ORMS TOMORROW

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RESEARCH IN PROGRESS AROUND THE GLOBE

Exciting ongoing OR/MS research from universities worldwide

FINDING A JOB DURING A PANDEMIC

Academic and industry job markets advice

RACIAL INCLUSION IN THE OR/MS FIELD

Minority Issues Forum's leaders share moving responses

CONTENT

Letter from the Lead Editors 2

Crossword Puzzle 3

Interview with Dean J Cole Smith: How to Adapt to COVID-19 Academic Job Market 5

Interview with Prof. Dmytro Matsypura: Academic Job Market During COVID-19 7

Working During and After COVID-19: Interview with Dr. Jennifer Bechkoff & Karen Cowan 8

Hospital Resources During a Pandemic: Interview with Dr. Joseph Miller 10

Supply Chain Management Strategies Post COVID-19 12

How to be Racially Inclusive as Students, Educators, and Scientists in the OR/MS Field 14

Silver Lining of Global Warming? To the Routes in North! 19

Forecasting in the World of Big Data 20

Operations Research Applications in the Last Mile Distribution System 22

From Cocoa to Chocolate 23

Cybersecurity in Cyber Warfare: The Application of Demon Game Models 26

Letter from the Lead Editors

Dear OR/MS Community Members,

We are pleased to share with you the Spring/Summer 2020 edition of OR/MS Tomorrow in its new look and the first ever cross-word puzzle for which you will find some of the clues in this issue!

Some of the articles in this issue are about facing and conquering COVID-19 related challenges ranging from hospital resource management, supply chain resilience, to navigating the job market (Academia and Industry). Being the voice of OR/MS students, we saw the anxiety that COVID-19 has caused to our colleagues in the job market. We hope that this issue will provide some helpful tips during your job search journey. Many Thanks to Dean Cole Smith, Prof. Dmytro Matsypura, Prof. Jennifer Bechkoff, and Karen Cowan, for their valuable insights on this topic.

We also would like to thank Dr. Joseph Miller, MD, for taking the time to discuss with us the Henry Ford Hospital experience with managing its resources during COVID-19 Pandemic.

Speaking of challenges, we reached out to Prof. Julie Ivy to ask about her experience being an African American in the OR/MS community, and her advice to us - OR/MS students, scientists and educators - on how to be racially inclusive. Many thanks to Prof. Ivy and the INFORMS Minority Issues Forum members: Professors Maria Mayorga, Shannon Harris, Illya Hicks, Emmett Lodree, Mark Lewis, and Rubén Proaño, for the moving responses.

Finally, driven by the saying "Knowledge is power. Knowledge shared is power multiplied", we share a wide range of research articles including last mile distribution system and the applications of demon game models in cybersecurity. We welcome submissions for the Fall/Winter 2020 issue. If you are interested, please reach out to us via email at orms_tomorrow@mail.informs.org

Thank you and we hope you enjoy the content.

Amira Hijazi and **Jessica Leung**

OR/MS Tomorrow Family

This issue wouldn't have been possible without the effort of our family members:

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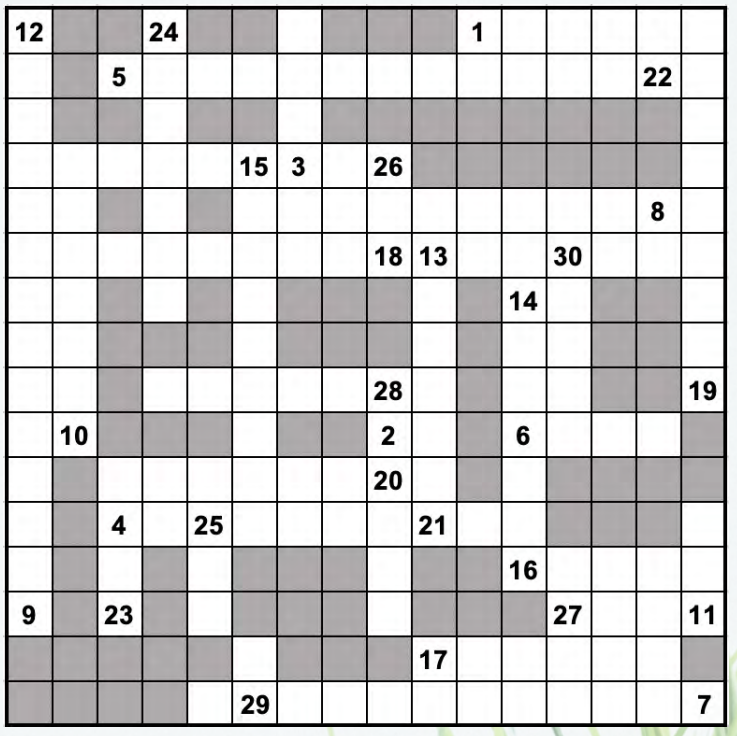
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Crossword Puzzle

Find the clues in this issue to complete the puzzle!

Send your answers to orms_tomorrow@mail.informs.org by August 10th to enter a lucky draw.

Winners will be announced on our website and social media and will receive a $50 prize!



Top to Bottom

2. Second largest producer of Cocoa in the world (5)

14. Quality guru who wrote "Quality is still free" (6)

15. A distribution which has mean = variance (7)

24. _____ algorithm inspired from evolutionary process (7)

25. An offline quality assurance method, acronym (3)

30. ISO 22000 _____ safety management system (4)

12. Vital few trivial many (6)

Right to Left

26. This solution method fetched Nobel prize in 2012 on cooperative game theory (7)

7. A jungle method used by Medeiros et al. to forecast US inflation (12)

28. Ability to stop the production line when a malfunction happens (6)

22. Industrial epidemic disease cured by six sigma (9)

18. This author conceived Red X, Pink X, & Pale Pink X (7)

20. _____ developed the concept of EOQ using a square root formula (6)

8. _____ effect in the classroom: how teacher's expectation correlate with a student's performance (9)

Left to Right

4. One of the four key operational strategies for supply chain resilience (10)

1. Father of scientific management, last name (6)

6. A traditional shipping route that borders Asia and Africa (4)

27. Hero of the movie Titanic who expired in 2020, first name (4)

13. A distribution with equally likely outcomes (7)

16. Sorting algorithm which is based on divide and conquer structure (5)

5. Devil game used in the cyber security in cyber warfare (5)

17. Programming language named after a TV show (6)

Bottom to Top

19. He revolutionized LP with polynomial time algorithm in 1984 (9)

3. An efficient heuristic developed to solve 2E-VRP-CO (4)

9. The Japanese term for production levelling is _____ (8)

10. One of the seven lean wastes (7)

21. A distribution for which the measures of central tendency are equal (6)

23. 3 M's : overburden (4)

29. A meta heuristic inspired from heating in metallurgy process, acronym (2)

11. Necessary conditions to get global optima in a non-linear program, acronym (3)

How to Adapt to COVID-19 Academic Job Market

In 2019, our former lead editor Rahul Swamy reached out to Dean J. Cole Smith of Syracuse University to discuss the unique challenges that job searching in academia presents. (The original article can be found here.) The COVID-19 pandemic and the resulting hiring freeze in almost every academic institute have many graduating students and academic professionals concerned and wondering about adaptation to the COVID-19 and post-COVID-19 academic job market. This month we met again with Dean Smith to seek his advice for current academia candidates.



Prof. J. Cole Smith
Dean of the College of Engineering and Computer Science
Syracuse University
Vice President of Publications at INFORMS

What does COVID-19 mean for OR/MS community members planning to enter the academic job market this year?

There is a danger in answering too broadly here, but the general trend is that many universities have been forced to delay hiring, or to even cancel faculty hiring for the short term. I am most familiar with the situation in the United States, but I know this applies to many other countries as well. Universities have been hit very hard financially, and many are trying to minimize furloughs and layoffs via hiring freezes. This applies to every university discipline, and thus applies to OR/MS hiring in sciences, engineering, business, computer science, or other fields.

Faculty hiring will return, probably in a reduced capacity in the Fall 2021 cycle. When it does, our field may actually be in a favorable position. For one, our research supports data science, analytics, and decision-making clusters that many universities are looking to build. For another, the startup costs for many of our researchers are more modest than some other areas, at least, in engineering and computer science fields. As Dean, if I were particularly cash-strapped, I may favor hiring someone in 2021 in the area of algorithms or operations research foundations, as opposed to someone who may require close to a million dollars in startup funding to create a lab. Those expensive labs may pay off quite well, but they are more challenging to finance in times like these.

What kinds of alternative careers leave the doors open for academia if and when any academic jobs open up?

I would start by reassuring readers that academic jobs will open up! The market for OR/MS faculty will persist.

My first advice would be to find a position that is designed to be temporary. That might be the case, for instance, in a postdoctoral fellowship or a visiting faculty position. Slightly less obvious would be as a teaching faculty member, i.e., a non-tenure-track faculty member whose primary role is instruction. In fact, these positions may indeed still exist in the short term, and I feel that many of our Ph.D. graduates might be extremely well-suited to teaching faculty roles. (Note that these roles have different terms across different institutions, e.g., clinical faculty, lecturers, and so on.) But it is reasonable to communicate the desire to gain instructional experience in the current environment with the intent to apply for a tenure-track job in the future. It might be appropriate to see if you can negotiate for some time to carry out at least a modest level of research, perhaps at least enough time to finish papers that come out of your dissertation if applicable.

Outside of academia, I would not advocate for taking a long-term position with the intent to make it a short stay. It is best to be upfront about what you are hoping to achieve while in the role. Indeed, this is probably a good time to consider what you want to contribute with your Ph.D. We sometimes get focused

on the job we want rather than the contributions we wish to make, which inverts the sensible order of our decision-making. I have found that research laboratory roles make the most sense for people who wish to get involved in real-world problems while having a little more leeway to remain active in research. But in reality, one would have to ask the supervisor and your future co-workers where their focus is and what the norm is regarding research. If publications are allowed but never done in practice, that should tell you something. If your colleagues are coming to INFORMS meetings and engaging in research, that might be more promising. And again, perhaps this environment is more what you are looking for in the first place.



What should job seekers do to remain competitive on the faculty job market until hiring resumes?

I would suggest two primary items. One, keep doing your research, if you are looking for a tenure-track position (and if the expectations for the tenure-track positions you seek include research). If I were hiring, I would want to know that research is compelling to you, and that your innate interest in your research compels you to continue to whatever extent is practical. Having said that, it is important to acknowledge what "keep doing your research" means. If you work in abstract mathematics, then I suppose you can continue to research and publish with only modest delays. If your research requires human subjects, access to high-performance computing, and so on, then perhaps you cannot. In that case, stay current and keep a notebook of ideas for future research. The idea is to not lose momentum in your studies.

The goal is not to continue publishing at the same rate you would if you were getting paid to do so, and had the requisite resources at your fingertips. This is not reasonable and not sustainable.

