from the United States Department of Education. I coordinated the following activities: a) research agenda in business outsourcing b) developed a knowledge base in global outsourcing management c) developed research papers about US outsourcing to India and present research results at professional conferences d) established student selection process for study abroad
e) organized and implemented the student selection process and f) confirmed and organized student internship details with Indian companies.

BIOGRAPHICAL SKETCH
Provide the following information for the Senior/key personnel and other significant contributors.
Follow this fonnat for each person. DO NOT EXCEED FIVE PAGES.

NAME: Mahour M. Parast

eRA COMMONS USER NAME (credential, e.g., agency login): MAHOUR_MELLAT_PARAST

POSITION TITLE: Eminent Scholar

EDUCATION!TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
Sharif University of Technology, Tehran, IR	BS	03/1996	Industrial and Systems Engineering
University of Science and Technology, Tehran, IR	MS	03/1999	Industrial Engineering
University of Nebraska-Lincoln, Lincoln, NE	PhD	05/2018	Industrial and Management Systems Engineering

A. Personal Statement

My industry experience and academic preparation in strategic management along with my extensive training in business analytics, statistics, and data science enables me to bring new perspectives to interdisciplinary research at the boundary of operations and supply chain management, innovation, and strategic management. My industry experience and engagement with both multinational corporations and start-ups has played an instrumental role helping me successfully integrate teaching with my research. For instance, my research in understanding the impact of service failures on profitability with respect to a firm's business strategy using a hybrid methodological approach using machine learning and statistical methods received the Best Application Paper award from the 2016 Decision Sciences Institute (DSI) annual meeting.

1. 1. Paras!, M. M. (2020) The impact of R&D investment in mitigating supply chain disruptions: empirical evidence form the US supply chains, International Journal of Production Economics (in press)
2. 2. Azadegan, A., Paras!, M. M., Lucianetti, L., Nishant, R., and Blackhurst, J. (2020) Supply chain disruptions and business continuity: an empirical assessment, Decision Sciences (in press)
3. 3. Esmizadeh, Y. and Paras!, M. (2020) Logistics and supply chain network designs: incorporating competitive priorities and disruption risk management perspectives (in press)
4. 4. Sabahi, S. and Paras!, M. M. (2019) Firm innovation and firm resilience to supply chain disruptions: A dynamic capability perspective, International Journal of Logistics Research and Applications (in press)
5. 5. Shekarian, M., Nooraie, S. V. R., and Parast, M. M. (2019) An examination of the impact of flexibility and agility on mitigation supply chain disruptions, International Journal of Production Economics (in press)

B. Positions and Honors

Positions and Employment

2001-2004   Research Assistant, University of Nebraska-Lincoln, ME
2004-2005   Instructor, South Dakota School of Mines, Rapid City, SD
2006-2007   Instructor, Argosy University, Washington, DC
2006-2007   Faculty member, University of South Dakota, Vermillion, SD
2006-2007   Lab Manager, RFID and Logistics Lab, University of Nebraska-Lincoln, NE

2007-2011	Faculty member, University of North Carolina at Pembroke, Pembroke, NC
2012-19	Faculty member, College of Science and Technology, North Carolina A&T State University, Greensboro, NC
2011-2020	Research Affiliate, Massachusetts Institute of Technology, Cambridge, MA
2018-Present	Eminent Scholar, Ira A Fulton Schools of Engineering, Arizona State University, Tempe, AZ

Honors

2017	Outstanding Young Investigator, NC A&T State University
2016	Best Application Paper, Decision Sciences Institute (DSI)
2016	Highly Commendable Paper, International Journal of Quality and Reliability Management
2015	Highly Commendable Paper, International Journal of Logistics Management
2011	Best paper award, American Society for Engineering Education (ASEE)
2006	Honorary Member of Phi Beta Delta (International Scholars Honor Society)
2006	Best Student Paper Award Academy of Management -OM Division
2006	Student Paper Award, American Society for Quality
2006	Student Paper Award, Midwest Decision Sciences Institute
2005	Outstanding International Student, Phi Beta Delta
2005	Doctoral Dissertation Travel Award, University of Nebraska-Lincoln
2005	Student Paper Award, American Society for Quality
2004	Student Paper Award, American Society for Quality