The second item would be professional development. To some extent, that overlaps with "stay current" advice above, but I intend this to regard more the idea of how does your research impact society? Why is it important? What problems need to be addressed that are important? Our field did brilliantly in quickly addressing certain problems surrounding the COVID-19 pandemic. Because this pandemic is ongoing, our studies will have lasting relevance. Now, what about ethical issues with respect to algorithms? What about addressing inequities in the systems we model and optimize, like healthcare, supply chain, transportation, and so on? Those are the questions we need to be asking. Giving thoughtful answers to how you can participate in that mission requires a lot of foresight, research into what has already been done, and more than a little idle thinking and brainstorming.

Related to this, take the time to educate yourself on newer forms of teaching that integrate technology in the classroom. How do you make good online videos? How do you flip a classroom (and when should you do so)? How do you serve students that are remote if your class is being delivered in-person? Bear in mind that there are inequities among students: Some can easily access technology-enhanced lectures, and others cannot. How does technology that you use serve to either narrow or expand those gaps?

What would you like to say to job seekers?

After your Ph.D., you deserved more quantity and diversity in job opportunities. Of course there are more dire consequences of COVID-19, but senior INFORMS members see the stress that it is causing those of you who are graduating now. There is an extra level of stress, too, in which many of you are trying to conduct research in an environment that is not optimal for being productive. (I hosted one recent leadership meeting, during which I heard my children in the background wondering which nearby materials are flammable. Good luck concentrating on your meeting when you hear this.) My advice to those of you who are trying to remain as productive as always while looking after children or elders, and being away from your labs: stop trying. Don't work yourself ragged. This is not a reasonable or fair expectation.

This crisis will abate. When it does, those of you who are able to conceptualize why you want to have the careers you are seeking, and the influence you can make in those careers, will be the best positioned for long-term career and personal success thereafter.

Interview with Prof. Dmytro Matsypura

Academic Job Market During COVID-19

We have invited Prof. Dmytro Matsypura from the University of Sydney to advise job seekers on the COVID-19 academic job market. Prof. Matsypura's research work focuses on applications of convex and combinatorial optimisation in forecasting, graph theory, finance, transportation, and ecology.



What does COVID-19 mean for people planning to enter the academic job market this year?

COVID-19 makes the hiring process very complicated for both job seekers and employers. First, universities are facing a lot of difficulties in the hiring process because of the financial constraints, i.e., many universities are having a hiring freeze. Second, even for those universities that do not have a hiring freeze, due to the international travel restrictions, it is simply impossible to invite overseas potential candidates to attend an interview, which is a very common practice in academia.

The fact that the potential candidate cannot be here makes it difficult for both sides to determine if the potential employment is a good idea. This is because the fly-in interview trip is an occasion where the potential candidates get to see the place they are going to live in and work at for at least the next 5 years. It also enables the employer to interact with the potential employee, e.g., during seminar presentation, going out for dinner etc. All of these activities are designed to give opportunities for both sides to learn more about each other. Therefore, COVID-19 has added additional complexity in the hiring process.

"Find someone who can say good things about you that go beyond *'this person is a good student'*..."

Will start-up packages / funding for new faculty be affected by the pandemic? If yes - how so?

Yes, it depends on how much the financial position of universities is impacted by the pandemic. Start-up packages and funding are all negotiable, school specific and on a case-by-case basis. There is really no guideline on how much budget is allocated. It will probably not be as much as what the school offered the year before.

How should we write our teaching and research statements favourably for the job application?

A teaching statement is designed to describe your approach to teaching rather than what you have been teaching. Ask yourself questions like:
- What is your teaching philosophy?
- What do you focus on?
- Do you enjoy it?
- How do you recover from mistakes?

You can describe your strategies of keeping students engaged and motivated. A research statement focuses on the research interest, and your current and future research projects. If you have research plans/pipelines, you should talk about them.

Do we need to take recommendation letters from committee members or can we take them from any professor of interest?

The recommendation letters do not have to be from a member of your committee. Get it from the people who know you the most, someone who can say good things about you that go beyond "*this person was in my class and was a good student*". You want a reference letter from someone who can speak about your personality, your problem-solving skills, your research, and your work methods etc.

Should we focus on tenure track or postdoc positions? How do candidates with a postdoc compare to students who just graduated?

It depends on your research area. For business school students, post-doc is not as common as those from engineering and sciences. It is also a question of opportunity. If, say, the postdoc position is on the topic that you are interested in, or with people you really want to work with and you can learn a lot from it, then you should apply! The biggest advantage of a postdoc is that you get to publish. But the disadvantage is that you will have to go on to the job market again within a year or two, whereas a tenure track position will allow you to stay for at least 5 years.

What would you like to say to job seekers?

Be prepared to receive a lot of rejections and don't be discouraged by lack of response. Because it only takes one job offer to get a job. KEEP APPLYING!



Jessica Leung
The University of Sydney, Australia

Working During and After COVID-19: Interview with Prof. Jennifer Bechkoff & Karen Cowan



Amira Hijazi
North Carolina State University



Abigail Lindner
Regent University

The COVID-19 pandemic has severely disrupted economies and workplaces around the world. In these anxious times, we spoke to Prof. Jennifer Bechkoff and Karen Cowan to hear their insights on how students can prepare for work in industry and what to expect during and after COVID-19.



Prof. Bechkoff serves as Associate Professor of Marketing Business Analytics at San Jose State University and chairs the Marketing & Business Analytics Curriculum Committee and the Lucas College of Business Undergraduate Curriculum Committee. She has taught classes on marketing research, soft skills, business research and communication, and consumer behavior.



Karen Cowan is a senior management professional who has worked in staffing and workforce management for over 25 years. She has experience in numerous sectors, including healthcare and IT, and has demonstrated strategic leadership to build high-performance teams and develop strong business partnerships and workforce solutions.

Q: What industries would you say have been most impacted by COVID-19 and will likely see recruiting changes as a result?

Cowan: There are some obvious ones that you probably are aware of like aviation, travel, tourism, and hospitality. Those are definitely struggling - a lot of furloughs, a lot of layoffs. There's a trickle effect, of course, as then the suppliers of those businesses are affected; for example, the linen services for hospitality.

One industry that has done surprisingly well is sporting goods as people are getting outdoors more. Two months ago my step-son's company had the best month they've had in five years, and the month after that they surpassed that. Then, of course, pharmaceuticals have endured because people still need their medications and the research labs are taking off because now there's an acute need for testing and vaccines. Phone service and video technology are experiencing increased demand thanks to the need to work from home. The shift to shop at home has led to more business for shipping companies like Amazon and Instacart.

In terms of recruiting changes, you have so many people you have to furlough and lay-off and, when conditions return to "normal", you have to go back and rehire those people, but those workers may have gone off in the meantime and started new jobs.

Q: Do you expect more positions to transition into remote or partly remote working roles after the pandemic? Will this affect the work of recruiters?

Cowan: Companies are really trying to accommodate people. Fortune 500 companies and other businesses with lots of employees will likely continue working remote until some kind of resolution has happened. More people are able to work remote than ever before and they will continue those remote jobs while they can. Companies used to be against remote working because they didn't believe that people would be productive outside of the office. However, the shift in working environments caused by the COVID-19 pandemic has demonstrated that remote working is possible for many employees. Moving forward i expect that there will be larger percentage of companies making remote work possible for employees.

For recruiters, when you have an organization with more remote positions, those positions can be filled anywhere in the country. If people don't have to physically come into an office, they can come from anywhere, which widens the talent base. Maybe the perfect person is in Connecticut while the company is in California. With remote work, that match could happen. I know a common complaint in recruiting is "oh, they won't relocate", but we'll have less of that situation now.

What I think we're going to see as a result of the transition to remote working is a decay in office culture - increased isolation, distractions, a blurring of work and home life, and less camaraderie. That's going to be an opportunity for consulting firms and human resources departments to put together training sessions, and for the management teams to make sure that this is something that we can do on a virtual basis.

Q: How can students adapt to the COVID-19 job market?

Bechkoff: Many companies are in a hiring "chill" so it's going to be tough, but I encourage students to not feel defeated. If you are actively seeking a job, you should first focus your energy on industries that are faring well during this crisis, such as healthcare, social work/counseling, grocery, eCommerce, biotech, gaming, cycling, home office, home fitness, home improvement, telecom, sports equipment, pharmaceuticals, entertainment streaming, and communications. Don't be afraid to expand the geographical location of your search as there are many telecommuting jobs available that don't require the employee to live in the company's location.

Q: What should candidates be aware of when interviewing via video vs. in person? What can they do to present themselves as the best candidate?

Bechkoff: There are two types of video interviews: One-way and two-way. For a one-way video interview, you have the chance to

prepare your answers (if given them ahead of time) to record for the interview. Responses should be rehearsed to portray confidence and eloquence. For a two-way video interview, body language is important. Sit up straight, don't lean, smile, and be cognizant of your tone so you sound enthusiastic. Two-way video interviews tend to be shorter than in-person interviews, so it's important to create a bond as soon as possible; make sure you have thoroughly researched both the company and the interviewer so you have something with which to start that dialogue.

For all video interviews, it is important that you still dress business formal (from head to toe!), check your technology ahead of time, use a computer (not a phone), remove distractions (people/pets), center the camera to your eyes, make sure you fill the frame (don't leave dead space above your head), avoid earbuds unless you're forced to take the interview in public, have the lighting in front of you (rather than behind you), and move the video window close to the webcam so when you're looking at the interviewer in the video window, it appears to the interviewer as if you're looking directly at him/her.

In order to present yourself as the best candidate, you have to be likable, communicate clearly, and elicit confidence. By the time you've secured an interview, the company already knows your qualifications and deems them sufficient; thus, the interview is no longer about your qualifications, but rather all about you. Are you a good fit? Are you somebody with whom their employees will want to work side-by-side? Are you going to add value to the company? The interview is the time to practice your very best soft skills. Show them that your hard skills are only part of the package. It's time to shine.

Cowan: It's important to remember the three P's: Prepare, Practice, Present. When you're using Zoom, or similar technology, there is always the potential to run into technical problems. It's a good idea to go on at least ten minutes before time to do a trial run. Start a personal video chat and adjust the camera, check the lighting, and remove distracting decor so that nothing detracts from you, the candidate. Make sure that the camera is positioned so that it looks like you're looking at the interviewer. Practice speaking so the volume is right and prepare all the logistics on that end.

Then just prepare the way you would for any interview. Present yourself professionally, fixing your hair, checking your teeth (!), and dressing appropriately. Be ready to give examples of how you were successful, how you solved a problem.

Q: For students who have lost or had postponed internship and job opportunities, what skills would you recommend they develop now to be competitive against other qualifying candidates?

Bechkoff: If you have extra time on your hands, you should definitely upskill right now. There are a plethora of free classes available online. Classes that help you obtain extra certifications or gain more depth of knowledge in your particular field of interest are obviously useful; but, also consider taking classes outside of your major in an area that marries well with your primary field of study. For example, a marketing major might consider taking some psychology courses or an operations researcher might consider taking some communications courses. Also, make sure to learn as many productivity tools as possible; remote collaboration tools (Slack, Microsoft Teams, SharePoint, G Suite), video chat programs (Zoom, Skype, WebEx, GoogleHangouts, GoToMeeting), and CRM services (Salesforce, HubSpot). These will add to your remote work skills to make you more marketable. And always, always brush up on your soft skills.