C. Contributions to Science

1. My dissertation work presents an empirical analysis of quality management practices in the petroleum industry. The research examines how different practices associated with quality management improve organizational quality results. The research also examines the effect of corporate social responsibility in improving organizational quality results.
   a. Parast, M. M. (2014) Linking quality citizenship to process design: A quality management perspective, International Journal of Production Research, 52 (18), 5484-5501.
   b. Paras!, M. M. (2013) Quality citizenship, employee involvement and operational performance: An empirical investigation, International Journal of Production Research, 51 (10), 2805-2820.
   c. Paras!, M. M. (2013) Convergence theory in management of quality: evidence from the petroleum industry, International Journal of Quality & Reliability Management, 30 (2), 177-196.
   d. Parast, M. M. and Adams, S. G. (2012) Corporate social responsibility, benchmarking and organizational performance in the petroleum industry: A quality management perspective, International Journal of Production Economics, 139 (2), 447-458.
   e. Paras!, M. M., Adams, S. G., and Jones, E. C. (2011) Improving operational and business performance in the petroleum industry through quality management, International Journal of Quality and Reliability Management, 28 (4), 426-450.
   f. Paras!, M. M., Adams, S.G., and Jones, E.G. (2007) An empirical study of quality management practices in the petroleum industry, Production Planning and Control, 18 (8), 693-702.

2. I have been working on disruption risks and resilience management practices. This stream of the research has resulted in identifying organizational capabilities that mitigate the effect of supply chain disruptions on organizational performance and improve organizational resiliency.
   a. Paras!, M. M. and Golmohammadi, D. (2020) The impact of firm size and business strategy on mitigating service disruptions: evidence from the US domestic airline industry, IEEE Transactions on Engineering Management (Accepted for publication)
   b. Azadegan, A Parast, M. M., Lucianetti, L., Nishant, R., and Blackhurst, J. (2020) Supply chain disruptions and business continuity: an empirical assessment, Decision Sciences, 51(1), 38-73.
   c. Shekarian, M. and Paras!, M. M. (2020) An integrative approach to supply chain disruption risk and resilience management: A literature review, International Journal of Logistics Research and Applications (Accepted for publication)
   d. Esmizadeh, Y. and Parast, M. M. Logistics and supply chain network designs: incorporating competitive priorities and disruption risk management perspectives, International Journal of Logistics (Accepted for publication)

e. Paras!, M. M. (2020) The impact of R&D investment in mitigating supply chain disruptions: empirical evidence form the US supply chains, International Journal of Production Economics (in press)

f. Sabahi, S. and Paras$M. M. (2020) The impact of entrepreneurship orientation on project performance: A machine learning approach, International Journal of Production Economics (in press)

g. Nooraie, S. V. R., Fathi, M., Narenji, M., Paras$M. M., Pardalos, P. M., and Stanfield, P. (2020) A multi-objective model for risk mitigating in supply chain design, International Journal of Production Research (in press)

h. Sabahi, S. and Paras$M. M. (201g) Firm innovation and firm resilience to supply chain disruptions: A dynamic capability perspective, International Journal of Logistics (in press)

i. Shekarian, M., Nooraie, S. V. R., and Paras$M. M. (201g) An examination of the impact of flexibility and agility on mitigation supply chain disruptions, International Journal of Production Economics (in press)

j. 14. Kamalahmadi, M. and Paras!, M. M. (2016) A review of the literature on the principles of enterprise and supply chain resilience: major findings and directions for future research, International Journal of Production Economics, 171 (1), 116-133

3. I have conducted research in scholarship of teaching and learning. As part of my participation in several research projects, I examined the effect of teaching and learning practices on enhancing students' learning outcomes.

a. Fini, E. H., Awadallah, F., Paras$M. M., and Abu-Lebdeh, T. (2018) The impact of project-based learning on improving student learning outcomes of sustainability concepts in transportation engineering courses, European Journal of Engineering Education, 43 (3), 473-488.

b. Fini, E. H. and Paras$M. M. (2018) Use of a case study to improve learning outcomes of construction engineering students, International Journal of Engineering Education, 34(2A), 537-544.

c. Fini, E. and Parast, M. M. (2012) Empirical analysis of effect of project- based learning (PBL) on improving student learning in transportation engineering, Journal of Transportation Research Record, 12, 167-172.

d. Paras!, M. M. (2010) Effectiveness of case study in enhancing students' learning in operations management, Operations and Supply chain Management: An International Journal, 3(1), 4g_55_

D. Additional Information: Research Support and/or Scholastic Performance

Invited Talks/Seminars

Institution	Title	Date
1. Shanghai Jia Tong University	Technological innovation in infrastructure	7/19
2. Jinan University	Managing risk in technological innovation in infrastructure	7/19
3. Harbin Institute of Technology	Managing technological innovation process	6/19
4. University of Bath	Managing technological innovation process	5/19
5. Washington State University	Managing risks in technological innovation	4/19
6. University of Hawaii	Managing risks in technological innovation	4/19
7. Qatar University	Supply chain risk and resilience management	3/19
8. University of Minnesota	Managing risks in technological innovation	2/19
9. Hong Kong Polytechnic University	Managing risks in technological innovation	12/18
10. National Cheng Kung University	Managing risks in technological innovation	12/18
11. Chang'an University	Supply chain risk and resilience management	12/18
12. Columbia University	Managing risks in technological innovation	10/18
13. California State University	Managing risks in technological innovation	10/18
14. EMPA (Switzerland)	Managing risks in technological innovation	6/18
15. University of Rhode Island	Managing risks in technological innovation	4/18
16. Worcester Polytechnic Institute	Managing risks in technological innovation	3/18
17. University of Illinois	Managing risks in technological innovation	2/18
18. Adhesive and Sealant Council	Supply chain risks in chemical industry	4/16
19. International Management Conference	The future of quality management	12/14
20. The Adhesive and Sealant Council	Bio-adhesive technology commercialization	10/14
21. International Management Conference	Best practices in quality management	12/11
22. Shahid Beheshti University	Supply chain management in pharmaceutical industry	12/11
23. Clark Atlanta University	How to develop and write a research paper	4/11
24. University of Nebraska	How to develop and write a research paper	7/10

PROFESSIONAL DEVELOPMENT AND CONTIUED EDUCATION

Topic	Institution	Date
1. Supervised Machine Learning	SAS	2019
2. Applied Bayesian Statistics	Statistical Horizon	2018
3. Longitudinal SEM using STATA	Statistical Horizon	2018
4. Big Data Analysis in Behavioral Sciences	American Psychological Association	2017
5. Latent Growth Curve Modeling	Statistical Horizon	2016
6. Longitudinal Data Analysis in SAS	Statistical Horizon	2015
7. Meta-Analysis	Statistical Horizon	2015
8. Longitudinal Data Analysis with SEM	American Psychological Association	2015
9. Intermediate and advanced SEM	Wayne State University	2014
10. Multilevel analysis	Statistical Horizon	2014
11. Crisis Management and Business Continuity	MIT	2013
11. Mediation and Moderation	Statistical Horizon	2012
12. Social Network Analysis	Statistical Horizon	2012
13. Innovation I-Corps	National Science Foundation	2012
13. Intermediate and Advanced SEM	Virginia Commonwealth University	2009
14. Intermediate and Advanced SEM	University of Kansas	2008

Service to Discipline

Editorial Review Board   Journal of Business Ecosystems, 2018-present

Ad Hoc Reviews   Decision Sciences Journal
International Journal of Production Economics
International Journal of Production Research
International Journal of Project Management
International Journal of Logistics Management
Supply Chain Management: An International Journal
International Journal of Quality and Reliability Management
European Journal of Operational Research
Production Planning & Control
IEEE Transactions on Engineering Management

Book Reviews   Foundations of Data Analysis (2017), Cognella.
Business Statistics (2011) Donnelly, Pearson.
Applied Statistics for Business & Economics, (2010) Doane, D.P. and Seward, LE. (3rd Edition), McGraw-Hill.
Business Statistics, A Decision-Making Approach, 7th Edition, (2008) David Groebner, Patrick Shannon, Philip Fry and Kent Smith, Prentice-Hall.
Statistics for Engineers and Scientists, (2006) William Navidi, 1st Edition, McGraw-Hill.

Applied Probability and Statistics (2005) William W. Hines, Douglas C. Montgomery, Connie M. Borror, David M. Goldsman, 4th Edition, John Wiley and Sons.