Cowan: Students need to be flexible and adaptable. If they can develop skills in or show examples of critical thinking and problem solving, companies love to see that. For recent students or workers returning to the labor force, you could look at your skill set or major and ask, "What can I do to expand that?" Maybe you take a digital marketing course or a social media course. If you could get a certification or a continuing education class to hone those skills and show initiative while in transition, companies will be impressed. Data analytics is really becoming hot right now, so that would be a great skill to learn and put in a resume.

Q: How can students build connections with potential employers during the present circumstances? Since the traditional networking events, i.e career fairs and conferences, have been canceled, what other online sources are available?

Bechkoff: The first thing you should do is to reach out to your current connections via phone/email and start a dialogue. Networking involves nurturing relationships. Start slow and think long-term. Do NOT ask anyone for a job.

Next, join professional organizations where you'll meet like-minded people. Every field has several prominent organizations. It's an easy way to get to know people who work in your field or in your community.

Finally, reach out to those who work in your field or work for companies of interest. Start slow by commenting on a post of theirs or by sharing something they've written. Make good use of LinkedIn. Then, you can "cold call" potential contacts by sending them an email with an explicit ask. Explain what caught your attention about them or their work and make the ask in a way that can be answered with a yes or no answer. For example, "My name is A and I really admire your work on B. I'm interested in learning more about C and was hoping you'd be willing to provide some insights from your experience. If you're open to it, I'd love to video chat to ask you some questions and learn more about C. Would it be possible for us to meet via Zoom?" Nobody likes doing this, but if you want to expand your professional network, this is another way to do it. Start connecting with as many people as you can.

Q: What else would you like to say to job seekers?

Bechkoff: Finding a job under the current economic condition is going to be tough, but not impossible. The market is extremely competitive so be prepared to put in the work. If possible, avoid the applicant tracking system and apply through contacts within the company. Personal connections, remote job skills, and excellent soft skills will be the keys to your success.



Hospital Resources During a Pandemic



Egbe-Etu E. Etu
Editorial Staff Writer
ORMS Tomorrow Magazine

Over the last few months, the 2019 Coronavirus (COVID-19) pandemic has put a strain on the healthcare system, sickened many hospital staff, and stretched hospital resources to their limits and beyond. As of June 5th, 2020, the estimated number of infected patients worldwide stands at 6.7 million, with a recorded death toll of 395,597 (WHO, 2020). According to the Center for Disease Control and Prevention, the United States has the highest death toll of 110,699, with 1.93 million people infected by the virus.

The primary function of a hospital is to provide the general populace with complete health care service, but this has been challenging for these institutions during this pandemic. A shortage of resources and unlimited demand for service has hindered their ability to provide care to the numerous infected patients. **You might be wondering, "What is health care resources?"**. Ransom and Olson (2017) define health care resources as all the materials, personnel, facilities, and funds that can be used for providing medical services to patients. So, it includes the personal protective equipment (PPEs), ventilators, beds, triage rooms, hospital buildings, physicians, nurses, and paramedics that are put together to provide care to patients.

For a long time, health care services have been inherently scarce: money for services is not unlimited, facilities for delivering services are finite, and medical professionals are limited in time, geography, skills, and capacity. The pandemic has only brought out some of the strengths and weaknesses we face in society and the healthcare system. This interview will focus on telling the story of some of the issues faced in the hospital emergency departments during the pandemic. How they were solved, lessons learned, and how research can be employed for improvement. We interview an experienced emergency physician to get some insights into what the hospital has done to cope with the limited resources.

Interview with Dr. Joseph Miller



Dr. Joseph Miller, is an emergency care physician and a director for the combined internal medicine and emergency medicine residency program at Henry Ford Health System in Detroit, Michigan. He is a clinical associate professor at Wayne State University, Detroit. His research interests focus on emergency neurological conditions such as acute stroke, epilepsy, and traumatic brain injury. Also, he does research in hypertensive emergencies, the operations/systems of the emergency department, and he teaches research methodology within the health system.

Can you tell us briefly about the Henry Ford Health System and its emergency department?

"The Henry Ford Health System (HFHS) cares for a large proportion of patients in southeast Michigan. There are nine emergency departments total within the system and five hospitals, plus two additional psychiatric units. The main emergency department is a large-level one trauma center in the heart of Detroit, specifically in the midtown area. The system is integrated and has a unified medical group that cares for all the patients that call us their medical home."

Health systems are facing so many issues with the COVID-19 pandemic. What are some of the resource shortages at Henry Ford Hospital?

"The main issues that we had with resource shortage, particularly during the first two months of the pandemic, were about PPE materials. We actually were doing okay on medications and I.V. fluids and other common resources for use. Still, just like many other health systems, we were in short supply. Our health system leadership had to be creative about resourcing proper PPEs and determining optimal use such that we conserved as much as possible for patients. Now, in theory, we could have had shortages of our mechanical ventilator supply. But fortunately, the hospital did not come close to the point of running out of ventilators. We still had plenty of ventilators throughout the entire pandemic. If the cases in Detroit had gone on for a longer period or had been more severe,

we could have easily run out of those as well. The other resource that we were relatively short on was hospital beds. We did reach near-total hospital capacity. If the pandemic had gone on for a few more weeks in Detroit, we would have transferred a lot more patients to field hospitals. Another shortage that we ran across was a shortage of standard intensive care unit (ICU) beds. So, we did have to convert quite a few units that were not typically running as full ICU's into ICU amid the pandemic. Another issue faced was with physician staffing. What happened was a lot of clinicians that don't typically work in the inpatient ICU, or emergency department helped cover from other areas of the health system. Many nurses, physician assistants, faculty in other specialties came to assist the emergency department. This is great as it shows the teamwork, dedication, and willingness of the employees."

What steps did the hospital take to address some of the resource shortage?

"The major steps had to do with sourcing PPE materials and operational changes. Converting units of the hospital from regular medical-surgical units to units dedicated to COVID-19 and including ICU's dedicated to COVID-19. So, for instance, our entire surgical intensive care unit was converted into a COVID-19 unit that helps us manage the surge of patients with critical illness related to COVID."

How did HFHS source for PPEs, and did you benefit from any of the "Big Three" automotive companies in Michigan?

"Yes, we benefited from many different sources. For instance, Ford Motor Company donated PPEs. We had PPE materials donated from general donations, and we set up a kind of centralized donation process. The other thing to mention is that we were involved in the establishment of a field hospital. The field hospital was put up to increase the capacity to potentially manage a thousand patients. Yeah, the field hospital wasn't needed for a short time but was there just in case the pandemic had become much worse. Eventually, I would say for residents in Detroit who obeyed the stay at home order; we were able to flatten the curve."

With the limited resources diverted to treat critical patients, what happened to the other deferred patients (e.g., pregnant patients, patient with transplants, etc.)?

"So, a lot of health care was deferred. In some cases, new transplants were not performed in the middle of the pandemic. However, clinicians used their judgment to determine things that cannot be deferred. For example, pregnancy patients continue to deliver babies during the pandemic. It continued with special precautions to protect pregnant women and their babies. Next, patients with a serious illness, or perhaps with a history of transplants and complications, continued to receive either virtual or in-person care, as needed, for acute or chronic illnesses. The health system actually went from doing an estimate of 400 virtual visits a week to 4,000 virtual visits a week using telehealth visits or video visits. So, an exponential rise in virtual visits."

Did the hospital dedicate any units to non-COVID related patients?

"Yes, essentially, we perform what we call 'cohorting', where special units were dedicated to COVID patients. Then there was a small number of units where we quarantine and designate as non-COVID. To protect the health of uninfected patients, but still had an acute illness or had pregnancy-related admissions."

What are some possible research areas you think prospective students, researchers, or institutions can engage in to help improve the health care system during a pandemic?

"There's so much research to do as a result of the pandemic. First, there is research in the area of predictive analytics for systems or regions to estimate the likelihood of a future outcome of the health system in terms of resources and capacity during a pandemic. Secondly, research on operational efficiency to develop methods by which systems can operationalize some of the changes that most health systems have implemented. But in a more data-driven approach rather than on the fly approach, which is what many systems were forced to do during the pandemic. Third, I think research related to how systems supply, allocate PPE, and other related medical resources amid a pandemic to protect employees the best. Fourth, research on telehealth to determine what scenarios and patients are best served purely through telehealth and virtual health rather than in-person encounters and how to best deploy the technology either during a pandemic or other aspect of care."

Telehealth is an exciting research area for students to delve into. Any security or connection concerns?

"Yes, research has to be done in addressing the security and connection issues. Patient confidentiality, privacy, and data are important. I think there are telehealth systems and providers that have established a secure Health Insurance Portability and Accountability Act (HIPAA) compliant connection. Still, the issue has come up throughout the pandemic. Many clinicians that do not have access to some of these more robust information technology (I.T.) solutions made use of Zoom or other less secure virtual visit methods. This puts the patients at risk and raises security concerns."

Lastly, as a medical professional, what practical lessons have you learned?

"A couple of things we've learned is that having good data can help guide and inform rapid changes. Having that in place for an operation before a pandemic can help you decide how best to use resources. The second lesson is that having a conservative and extensive use of PPE can help save a lot of medical professionals. I think a lot of us learned that early on, as a lot of providers, clinicians, and nurses became sick. With time, we had a better handle of things as we started to make more judicious use of PPEs, the number of ill medical personnel reduced. But I think if clinicians, nurses, physicians, everyone involved was more cautious at the beginning, they might have saved a lot of lost hours of work. Finally, we were uncertain about recycling and reusing medical equipment at the beginning. Now, we have much knowledge about it and how to handle it."

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Supply Chain Management Strategies Post COVID-19

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The supply chain is a network of organizations involved in producing, distributing, and delivering a product to end customers and is considered the backbone of many industries. With increasing globalization and outsourcing strategies, supply chains are becoming very complex. As a result, supply chains are more vulnerable to disruptions, and industries are facing a huge challenge in both supply chain planning and design. On March 11, 2020 the World Health Organization (WHO) declared COVID-19 a global pandemic. The COVID-19 outbreak resulted in international border closures and shutdowns of many critical facilities and thus has exposed the fragility of the global supply network.

The outbreak of COVID-19 has made many organizations realize the importance of supply chain resilience, and post COVID-19, many firms across industries will consider reconfiguring their supply chains to be ready for disruptions. Supply chain *resilience* is the ability of firms to prevent and quickly recover from costly supply disruptions. This article highlights some key strategies for building resilience in supply chains and reveals some new insights that have emerged within various industries as a result of COVID-19. Ultimately, the main purpose of this article is to inspire the broader OR/MS community on this emerging issue facing supply chains.