Chairpersonship   Co-Chair, Sustainable Bio-Adhesive from Bio-Mass Symposium, January 29-30, North Carolina A&T State University, Greensboro, NC (2018)
Co-Chair, Sustainable Bio-Adhesive from Bio-Mass Symposium, January 26-28, North Carolina A&T State University, Greensboro, NC (2017)
Scientific Committee Member, the 9th European Decision Sciences Institute Annual Meeting, Udine, Italy (2018)
Scientific Committee Member, the 8th European Decision Sciences Institute Annual Meeting, Granada, Spain (2017)
Track Chair, Service Management, The Global Interdisciplinary Conference: Green Cities Business, Engineering, Architecture, Design & Technology June 26-

29, 2019, Wroclaw, Poland.

Track Chair, Service Management, The Global Interdisciplinary Conference: Green Cities Business, Engineering, Architecture, Design & Technology June 27-30, 2018, Nancy, France.

Track Chair, Entrepreneurship Track, Northeast Decision Sciences Institute Annual Meeting, Springfield, MA (2017)

Track Chair, Manufacturing Management Track, International Decision Sciences Institute Annual Meeting (2013)

Session Chair, Supply Chain Management Track, Decision Sciences Annual Meeting 2011)

Track Chair, Supply Chain Management Track, Decision Sciences Annual Meeting (2009)

Track Chair, Decision Support/Artificial Intelligence/Expert Systems Track, Decision Sciences Annual Meeting (2008)

Session Chair (Decision Support/Artificial Intelligence/Expert Systems), Decision Sciences Annual Meeting (2008)

Session Chair, Engineering Management Track, Industrial Engineering Annual Conference, Orlando, FL (2006)

National Organizations	PanelisUReviewer (NSF): Small Business Innovation Research (2012, 2013, 2014, 2015, 2016); Environmental Sustainability (2010, 2011, 2014); Transforming Undergraduate Education (2010, 2011, 2012); Major Research Instrumentation (2012); Systems Science (2015); Science of Science and Innovation Policy (2015, 2016); Innovation and Organizational Sciences (2009)
	PanelisUReviewer, EPA Small Business Innovation Research (2016)
	Reviewer, Decision Sciences Institute Annual Meeting (2007, 2010)
	Reviewer, Academy of Management Annual Meeting (2006, 2007, 2008, 2012, 2015)
	Reviewer, Institute for Industrial Engineers, Engineering Management (2006)
Memberships	International Supply Chain Risk Management Network (ISCRiM)
	Decision Sciences Institute (DSI)
	Production and Operations Management Society (POMS)
	Academy of Management (AOM)
	Phi Beta Delta (International Scholars Honor Society)
	Alpha Pi Mu (Industrial Engineering Honor Society)

BIOGRAPHICAL SKETCH
Provide the following information for the Senior/key personnel and other significant contributors.
Follow this fonnat for each person. DO NOT EXCEED FIVE PAGES.

NAME: Zachary M. Boyd

eRA COMMONS USER NAME (credential, e.g., agency login): ZACHARY_MARK_BOYD

POSITION TITLE: Postdoctoral research associate

EDUCATION!TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
Brigham Young University, Provo, UT	BS	0412013	Mathematics
Brigham Young University, Provo, UT	MS	08/2014	Mathematics
University of California, Los Angeles, CA	PhD	08/2018	Mathematics
University of North Carolina, Chapel Hill, NC	Postdoctoral	07/2021	Mathematics

A. Personal Statement

I have the analysis capabilities, modeling experience, literature knowledge, and motivation necessary to successfully support the proposed research project. I have a broad background in data science, network models, and mathematical analysis, with specific training and expertise in dynamical processes on networks, scalable computational solutions, and interpretation of algorithmic results. My research includes work with directed, time-varying, multi-layered networks of the type considered in this project. As NDSEG fellow at UCLA and now a postdoc at UNC, I have developed state-or-the-art data clustering and importance quantification approaches under a variety of different assumptions, which will be a key component in data interpretation for the present project. I also have experience applying these abilities in domains as diverse ad neuroscience, anti-terrorism, physics, and genealogy, to name a few. The communication skills required to work with scientists in such broad enterprises will be a key component to the rapid development of working tools, as required by the proposal, especially insofar as our team is multi-institutional. This work is a natural fit for my own research program, which involves applying my deep knowledge of network modeling to a variety of application domains in cooperation with domain experts, such as the PI, who will appreciate when and where these advanced tools will solve real, outstanding problems in their domains.