A recent article from McKinsey & Company highlights that a typical supply chain is vulnerable in five areas: planning and supplier networks, transportation and logistics system, product complexity, organizational maturity, and financial resiliency (Alicke et al., 2020b). The first stage to support resiliency is to identify the supply chain's exposures and vulnerabilities. These vulnerabilities can be categorized into macro risks and micro risks (Ho et al., 2015). *Macro risk* is the risk caused by natural disasters (e.g., weather-related events and earthquakes) and man-made risk (e.g., political conflict, war, and terrorism). *Micro risk*, on the other hand, is attributed to the internal factors of a company, such as relationships with stakeholders and supply chain members. Both macro and micro risks can contribute to supply chain disruptions that result in longer lead times and uncertainty in demand.

To mitigate these risks, companies first have to understand their supply chain structure. They have to map the supply network and identify which supply chain members (such as manufacturers, distributors, and retailers) are most vulnerable. It is very common that a firm does not interact with its supply chain beyond the Tier 1 firms, i.e. a company's direct suppliers. However, in reality, the most supply chain criticality may lie in the further removed sub-tiers of the network.

The relative fragility of the supply chain can be measured quantitatively using network analytics algorithms and can be compared with standard industry benchmark (in terms of supply chain node criticality index) to draw meaningful comparisons (Alicke et al., 2020b). For example, the supply chain members that have higher interconnectivity or more dependence may be more critical or more exposed to disruptions. Post COVID-19, business leaders

may reconfigure their supply chains to adopt effective resilience strategies. For example, digitizing the entire supply chain system may help in creating a better coordination among the supply chain members (Alicke et al., 2020a). Digitization creates a complete integrated system that is transparent to all the members involved in the supply chain, and it enhances members' capability to anticipate risks; thus, digitization could play a vital role in developing resiliency.

Next, we will discuss operational strategies related to resiliency. The study of Tukamuhabwa et al. (2015) highlights that the key operational strategies for building supply chain resilience are flexibility, redundancy, supply chain collaboration, and supply chain agility. *Flexibility* is the ability to adapt to changes at minimum cost, time and/or effort. Flexible strategies help in rapid supply chain recovery during disruptions. *Redundancy* creates resilience by allowing firms to use spare resources during demand and supply surges, such as surplus inventory or multiple suppliers of the same product part. However, incorporating redundancy into a supply chain may sometimes be very costly, such as through holding costs for surplus inventories or administrative costs for multiple suppliers. *Supply chain collaboration* refers to the ability of the supply chain members to act as a single entity and work together for the mutual benefit of all the members. This cooperation enables better supply chain planning and risk profiling and can substantially mitigate uncertainties in supply chain. *Supply chain agility* refers to the change in supply chain process in response to any disaster. Supply chain agility comprises of two factors: *supply chain visibility* and *supply chain velocity*. Supply chain visibility is the ability to monitor the entire supply chain environment while supply chain velocity focuses on the strategies of quick recovery against disruptions.

Finally, in light of COVID-19, we address one other important perspective on supply chain resilience: the intertwined supply network (ISN). An Intertwined Supply Network (ISN) represents the interconnectivity of the supply chains that support various markets and society. For example, in March 2020 during the COVID crisis, Vincenzo Boccia, the president of the Italian chamber of commerce Confindustria, highlighted the interconnectedness of different industries' supply chains and stated that it is very difficult to determine the most vulnerable supply chain in Italy since "the suppliers in the automotive sector are at the same time producers for valves for respirators" (Ivanov and Dolgui, 2020). The existence of intertwined supply networks means that supporting one industry's supply chain resilience has complimentary benefits for other industries. This means the ISN is societally important during the pandemic in that supporting one industry's supply chain may simultaneously contribute to the survivability of other supply chains related to food distribution, communication, and other essential services. Thus, the COVID-19 outbreak has reinforced that resilience strategies need to be designed with intertwined supply chains in mind for overall market and societal well-being.

In this article we discussed the different sources of supply chain disruptions, the concept of supply chain resilience, and the various strategies to make supply chains more resilient. We also highlighted the importance of ISN viability to ensure long term survival during large disruptions. Supply chain resilience is an emerging area to explore for budding OR/MS researchers and an essential field for supply chain practitioners.

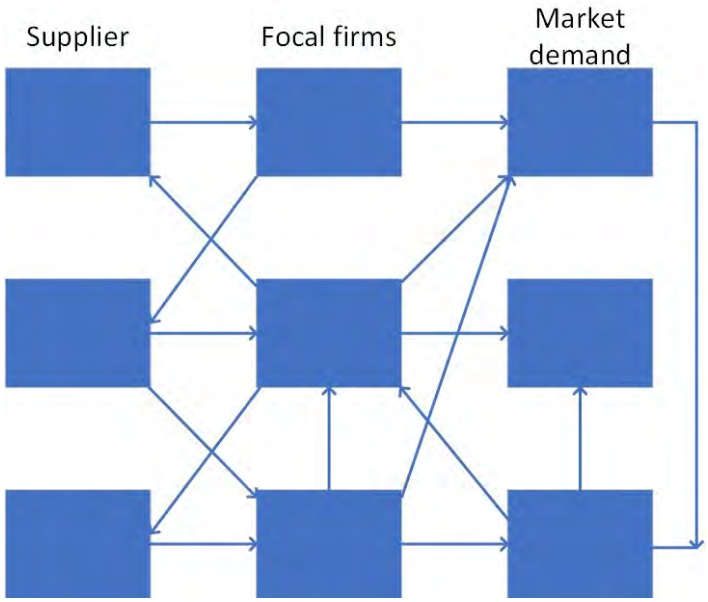


Figure 1: A typical ISN network

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How to be Racially Inclusive as Students, Educators, and Scientists in the OR/MS Field!



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My name is **Julie Simmons Ivy**. I am a tenured full professor in the Edward P. Fitts Department of Industrial and Systems Engineering at North Carolina State University. I am also the first and only African-American female full professor in my department and the second in the College of Engineering. It seems overnight I went from having no voice to being asked to be a voice for all African Americans. I am not sure that I am ready. In fact, it is not a role that I can play – I cannot speak for all African Americans. I can only share my story and my vision for what I would like to see in the future.

I know for many members of the INFORMS community these are very confusing and scary times. If you are not from the United States (US), it can be even more confusing because you have one vision of the US. You may be realizing that it is not really living up to this vision for all people. You may not have realized that for some of us, it has never lived up to its constitution.

In fall of 1995, I was selected to attend the INFORMS Doctoral Colloquium and Annual Meeting in New Orleans as a relatively early stage doctoral student from the University of Michigan. It was my introduction to my community of practice and to the home of my profession. It was an overwhelming and life changing experience. I now saw the greater community of operations researchers and management scientists – people who looked at the world from the same lens I did. However, there were very few people who looked like me. Although I have attended most if not all of the Annual Meetings since my first in 1995, INFORMS has not always been the most comfortable place for me.

Despite this, since completing my PhD in 1998, I have become an active member of INFORMS, serving in many officers roles in the Health Applications Society (it was a section back then), serving on panels, committees and working to build a relationship and network within my community of practice. Then in 1999, the INFORMS Minority Issues Forum (MIF) was formed by **Mark Lewis**, **Illya Hicks**, **William Christian** and **Tasha Innis**. With this INFORMS became not only my community of practice but my professional home. I remain involved in the MIF community – my home within INFORMS. I am particularly enjoying watching it grow and flourish as more underrepresented minority graduate students join and transition to faculty members and industry leaders and MIF leaders. While our numbers are growing, they are not representative of the population and they are still extremely small.

While MIF is a comfortable place, INFORMS can improve in the areas of inclusion specifically for underrepresented minorities. As operations researchers and management scientists, we know that it is always possible to do better, that is the foundation of our science. It is our role to think about how we can as a community do the hard work to become more inclusiveand serve as a model for our profession and for others. I believe this conversation and the work that has been done over the past couple of years with the introduction of the INFORMS Diversity, Equity and Inclusion Committee are setting the stage for this hard work to commence.

I appreciate the student editors of OR/MS Tomorrow for the invitation to write an article about the current events around racial injustice and the thoughtful questions that they have posed. To provide the best possible answers from a variety of perspectives, I have shared the questions with the INFORMS MIF Board and former MIF Board members. All of their opinions and experiences are represented in the responses.

Thank you to the current and former MIF Board members for their thoughtful responses to the questions from our INFORMS student members.

- 
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  Dr. Illya V. Hicks,
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  Rice University
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  Dr. Mark E. Lewis,
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  Cornell University
- 
  Dr. Emmett Lodree,
  Professor of Operations Management,
  Culverhouse College of Business,
  University of Alabama
- 
  Dr. Maria E. Mayorga,
  Professor of Personalized Medicine,
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  North Carolina State University
- 
  Dr. Rubén A. Proaño,
  Associate Professor of Industrial and Systems Engineering,
  Rochester Institute of Technology and the current President of the INFORMS Minority Issues Forum

What racial biases, if any, exist in the classroom or workforce that bar students of color from entering the OR/MS fields?

Illya Hicks: Implicit biases. This shows up in teaching through the Pygmalion effect (how a teacher's expectations correlate with a student's performance). We have to get beyond just the metric of research in academia and focus on holistic people that are good researchers that also care about people and are aware of their implicit biases.

Mark Lewis: Just like the rest of society, we are battling history. For a long time, when I said "HBCU" I was met with a blank stare. If I were (again) a young Black student, why enter a field that has very few Black people? I love what Gabriel Zayas-Caban and Emmett Lodree are trying to do. Show the young URM students that this can be an exciting field with several places like the MIF that are welcoming, encouraging and hopeful that you will succeed.

Emmett Lodree: Like Mark said, a major barrier is that there just aren't enough URM students and faculty in the field to begin with. Students may not be as likely to pursue the field where they are not as likely to fit in socially or where they feel like they can't really connect with any of the professors. For students who do have the courage to give it a try, they may end up feeling isolated because there are no or too few URM students and faculty in the department.

Rubén Proaño: There are language biases toward minority students. English is a fluid language that does not have a governing body. Yet, as soon as people hear you speaking with an accent, there is a judgment, and people stop paying attention to what you are trying to say.



How can we create an anti-racist class and teach equality in our class of graduates?

Illya Hicks: Here is a **link** my school has. Faculty members should make an effort to incorporate more diverse scholarly research within their courses. For example, if a URM made some contribution that is relevant to the course, explicitly state that and highlight it with historical context.

Mark Lewis: Most schools have humanities departments. Connect with someone who studies Race/Ethnicity within those schools and ask that their course gets listed as a humanities elective. Depending on your school, you might find a set of courses. If you have the right leadership, they could require that all students take a course from that set of courses.

Emmett Lodree: Think about some different delivery mechanisms: (i) a formal course, (ii) a seminar series, (iii) orientation training, (iv) subsets of (i), (ii), and (iii). Mark touches on (i), so I will address (ii) and (iii). My department has a seminar series for PhD students, as do most PhD programs. You could request from the PhD program/graduate coordinator in your department that one or more of these seminars address this topic. For option (iii), petition that any graduate student who receives funding from your department, college, and/or university complete training related to implicit bias and race relations. Request that the training be a mandatory part of the in-person orientation process as opposed to watching a video on their own time. This request may have to go to your college dean or associate dean.

Rubén Proaño: An anti-racist classwill be mostly attended by those who are already non-racists, and even by those who have been victims of racism and biases. We need to consider how everyone could take courses that raise awareness of inequities, disparities, and racial biases. Several liberal art courses in History, Sociology, and Public Policy can offer a thought-provoking perspective on these issues. As faculty members, we can suggest students take different course sequences to meet the degree requirement. We should try to suggest more courses to help students learn more about racial/ethnic issues in the US.

When we see racism in the lab group, how should we react and what should we do?

Illya Hicks: Talk to a supervisor (grad student, postdoc) and the professor. If you have to, go to the department head and dean.

Mark Lewis: This is a difficult one, because you are going to have to go back to the same lab. My recommendation is to seek out an advocate on the faculty to do the reporting for you. Ask that they document it. Most universities (in my opinion) are not going to react to an isolated incident unless it is severe. Documenting helps establish a pattern.

Emmett Lodree: If racism in your lab affects someone else, be there to support the person it happened to. Try to be there every step of the way in helping to identify formal and informal channels to get the situation resolved. If it happens to you, get it off of your chest by talking with your friends who are there, extended friends and family who live somewhere else, and mentors. In general, just talk with people you trust, and together you will likely formulate an action plan on what to do next.

Rubén Proaño: Faculty members should update their course syllabus to make it clear that any explicit or implicit form of racism among students and faculty is not tolerated.

Maria Mayorga: It is also important to acknowledge what you see. Often people experiencing racism are told that maybe they misinterpreted something, it was just a joke, or they are overreacting. If you see something, acknowledge it and say something.

How should we react to racism among our fellow faculty members toward both other faculty members and students?

Illya Hicks: Report to department head, dean, provost, president. They should be uncomfortable.

Mark Lewis: I like the idea of reporting it, but I would start with a person (who may not be in leadership) who you trust to discuss it. And always document your complaints.

Rubén Proaño: We should report it. All universities have a process in place, which should be well known to all faculty members. Universities also have an ombudsperson who can help channel these reports if there is a concern for reprisals.

Emmett Lodree: In addition to documenting the actual incidents, also document what happens after reporting to your department head, dean, president, etc. If you do not receive satisfactory responses and actions from your administrators, seek legal counsel.

What is the most impactful way we can be an ally and anti-racist through research publications and projects? For example, should we seek out citing black researchers? Should we include a section on disparities in our work?

Illya Hicks: Yes, cite URM researchers. Try to collaborate with URM researchers. I would caution to only include disparities in research when it is a part of the research though.

Mark Lewis: Where we can, we should advocate for each other on all levels.

Emmett Lodree: OR/MS as a field needs to figure out ways in which we can contribute to research in the racism/discrimination space. The work that Dr. Michael Johnson does in the area he calls "Community Operations Research" is an example of research that is relevant to race and discrimination. I would personally like to see a subfield called OR/MS applications in race and discrimination that would eventually become a mainstream INFORMS section or society, and also a department area in top INFORMS journals, namely Management Science and Operations Research. I see this as a longer term goal to work towards.

Rubén Proaño: Our journals often ignore the impact of innovative ideas. We have tons of publications that deal with marginal technical enhancements. However, there are ideas whose influence over time grows in diverse ways. Yet they are dismissed in our review processes because they are considered simple applications of published theory. This behavior incentivizes volume rather than long term impact. Not all faculty, especially minorities, have access to resources that can help produce in volume. We need to change how we assess publications so that we reward the impact of ideas.

How can we empower and encourage young black students to pursue STEM fields or graduate study?

Illya Hicks: Focus more on applications that black students would be interested in. Do a survey of the black undergrads. We also have to expose them early to research and show them that academia is just as exciting and important as an industry job out of undergrad.

Emmett Lodree: (1) Money - financial incentives including scholarships, fellowships, grants, research assistantships, and teaching assistantships set aside for URM students to pursue undergraduate, masters, and PhD studies in our field. Meaningful stipends for URM undergraduate students to participate in research projects/programs would also be helpful (the stipends I've seen are not substantial enough to make much of a difference relative to the cost of tuition and fees). (2) Black professors, professionals, and current PhD students have to recruit them by reaching out to promising undergraduate URMs that they interact with in their courses or on their jobs. Unfortunately, there are only a few URM undergraduate students in the field at my university, which means that even fewer of them have the desire or mathematical ability for graduate studies. (3) With so few students in undergraduate programs, we need to solve that problem first by recruiting high school juniors and seniors possibly through project-based research projects in our field. This would take money.

Shannon Harris: MIF and INFORMS should volunteer at local middle/high schools to help empower and encourage young black students to pursue STEM. If they see us and can talk to us, I think that can help.

Maria Mayorga: Make undergraduate students aware of your research; show your enthusiasm and encourage them to engage in undergraduate research. Many students may have never considered graduate education. (For me it was not until I met several URM graduate students that I even thought it was a possible avenue.) Be sure to encourage and advise talented students.

How can we best support the success of our black peers and friends in graduate programs?

Illya Hicks: As faculty, we need to be advocates for URM graduate students. As students, collaborate and help increase their visibility.

Mark Lewis: The strongest advocate you can be is to be present. Start a Slack channel to let people know which conferences you will attend and make it a point to connect.

Emmett Lodree: Mentorship program.

Rubén Proaño: I agree with Lodree. Mentorship programs at an early stage are key to encourage students to consider STEM disciplines and to succeed in their efforts.

Maria Mayorga: As students, be intentional in including your peers to activities both social and academic; for example study groups, review groups for talks, etc.



There are almost no African-American faculty in my school! How can we make sure that universities and especially engineering schools consider equality in hiring faculty members?

Illya Hicks: Put pressure on your dean, provost and president. Have a petition. Have the minority organizations write a letter. Ask for a meeting with them. Minority faculty members or allies should try to be part of search processes, and actively invite minority graduate students to apply for the position.

Mark Lewis: Agree with above, but also do your homework. What are other universities doing? Here is a **report** from a task force on faculty diversity I chaired a couple of years back. The focus is on both URM and women faculty. If your university is doing very little, you should ask if they would be willing to glean ideas from the greater community.

Emmett Lodree: (1) As mentioned above, go to the higher ups at your university and ask what they are doing to increase the percentage of URM faculty there. This should come from a unified voice that includes as many URM student and faculty organizations as possible at your university. (2) There aren't enough URM applicants to begin with, so get your university to invest in fellowships, assistantships, recruiting trips, etc. to increase the number of URM students in PhD programs. This is a solution that would address the problem in the long run, and other universities would have to do the same for it to work.

Rubén Proaño: In my department, as part of the faculty search process, we ask the candidates to interact with our undergraduate and graduate students over a meal (breakfast, lunch, or dinner). During these meetings, our students can assess the candidate and offer a perspective on the candidate's interest in the students, teaching, research, and her/his capacity to attract a diverse pool of students to our department. Minority students are encouraged to volunteer and participate in these meetings. The students' evaluations are carefully considered during the candidate's final assessment. Ask your university to consider having an informal meeting between faculty candidates and groups of students. Make sure that representatives of minority student organizations are invited to be part of these meetings. I agree with Lodree's comment that universities must increase the number of URM applicants.

What are the specific operational and recruitment policies that industries and universities should follow to encourage diversity and equality for all?

Emmett Lodree: (1) I can't really think of operational policies, but strategically your college should have an administrative position dedicated to diversity and/or URM issues. If your college doesn't, petition your dean to create such a position and/or run the idea by URM faculty in your college. As a URM applicant, I would be more comfortable working for a university that has a dean for diversity in the college for the department I would be in. (2) Invite URM scholars as guest lecturers and/or seminar presenters on a regular basis. That way, both sides can "feel each other out", and the formal interview can come later. (3) Money. Your college and/or university has to finance a dean/director of diversity position in your college, and finance a URM seminar series.

Illya Hicks: We need more minority candidates making the short list and being allowed to interview (look at the NFL Rooney rule)for graduate study. Focus on what I call the gatekeepers. We have to have hard discussions about how one defines success; what is a good or baseline acceptable candidate; that everyone has different backgrounds; and that an insufficient background is not an indicator of an unsuccessful candidate.

Mark Lewis: In hiring there are multiple "pools". There is the talent pool of people that apply, and then there is the interview pool of people that get interviews (Zoom or otherwise). What a lot of places have focused on is the first and not the second. At the faculty level, there should be oversight at each level...all the way up to the offer letter. Check out the **Strategic Oversight Committee**. We have had some success for women hiring. We need more for URMs. As for graduate students, make certain to recruit at national events and then follow up. Secondly (and more importantly) find out what metrics people use to evaluate candidates.

Should we talk about race with students?

Mark Lewis: This is a loaded question. Who is the "we"? If you are African-American, you talk about and are asked to talk about race all the time...as though one person speaks for 50 million people. If "they" are serious about it, they need to discuss it, and discuss and discuss it.

Emmett Lodree: I assume you mean talking with students who are not underrepresented minorities, and I also assume that you are referring to informal settings (e.g., in between classes or at lunch) as opposed to formal (e.g., a panel discussion on the topic of race). I agree with Mark that this is a loaded question and that there are many possible answers. A general answer is that it depends on how comfortable you are with the student(s) you interact with.

Rubén Proaño: Yes, do not be afraid to talk about race, ethnicities, and cultures. It is worth sharing different perspectives on problems. We need to help our students realize their prejudices.

How can we talk about race when the majority of the students are white?

Illya Hicks: Just do it. Have an informal open forum setting with food and breakout rooms to induce open and honest discussion.

Mark Lewis: You can have a facilitator. Most universities have them on staff. You should do a "pre-meeting" with the facilitator to explain what concerns you might have with even having this discussion.

Emmett Lodree: Connect with Black organizations on your campus. When I was an undergraduate student, that was NSBE (the National Society of Black Engineers). As a graduate student at U. of Missouri, we had a really active organization called the Association for Black Graduate and Professional Students that brought students from many different majors together, many of whom I am still in contact with. I suspect most universities would have student organizations like these, but if yours doesn't, consider starting one. Lastly, do exactly what you're doing now: reach out to the INFORMS MIF.

Rubén Proaño: As minorities, we often try not to share our different perspectives on daily problems with our students. We should take every opportunity we have with students to share our opinions on current events and life in general. American minorities have a very diverse cultural heritage that is not shared. Engaging with students beyond the classroom to talk about life, sharing meals, and offering a different perspective on their problems helps students realize that, as human beings, we share similar problems and goals. Yet, not everyone has the same opportunities to resolve their conflicts or succeed in achieving their goals. Sharing our cultural heritage with our students also helps them realize that there is usually no unique solution for similar problems.

Do you have any suggestions or programs that can be implemented in the INFORMS student chapters to promote racial inclusion?

Illya Hicks: Call out double standards when possible. Also, as a group, have hard discussions on equity within the chapter and the profession.