1. Boyd, Z.M., Bae, E., Tai, X.C., & Bertozzi, AL.. (2018). Simplified energy landscape for modularity using total variation. SIAM J. Appl. Math., 78, 2439-2464.
2. Boyd, Z.M., Porter, M.A., & Bertozzi, AL. (2019). Stochastic block models are a discrete surface tension. J. Nonlinear Sci.
3. Moorman, J.D., Chen, Q., Tu, T.K., Boyd, Z.B., & Bertozzi, AL. (2018). Filtering methods for subgraph matching on multiplex networks. Proc. GTA2 Workshop, IEEE Conf. Big Data, Seattle, pp 3979-3984.
4. Boyd, Z.M, Marzuola, J., Osing, B., Fraiman, N., Mucha, P.J., & Weare, J. "A metric on the state space of Markov chains based on hitting probabilities." In preparation.

B. Positions and Honors

Positions and Employment

2014   Contributor, Foundations of Applied Mathematics curriculum, Provo, UT

2015-2018	Graduate research assistant, Los Alamos National Laboratory, Los Alamos, NM
2017	Lecturer, Open Source Macroeconomics Laboratory at the University of Chicago, Chicago, IL
2017	Volunteer, FamilySearch Engineering, Salt Lake, UT
2018	Graduate mentor, UCLA Applied Mathematics Research Experience for Undegraduates, Los Angeles, CA
2019-2020	Consultant, Robinson Bradshaw law firm, Chapel Hill, NC

Honors

| 2008-2013 | Monson Presidential Scholar, Provo, Utah |
| 2015-2018 | National Defense Science and Engineering Graduate Fellow, Los Angeles, CA |

C. Contributions to Science

1. My dissertation work presents analysis, algorithms, and applications of community detection, a fundamental tool of network analysis across application domains. For the popularity modularity approach to community detection, I proved fundamental limits on convexity-bases approach, connected the problem to total variation techniques, showed how non-convex approachs can improve on convex ones, and scaled up my codes to application networks involving millions of relationships. Performance on a variate of application domains were comparable with the state of the art but with better analytical underpinnings and guarantees. For the more complicated but more principled stochastic block model, I made similar contributions, eventually providing efficient codes that work on much larger networks than competing approaches.
    a. Boyd, Z.M., Bae, E., Tai, X.C., & Bertozzi, AL.. (2018). Simplified energy landscape for modularity using total variation. SIAM J. Appl. Math., 78, 2439-2464.
    b. Boyd, Z.M., Porter, M.A., & Bertozzi, AL. (2019). Stochastic block models are a discrete surface tension. J. Nonlinear Sci.

2. In addition to the contributions described above, with a UCLA REU team, I developed algorithms for detecting adversarial activities in transaction networks of interest to DARPA The problems are normally combinatorially difficult, but we exploited special structure in the data to get efficient and accurate solutions. This work had a transformative effect on how DARPA viewed adversarial network detection and led to further expansions of these techniques after I left the project.
    a. Moorman, J.D., Chen, Q., Tu, T.K., Boyd, Z.B., & Bertozzi, AL. (2018). Filtering methods for subgraph matching on multiplex networks. Proc. GTA2 Workshop, IEEE Conf. Big Data, Seattle, pp 3979-3984.
3. With a team of collaborator, I have developed a metric (distance) on the nodes of directed networks (that is, those with asymmetric links, as in supply chain networks, or Twitter follower networks) which uses notions of reachability to recover a symmetric distance despite the inherent asymmetry of directed network structures. We show that including the directed information in distance measurements enhances many procedures, such as community detection, visualization, data exploration, and chain discovery.
    a. Boyd, Z.M, Marzuola, J., Osing, B., Fraiman, N., Mucha, P.J., & Weare, J. "A metric on the state space of Markov chains based on hitting probabilities." In preparation.

D. Additional Information: Research Support and/or Scholastic Performance

Title: Global Supply Chain of Medical Equipment: Vulnerability Assessment, Emergency Response Tool, and Financial Impact Analysis

PI: Kayvan Miri Lavassani Ph.D., North Carolina Central University

Co-PI: Raj Iyengar Ph.D., North Carolina Central University

                        Mahour M. Parast Ph.D., Arizona State University

                        Zachary M. Boyd, Ph.D., University of North Carolina, Chapel Hill

Background: NCCU's School of Business has been working on the application of network analysis in the study of firms over the past several years. Dr. Kayvan Miri Lavassani has been leading efforts in this area by founding the Innovation & Entrepreneurship Business Ecosystem Lab (IEBE Lab), as well as the Journal of Business Ecosystems (JBE) at the School of Business. In response to COVID-19, Dr. Lavassani formed a team of researchers from several universities to explore various aspects of the global supply chain of medical equipment in light of the global pandemic.