Julie Ivy: A student chapter of INFORMS can host events to build community among members and expose other students particularly undergraduate students to the field of operations research and management science. This can include events that allow your members to share their cultures with each other - food always helps - consider a potluck. A student INFORMS chapter should consider partnering with other student organizations such as NSBE (National Society of Black Engineers), SHPE (Society of Hispanic Professional Engineers), AISES (American Indian Science and Engineering Society), and SWE (Society of Women Engineers) on a research symposium, poster session, or case competition - activities that expose students to OR/MS. A student INFORMS chapter could partner with their department or college to invite underrepresented minority researchers to visit your campus for a seminar. Consider having service activities within K-12 students to expose them to OR/MS with a focus on schools with higher populations of underrepresented minority students. An important component of creating an environment that promotes equality is building relationship, community, and trust among members. In doing so creating environments that are comfortable and safe for all members of the community.

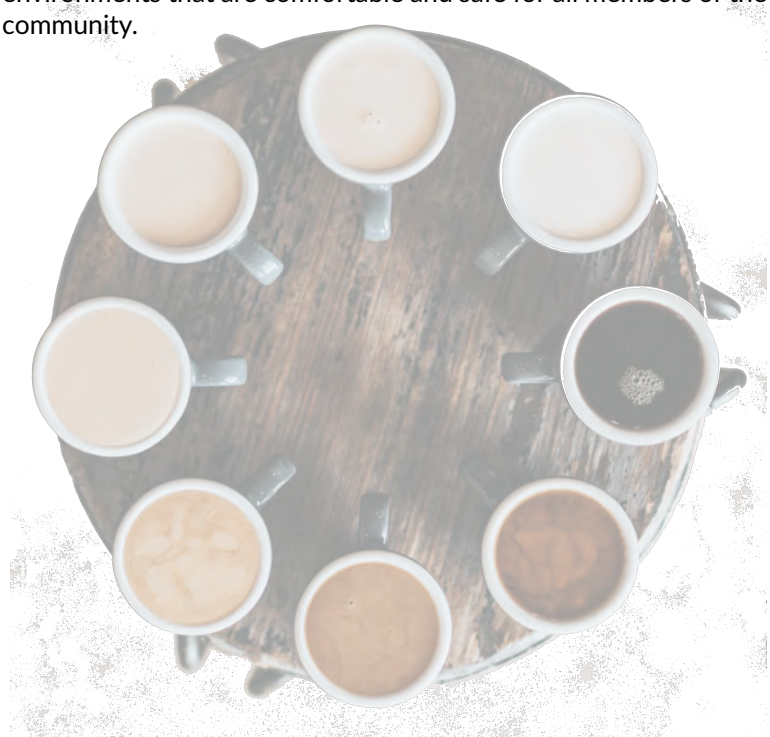




Figure 2: Arctic shipping routes, Source: The Arctic Institute



Figure 3: Container ship in the Arctic, Source: Arctic Council

Silver Lining of Global Warming? To the Routes in North!



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Global warming and sea-level rise are, for sure, a worry. Many major ports are on the front line in fighting with these dramatic effects. Solace for the maritime industry is the emergence of a potential new shipping route from the melting glaciers in the Arctic sea, as shortcuts to connect the world's major markets. The most compelling advantage of Arctic shipping is its distance. the world's busiest route between East Asia and Europe, traversing in the Arctic can decrease to 40% of the total distance. Natural resources, such as hydrocarbons and rare minerals, are another incentive for Arctic shipping growth.

On the other side, the major concerns of shipping in the Arctic are the uncertainty and technical requirements posed on both ships and facilities because of the extreme environment and constantly changing ice conditions. Even with icebreaker escort, additional construction cost is needed to reinforce vessels to navigate in ice-covered areas. Substantial investment is expected in ports and facilities alongside Canadian and Russian coastal areas to put Arctic routes into use and provide basic cargo handling, navigation, and rescue services.

Container shipping companies do not agree on adopting Arctic shipping and the shortened distance of Arctic routes does not lead to the enthusiasm in these new routes**?**. While some liners rejected Arctic shipping routes because of environmental concerns, many trial voyages have been conducted by pioneering companies since 2013.

Academia mainly focused on the economic and navigational viability of Arctic shipping, and there are very few studies on its socio-economic impacts, considering the vulnerability in the Arctic area. The externalities of freight transportation in the North, which include the impacts of air pollution on local people, implications for global warming, and risks of an oil spill, should be further investigated.

The transport volume in arctic shipping routes is preliminarily estimated with a series of very generous assumptions on voyage conditions to identify any external costs. Based on a logit model incorporating different transport options, Arctic shipping route can take up to 13% market share of the container transport volume. As a comparison, the traditional shipping routes via the Suez Canal or Panama Canal would take almost all the left market share, whereas the rail and air transport options are negligible.

It is found that environmental costs by using Arctic routes tend to be higher than conventional options due to their smaller ship size and lower load factor. The successful development of Arctic shipping routes would lead to worse environment outcomes per unit. Because the Arctic area is more vulnerable and important to the entire global warming problem, imposing emission charges or higher canal fees on Suez Canal and Panama Canal would push traffic volumes to the North, which is undesirable from the perspective of global environmental effects.

Future studies should endeavor to investigate other externalities of Arctic shipping. More specifically, the first venue is how the local ecosystem would be affected by shipping noise, oil spill, and other disturbance. The second aspect is how the commercialization of Arctic routes would impact on its landside communities. The routine shipping in these sea areas would significantly change local people's hunting and fishing behavior and threaten their food supply security. However, this does not imply they are entirely opposed to the open of Arctic routes. Local communities want their voices heard, be involved in setting regulations, and an improvement to their quality of life through more job opportunities and resources. Therefore, together with quantifying the costs to local communities, research should also be focused on how to benefit both local people and shippers to achieve a win-win situation.

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Forecasting in the World of Big Data

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The International Data Corporation forecasts that in the next five years, the total data stored on servers worldwide will exceed 175 billion terabytes (Reinsel et al., 2018). The enormous amount of data available nowadays has served as the basis for many significant innovations and triumphs in data analytics. Forecasting, one of the oldest data-analytic disciplines, has witnessed some particularly exciting developments in the face of big data. Rather than problems involving individual or small groups of time series (data indexed by time), many modern forecasting problems present with hundreds or thousands (even millions) of time series, especially in the fields of business and economics. Modern machine learning methods, capable of consuming large amounts of data to separate signal from noise, provide forecasters with a powerful toolkit for tackling these problems. Here, we take a look at several contemporary applications of machine learning in forecasting and discuss how such methods help forecasters to make remarkably accurate predictions.

Traditionally, forecasting has involved statistical methods such as autoregression and exponential smoothing applied to individual time series. These methods learn temporal patterns from the series they are trained to forecast. What may come as a surprise is that even the most sophisticated machine learning methods consistently lose to these classic methods if they are trained only on the forecast target (Makridakis et al., 2018). One reason for their underperformance is that a single series often does not contain enough information to fit an elaborate model. However, in many contemporary problems, there can be an extensive set of time series available to the forecaster. For such problems, it is possible to improve on classic methods, sometimes substantially, by training machine learning models across multiple time series. Both Uber and Amazon fit deep recurrent neural networks on huge time series databases to predict future demand for their products. In particular, Uber forecasts rideshare demand during special events by training neural networks on historic rider and driver data from hundreds of cities (Laptev et al., 2017). Amazon uses neural networks to forecast item-level sales based on the historic demand for thousands of related products (Salinas et al., 2020). These approaches are novel in that they learn across multiple time series, rather than on the forecast target only. The motivation is that information can be shared across time series to better learn complex temporal dynamics, something deep neural networks can facilitate via their ability to extract features automatically.

Similar techniques to those used at Uber and Amazon took out the top positions in the recent M4 forecasting competition. M4, so-called after its organizer Spyros Makridakis, is the fourth iteration in a series of famous competitions that began in the 1980s. Participating teams were required to forecast 100,000 time series spanning business, finance, economics, and demography. Uber data scientist Slawek Smyl produced the winning forecasts by mixing neural networks with exponential smoothing. This approach, described in detail in Smyl (2020), learns global model parameters across the full set of time series and hierarchically incorporates these with local parameters learned on the specific series being forecast. The second-place submission (Montero-Manso et al.,

2020) combined forecasts from nine classic methods, including autoregression and exponential smoothing, using weights generated by gradient boosted trees to form an ensemble forecast. The trees were grown on the full set of time series, allowing them to learn the ensemble composition appropriate for the temporal patterns present in the forecast target, a technique they refer to as "meta-learning." The distinguishing characteristic of these two teams is that their forecast methodologies augment battle-tested statistical methods with machine learning. Unsurprisingly, such approaches are not computationally cheap, and require between a week and a month of computational resources. Nevertheless, it would seem to be a fair price—Makridakis et al. (2020) observed that, on average, forecast accuracy improved with computation time across a broad set of M4 teams; see Figure 4.

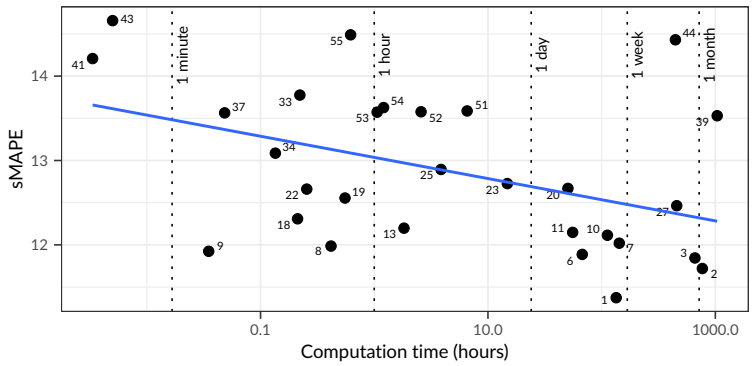


Figure 4: Forecast accuracy, measured by symmetric mean absolute percentage error (sMAPE), expressed as a function of computation time for forecasting methods from the M4 competition. The labels indicate finishing places. This figure is reproduced from Makridakis2020.

Big data has also permeated economics. In fact, economists advised governments by analyzing hundreds of economic time series as early as the 1930s (Fuleky, 2020). Nowadays, big economic datasets are updated in real-time and are publicly accessible; see FRED-MD and FRED-QD. Forecasters use these databases to train models for predicting policy-informing variables such as gross domestic product (GDP) growth, unemployment, and inflation. An important feature of economic time series is that they can be directly predictive of one another. For example, unemployment this month has the potential to tell us something about future GDP growth. As a result, forecasters often use large sets of economic time series as predictors in machine learning methods. Medeiros et al. (2019) trained a random forest to forecast U.S. inflation using roughly 500 predictor time series and showed that the resulting model delivers state-of-the-art accuracy. Unlike classic methods, random forests are able to learn complex nonlinear relationships between the forecast target and the predictors, which the authors argue explains their excellent performance. In the same vein, Exterkate et al. (2016) showed that kernel ridge regression leads to good forecasts for a variety of important economic variables. Kernel ridge regression combines regularized regression with the famous "kernel trick" to capture nonlinearities in the data. Other regularization tools such as the Lasso also yield high-quality forecasts (Li and Chen, 2014) and have the particularly attractive quality of producing interpretable models that depend only on a fraction of the predictors.

So, what does the future of big data forecasting hold? This question is one that we should have an answer to soon enough, at least in part. The fifth iteration of the Makridakis competitions (M5) is well underway and due to conclude shortly. Hosted on the data science platform Kaggle, it is the largest competition yet, with more than 5000 registered teams and $100,000 in prize money. This round, the challenge is to forecast sales for Walmart at the item, department, product category, and store levels—approximately 40,000 series in total. M5 is thus an important continuation of research into big data forecasting, which we anticipate will lead to new and exciting applications of machine learning.

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Operations Research Applications in the Last Mile Distribution System



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Nowadays, the last mile distribution system accounts for about 30% of the total distribution cost, which has become the biggest problem plaguing logistics companies, e-commerce companies and related businesses. These organizations face a tradeoff between controlling the cost for logistics and enhancing customer experience. Improving the quality of service may incur unbearably high distribution costs while decreasing the cost of logistics may degrade the service quality. In contrast to the conventional parcel delivery, diversified delivery services are more attractive in the context of e-commerce last mile delivery. For example, many major e-tailers such as Amazon or JD maintain their own fleet to handle same-day deliveries (McKinsey Company, 2014). Similarly, some logistics companies like Australia Post provide self-pick-up service for customers by placing parcel lockers at opportune locations. In addition, increasing awareness about the need for alleviating the environmental footprint of logistics operations has increased the necessity of reverse logistics and accelerated the adoption of low-emission vehicles (e.g., electric vehicles). For example, UPS has recently expanded the size of its fleet of electric vehicles (EVs) by working with a wide array of manufacturers (UPS, 2018).

Within this context, logistics companies face many issues and interesting problems which fit well within the optimization framework. For example, companies need to decide whether to incorporate new delivery services or EVs into their current distribution systems. Companies also need to consider which delivery services to select, such as home delivery, collection of convenience stores or parcel lockers. Finally, a key issue for companies is to redesign their pickup and delivery options while reducing the total cost as much as possible. Applying operations research techniques can provide invaluable help in addressing these issues to achieve better decision-making. Many of the relevant optimization problems have been well studied by researchers.

The most relevant problem for last mile delivery operations is the two-echelon vehicle routing problem with covering options (2E-VRP-CO) developed by Enthoven et al. (2020). In their study, they consider a two-echelon distribution system including the last mile distribution system as the second echelon. Customers can be served by home delivery (cargo bikes) or parcel lockers within a specified covering range. They also design an efficient adaptive large neighborhood search (ALNS) heuristic for the 2E-VRP-CO to provide high quality and near optimal solutions for real-sized instances. It is worth mentioning that ALNS proposed in Ropke and Pisinger (2006) has been successfully used on related vehicle routing problems (VRPs) and location routing problems (LRPs). The ALNS is based on the heuristic algorithm of destroy and repair mechanisms and has strong universality since it does not depend on the specific problem structure.

Another related problem is the vehicle routing with demand allocation problem (VRDAP) proposed by Reihaneh and Ghoniem (2019). This problem arises in the food bank distribution system. The decision-maker tries to assign customers to delivery sites and route a fleet of vehicles to deliver goods from a central depot to designated delivery sites. The authors investigated an effective branch-and-price (BP) algorithm to provide optimal solutions. Furthermore, computational results demonstrated that the proposed algorithm greatly outperforms commercial solvers such as CPLEX and decomposition-based heuristics in the literature. In fact, due to the high input and operating costs, many practical scenarios of the problem require high accuracy of solutions. Therefore, the application of exact algorithms, such as branch-and-price-and-cut (BPC) algorithm, is quite important for making profitable decisions. We refer the reader to Costa et al. (2019) for a survey on the leading BPC algorithms for VRPs.

Currently, a wide range of relevant research problems are also related to the use of EVs for goods distribution. Recent publications mainly focus on the following three aspects: (a) the charging strategies of EVs (partial recharges or full recharges), (b) the locations of charging facilities (recharging stations or battery swapping stations), (c) the uncertainty related to batteries (travel range or energy consumption). For the first two aspects, researchers usually define the battery level and the location of charging stations as new decision variables, respectively. For the last aspect, approaches that integrate uncertainty into optimization models, stochastic optimization and robust optimization, are developed to solve problems. Gounaris et al. (2013) study several VRP variants with uncertain demand and Costa et al. (2019) provide an extensive review of exact algorithms for the robust VRPs. In general, new problems can be solved by extending or modifying existing problems, and then the existing algorithms can be applied to solve the problems. Hence, we refer the reader to Savelsbergh and Van Woensel (2016) for a survey on the solution methodologies for city logistics. For recent surveys of the related technological and marketing background of EVs, we refer the reader to Pelletier et al. (2016). For a comprehensive overview of optimization models for EVs, we refer the reader to Shen et al. (2019).

To conclude, the technological edge and convenience offered by e-commerce has driven a steady increase of parcel volumes, which accentuates the pressure on last-mile delivery systems and leads to a demand for new logistics solutions. Therefore, applying operations research methods to optimize the last mile distribution system in order to realize resource sharing and improve service quality is particularly important.

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From Cocoa to Chocolate



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If you ever savored a bar of chocolate, sipped a cup of hot cocoa, or indulged in a slice of chocolate cake, you are benefiting from the work of countless farmers, firms, and distributors who coordinate the operations of the complex cocoa supply chain. We spoke with Srinivasan Balan about his experience in this process. From 2012 to 2015, Srinivasan, current Industrial Engineering PhD student at North Carolina State University, worked for Olam International Ltd., a leading agribusiness company, and managed the supply chain for, among other commodities, cocoa in West Africa.

Q: Can you tell us a bit about the history and current state of cocoa and chocolate?

Cocoa dates back three thousands years. In Mesoamerica, the Mayans and Aztecs considered the cocoa tree a god and drank cocoa juice during religious rituals. Today, cocoa is one of the largest traded commodities in the terminal market (an assembly and trading place for commodities). Between 2010 and 2019, cocoa farmers worldwide collectively produced 4.8+ million tons of cocoa annually. Ivory Coast alone employs over 6 million cocoa farmers and ranks as the world's top cocoa producing country with 2.1+ million tons of beans produced annually.

Trends in chocolate highlight the rapid growth of cocoa production. In 2010, the chocolate industry was worth $70 billion and is predicted to grow to over $200 billion by 2025. Europe, the largest market for chocolate, accounted for 49% of the global market share in 2017 with Switzerland ranking as the continent's largest per capita chocolate consumer at 10.5 kg (23 lbs) of chocolate per capita. In Asia, however, per capita consumption remains small (300 g in India and 400 g China), but rising purchasing power and rapid national growth has prompted increased consumption.

In emerging markets, the annual consumption rates of cocoa butter and cocoa powder, key chocolate ingredients derived from roasting and pressing cocoa beans, are growing at compound annual growth rate of 7% and 5%. Assuming steady world population growth of 1.2%, growth in the cocoa grinding pace of 3%, and expected chocolate consumption growth rate of 7.3% by 2025, growers and processors will not be able to meet demand without effective agronomic practices supporting a high quality, high-yield cocoa crop.

Q: What affects cocoa yield and price?

First, cocoa requires very specific growing conditions - high annual rainfall, humidity, and temperature (minimum 16C) - so about 30% of cocoa beans never make it to processing because of mold and disease. To combat these threats, the International Cocoa Organization (ICCO) is conducting research to develop disease- and drought-resistant cocoa trees. In addition, government-supported rehabilitation, replanting schemes, and improved chemicals and fertilizers are boosting cocoa bean yields. For instance, the government of Ghana proposed various propagation techniques to improve cocoa production and integrated crop & pest management for mature farms.

The price of cocoa is sensitive to the political and economic conditions of the exporting countries. Most cocoa production occurs in West Africa - the Ivory Coast and Ghana together provide 60% of the global cocoa supply - and conflicts in this region impact regional and global cocoa prices. For example, in 2010 a civil war in the Ivory Coast significantly affected exports, and the primary procurement price for cocoa in West Africa surged drastically.

Local currency fluctuations also affect the price of cocoa beans. For example, in Nigeria, the primary procurement price, including direct costs and overhead, of 1 kg of cocoa beans in 2015 was 550 Naira, equivalent to $2.75 ($1 = 200 Naira). Just two years later, the price rose to 700 Naira per kg while the Naira lost some of its value ($1 = 450 Naira), so the equivalent price decreased to $1.56 per kg.

In the terminal market, cocoa future prices dropped drastically from $3,422 per tonne in late 2015 to $1,769 per tonne in mid-2017, which influenced the price paid to farmers for their cocoa beans (the farm-gate price). Futures and options on the London International Financial Futures and Options Exchange (LIFFE) and the New York Board of Trade, Coffee, Sugar, and Cocoa Exchange (NYBOT CSCE) allow producers to hedge this price risk.

Q: What do “cocoa supply chain” and “cocoa value chain" mean?

A value chain shows how companies add value to raw materials to produce finished goods for profit. The industrial grinders and chocolate manufacturers enhance product value, resulting in chocolates and other confectionery. Of the total cocoa supply chain revenue, 6.6% goes to the farmers; 7.6%, to processors; 35.2%, to manufacturers; and 44.2%, to retail. This shows how much value is added downstream in the value chain.

A supply chain shows how the product flows from suppliers to the customers. For cocoa, it begins with small-scale cocoa farmers. Cocoa beans grow on the branches and trunks of cocoa trees. Workers manually harvest and open the bean pods to separate the 20 to 30 sweet, pulp-covered beans inside and store them in baskets. Then the farmers ferment, dry and store the beans in preparation for transport. The fermentation and drying steps are important to reduce the bitterness and acidity of the cocoa beans.

Cocoa beans must be transported in jute bags to support ventilation and control moisture content. Quality inspectors gauge bean quality based on various parameters, including bean count per 100 g, moisture content, contamination, and appearance. A slatey appearance (greenish-grey or purple instead of dark brown), for example, indicates under-fermentation.

The next steps in the cocoa supply chain differ based on the origin country. The Ivory Coast, the world’s largest producer, and Nigeria, which produces 250,000+ tons of cocoa beans per year, follow a similar primary procurement model. Farmers sell their cocoa to government-approved local buying agents (LBA). The LBAs supply those cocoa beans, bagged in jute bags, to global trade houses (GTH), which generally buy cocoa beans from the farm gate, clean, process and transport them to the port city. From there, the beans are shipped to Europe or the USA. Generally, the GTH’s transaction budget takes into account direct costs and terminal-based profit to decide the purchase price at the farm gate.

The process in Ghana, the world’s second largest cocoa producer with 850,000+ tons per year, is different. The local supply chain falls under Cocobod, the Ghana Cocoa Board association. Farmers sell their beans through a government-approved trader or a License Buying Company (LBC), which pays them a price that the Producer Price Review Committee (PPRC) predetermines. Cocobod’s Quality Control Division then inspects the beans before Cocobod buys the beans for a PPRC-set price and sells them to the exporters and processors. Because of strict production and processing regulations through Cocobod, cocoa beans from Ghana are considered the finest premium cocoa. The biggest purchaser is the Netherlands, the home country of major cocoa grinders such as Cargill and Archer Daniels Midland.