Specific aims: The aim of this collaborative project is three-fold: 1. Assess the vulnerability across the global supply chain of medical equipment, 2. Develop an emergency response tool, and 3. Measure the impact of change in global supply chains on firms' financial performance. This proposal will enable the researchers to establish foundations for collaborative work and plan to apply for future funding opportunities within the 2020 calendar year.

Strategy: The global supply chain and production of medical equipment have experienced significant transformations over the past few decades which has made the supplies to be more vulnerable to ruptures in the supply chain across the world. Using proprietary data we will develop mathematical tools to evaluate supply chain vulnerabilities and fragmentations, global operational effect of supply chain interruption, and its financial impact. We acquire the supply chain data from financial resources; and we develop and evaluate the various aspects of the global supply chain of medical equipment using network analytic tools. This work can be extended to other industries.

Budget: The main cost associated with this project is access to the database. We access proprietary supply chain and financial data through S&P Global. This database will be made available to all faculty. While S&P Global provides access to large and complex data we still require to perform a significant amount of computation to mine the supply chain network data. Hence, we also require computers (hardware and software) capable of computing large and complex networks along with supplies. We also allocated a budget for travel to attend conferences and/or workshops; considering the COVID-19 the budget is expected to be used to attend virtual conferences/workshops. As the field of network analytics is a new area we require to hire highly skilled consultants for designing optimization models, and new algorithms. We have support from top-notch researchers in the areas of network science and supply chain at UNC-Chapel Hill and Arizona State University to support us in this endeavor. We have also added budgets for books, a website that displays our pilot projects, and any required cloud services.

Amount	Category
$ 22,000	S&P Global
$ 12,000	Supplies, computer hardware /software/cloud
$ 1,000	Workshop /Conference/Virtual Conf. and workshop
$ 8,000	Consulting /RA
$ 1,000	Books, website, web service
$44,000	Total

Budget Justification

$ 22,000	S&P global	
$ 12,000	Supplies, computer hardware /software/cloud	
	$ 3,500	1 Desktop computer, min. 32GB ram, 3-4 TB SSD, double or triple monitor, CPU: Inter Core i9 or higher, or Ryzen 9 r higher
	$6,000	4 Laptops min. 16GB ram, 1 TB SSD (Est. $1500 each)
	$1,500	Office supplies, 2 tablets, board, marker, Virtual collaboration tool
	$1,000	Cloud services for analysis, and editorial software
$ 1,000	Workshop /Conference/Virtual Conf. and workshop	
$ 8,000	Consulting/RA	
	$4,000	UNC-Chapel Hill
	$4,000	Arizona State University
$ 1,000	Purchase of books, journals, domain registration, Webhosting, web services	

Total: $44,000

The primary cost associated with this project is access to the financial data. S&P Global provides access to financial data. We require computers with the appropriate power to perform critical tasks. We will have one desktop computer with the excellent capability (as outlines above) and 4 laptops with good performance (as outlines above). We require office supplies including tablets, white/glass board as well as virtual collaboration tools which are essential during distance working that we are experiencing due to the COVID-19 pandemic.

We will require several cloud services including editorial (e.g. Grammarly) to help with the project writings as well all computational/data/graph services to particularly as it relates to graph analysis.

For workshops/conferences, due to the pandemic, several conferences in our filed are now online. We will use this line item for attending this conference as well as training classes or workshops related to our research.

We have a line item for consulting/RA. Our partners at UNC-Chapel Hill and Arizona State University have distinguished expertise in the area of network science and supply chain. They will make a notable contribution to this work with their mathematics and engineering expertise.

The last line item is with regards to the purchase of books/journals as well as registering a domain, hosting of the domain, and web services. Through this project we will develop an interactive pilot website that researchers can use to access the effect of supply chain rupture in several countries. Figure 1 (presented in the proposal) displays the effect of eliminating one country from the global supply chain. In the proposed website we will extend this visualization to all countries in the world that their rupture from global supply chain results in notable disruption.