At their destination countries, local processors roast the cocoa beans and shell them for the cacao nibs that, when ground, become cocoa liquor. Chocolate manufacturers like Mars Inc. and Hershey’s buy the cocoa liquor for their confectionery. Pressing the liquor creates two products: cocoa cake from the non-fat solid portion and cocoa butter from the fatty liquid portion. Cocoa cake is further ground to make cocoa powder. Of the two liquor derivatives, cocoa butter is more valuable, quoted at $7,728 per ton in March 2018, while cocoa powder cost about $1,800 per ton.

Once the final chocolate is ready to be shipped, the distribution or outbound logistics bring the product to the retail customers.

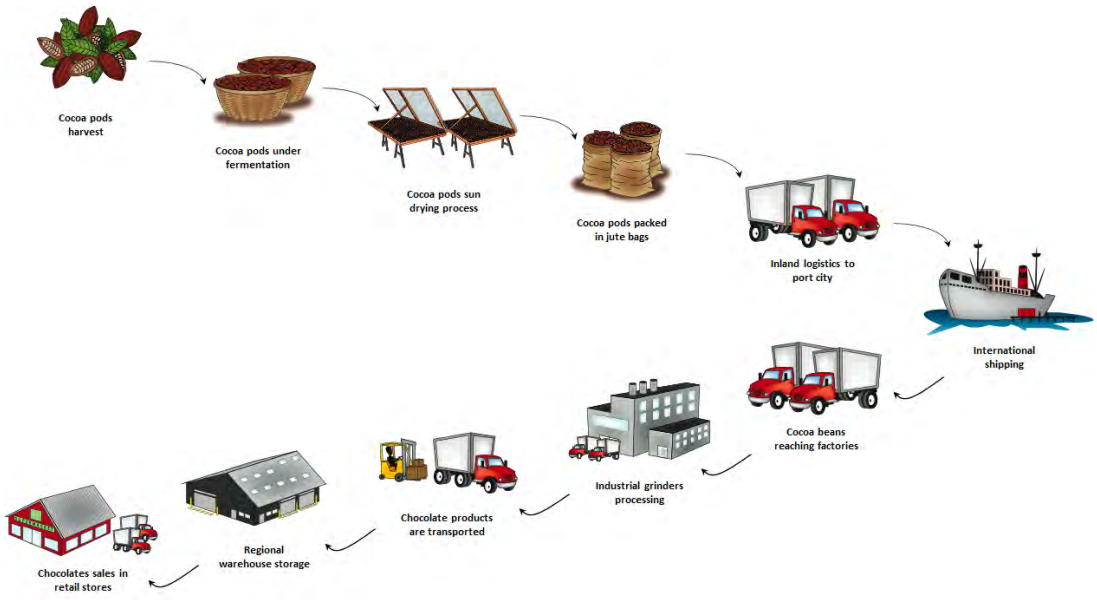


Figure 5: **Cocoa supply chain**

Q: Cocoa follows a long and complex supply chain, from small local farmers to, oftentimes, multinational foreign companies. How, if possible, might the supply chain be shortened for time and cost efficiency?



Cocoa passes through many hands. One way that some GTHs, including Olam, have tried to shorten the early stages of the supply chain while also enhancing their profit margin is to grind and process the beans in the origin countries, cutting out the separate processors. That way they export the higher valued cocoa liquor. Recently, Cargill announced its plans to invest more than $113 million in its Ivory Coast and Ghana facilities.

How can OR and other professionals help streamline the supply chain and/or help the cocoa industry keep pace with growing demand?

There are a few places where operations researchers and similar business and technical professionals play roles in cocoa value chain.

- In operations: Supply chain analysts are relevant in purchasing, manufacturing, crop procurement, and process improvements.
- In trading and planning: Business majors, data scientists and OR PhDs contribute to stock trading, futures & options trading, crop yield and planning problems.

Do you have any other thoughts on this topic that you'd like to share?

I think cocoa is a very exciting industry, and it is important to the many people who enjoy the fruits of its supply chain. I would just like to leave the readers with these questions:

1. What actions should governments take to enlarge the rehabilitation and replanting schemes that provide farmers with improved planting materials?
2. What incentives can the chocolate grinders and manufacturers provide to safeguard and improve the yield of cocoa crop year on year?
3. What can we do to ensure that the cocoa industry meets the ever-growing demand without affecting the livelihoods of the millions of farmers and traders in Africa, South America, and Asia?

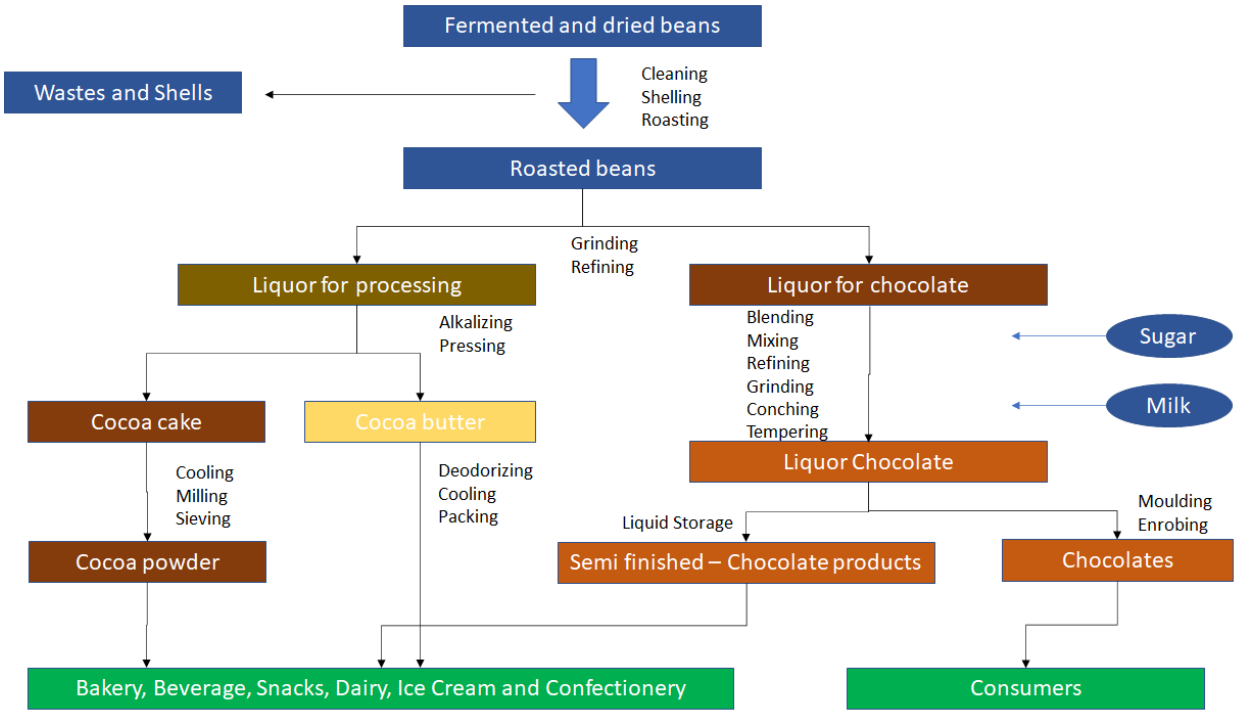


Figure 6: **Chocolate value chain**

Cybersecurity in Cyber Warfare: The Application of Demon Game Models



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Air, cyberspace, electromagnetic spectrum, land, maritime, and space are the six domains supporting human activity. Of the six domains, only cyberspace is entirely artificial and consists of digital networks, including the Internet, information systems and other communication networks (Bank of England, 2016). Although cyberspace is invisible, it creates massive opportunities for businesses, speeds up information exchange, and continues to transform human interactions.

In response to the threat of the potentially deadly coronavirus COVID-19, companies, governments, and schools around the world have encouraged people to work from home (WFH) to minimize the risk of infections. Workers and students use videoconferencing services, collaboration platforms, and other digital tools to conduct business and schoolwork. Shifting of physical meetings into the digital realm puts unprecedented pressure on network security and opens multiple vectors for cyberattacks, such as unsecured data transmission without using virtual private network (VPN) software (Boehm, Kaplan & Sportsman, 2020). Zoom's videoconferencing service has become a popular communication platform since COVID-19 pushed meetings, classes, and lectures online. However, several major security vulnerabilities in Zoom's software have been uncovered, including a security flaw that allows cybercriminals to take over a Zoom user's Mac machine (Singer & Perlroth, 2020). This cyber vulnerability raises a new concern about protecting assets against malicious attacks from cyberspace.

Demon game models, including attacker-defender models, defender-attacker models and defender-attacker-defender models, are widely used in defending infrastructure such as transportation networks and electric power grids (Alderson, Brown & Carlyle, 2014; Bell 2000; Bell et al., 2008; Brown et al., 2006; Ouyang, 2017; Yuan, Zhao & Zeng, 2014). The attacker, who can be an individual or a gang of cybercriminals funded by an organization or a state, aims to maximize the defender's loss. In contrast, the defender, who can be the network administrator or a group of security officers from a national security department, selects an optimal defensive plan to minimize the loss. The demon game reaches an equilibrium in which there would be no further enhancement regarding the other player's strategy. That is, both the attacker and the defender obtain their best strategies. The attacker's strategy reveals the most vulnerable assets in an underlying network, while the defender's strategy indicates the best defensive plan to minimize the loss based on the attacker's strategy.

Most of these models (Alderson, Brown & Carlyle, 2014; Ouyang, 2017; Yuan, Zhao & Zeng, 2014) generally assume that an attacker is perfectly rational and would always choose a strategy to maximize his/her expected utility or maximize the defender's loss. However, in reality, attackers have incomplete information that affect their decision-making processes. McKelvey and Palfrey (1995) introduced the concept of quantal response (QR) to model the apparent lack of rationality of the attacker. The attacker would choose worst-case strategies most frequently but not always, leading to stochastic choice probabilities. In this way, the concept of quantal response allows for biases when defining attack strategies. Cheung and Bell (2019) developed a demon game model that applies the concept of quantal response to cybersecurity in logistics management and addresses the issue of asset dependency in a digital logistics network. The solution to the model is a strategy for allocating limited resources for defending critical assets.

Regardless of a player's rationality, these demon games are one-shot games, in which the players (i.e., the attacker and the defender) play the game once and output their optimal strategies. In practice, the arms race between the attacker and the defender in cyber warfare is an interactive sequential game. Borrero, Prokopyev, and Sauré (2019) presented a framework that applies online optimization to model an interactive sequential game between two players, where one player can learn by observing his/her fully rational opponent's strategy to improve his/her strategy from time to time. In practice, both the attacker and the defender acquire information from time to time. As an interesting research direction, we can apply the concept of quantal response to model both the attacker's and the defender's rationalities by observing each other's strategies in an interactive sequential game so that the defender can rightly allocate resources to protect critical assets in a timely manner reflecting the attacker's information. The solution could provide insights to companies on how best to allocate their limited resources for enhancing cybersecurity.

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