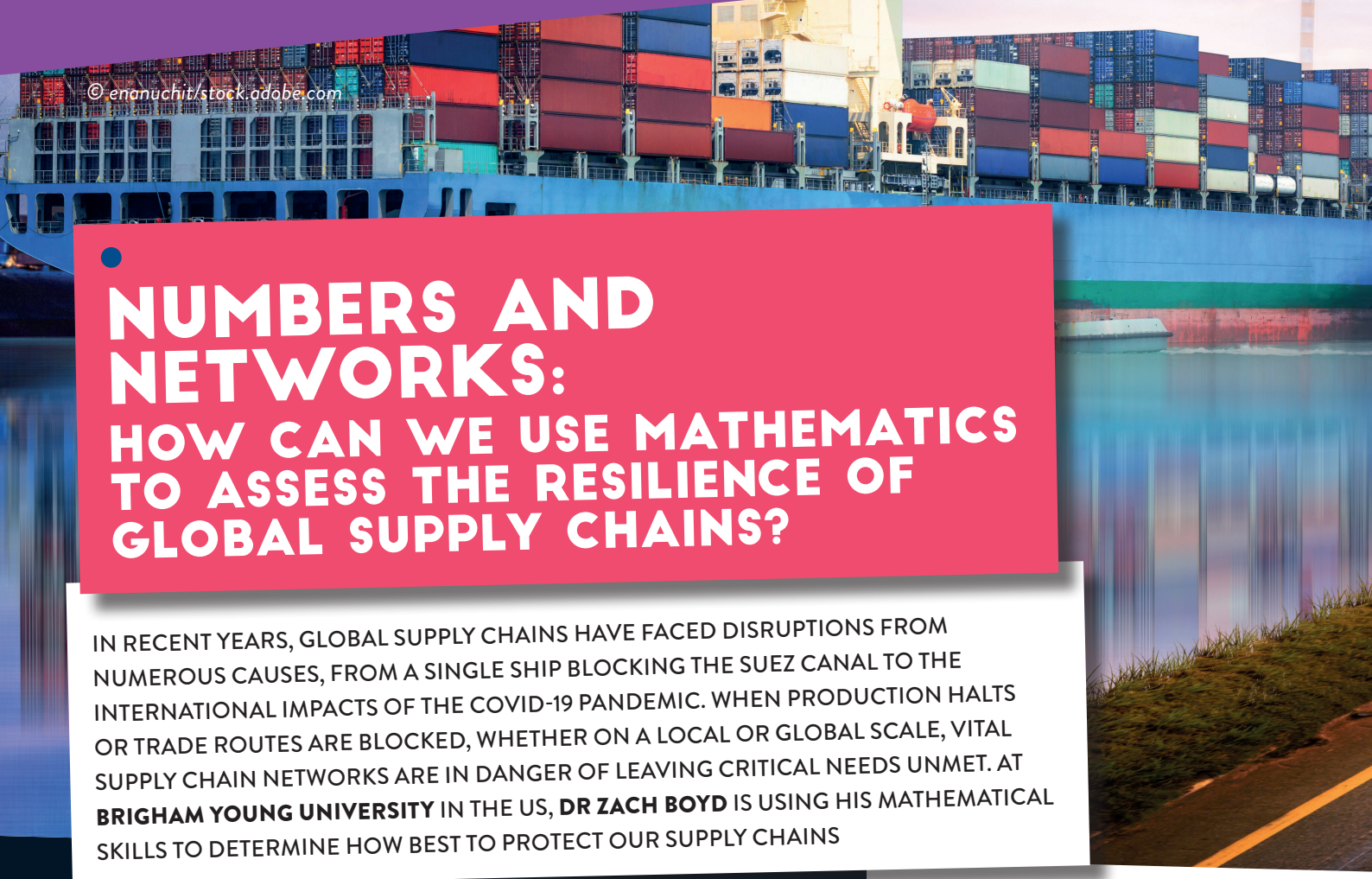

NUMBERS AND NETWORKS:
HOW CAN WE USE MATHEMATICS TO ASSESS THE RESILIENCE OF GLOBAL SUPPLY CHAINS?

IN RECENT YEARS, GLOBAL SUPPLY CHAINS HAVE FACED DISRUPTIONS FROM NUMEROUS CAUSES, FROM A SINGLE SHIP BLOCKING THE SUEZ CANAL TO THE INTERNATIONAL IMPACTS OF THE COVID-19 PANDEMIC. WHEN PRODUCTION HALTS OR TRADE ROUTES ARE BLOCKED, WHETHER ON A LOCAL OR GLOBAL SCALE, VITAL SUPPLY CHAIN NETWORKS ARE IN DANGER OF LEAVING CRITICAL NEEDS UNMET. AT **BRIGHAM YOUNG UNIVERSITY** IN THE US, **DR ZACH BOYD** IS USING HIS MATHEMATICAL SKILLS TO DETERMINE HOW BEST TO PROTECT OUR SUPPLY CHAINS

TALK LIKE A MATHEMATICIAN

CASCADING FAILURE – when a disruption in one link or node of a network spreads throughout the whole network

EDGES – the interactions between nodes in a network e.g., synapses connecting neurons in the brain or customer-supplier relationships between companies in a supply chain

NETWORK – a collection of entities (nodes) that interact with each other (edges)

NODES – the entities that interact with each other in a network, e.g., neurons in the brain or companies in a supply chain

SUPPLY CHAIN – a network through which a company acquires the goods and materials it needs to make its products

Whether you are aware of it or not, your life is infused with networks. The 86 billion neurons in your brain are linked by synapses to form a vast network that allows you to think, make decisions and perceive the world around you. The relationships you share with your friends and family form a complex social network that supports you throughout your life.

Though networks can vary dramatically in their size, complexity and function, they all share a similar structure. A network is a collection of entities (known as nodes) that interact with each other. These interactions (known as edges) link the nodes together. For example, if you have an Instagram account, you can connect to other users by following their accounts. In this scenario, the nodes of your Instagram network are the accounts you follow and that follow you, while these acts of following are the edges.

As networks are so pervasive in our lives, it is important we understand the rules they follow and the properties they share. Dr Zach Boyd, a mathematician at Brigham Young University, is studying global supply chain networks so that we know how best to react when these vital networks falter.

WHAT IS A SUPPLY CHAIN NETWORK?

A supply chain network consists of companies (nodes) that trade with each other (edges). Most of the trade interactions are customer-supplier relationships, involving one company buying materials or products from another. Zach uses the example of a pencil manufacturer to explain:

"In order to make pencils, PencilCo needs to buy wood from WoodCo, graphite from GraphiteCo and metal (to hold the eraser) from MetalCo. So, these three suppliers would be connected to PencilCo. Now, each of these three companies will also have their own suppliers. For example, MetalCo might need to buy metal ore from OreCo and specialised chemicals from ChemCo."

Supply chain networks can become incredibly complex, containing thousands of companies that are all connected in an intricate web of dependency. For example, ChemCo may need to buy pencils from PencilCo for the staff in its offices to use. Relationships like this cause the supply chain to loop back on itself and increase in complexity.

BUILDING MATHEMATICAL MODELS

Zach and his team analyse huge amounts of data to create mathematical models that help them assess the health of supply chain networks. These data mostly come from compliance reports that companies must submit to be registered on the stock market. In these reports, companies are required to disclose their major suppliers and customers. "Mathematically, these records make it fairly easy to construct a supply chain network," says Zach. However, it is predominantly large companies that submit compliance reports, meaning that many small, but potentially integral, companies are not included in the models.

Zach and his team are working hard to make their models more realistic. They use statistical tools to understand how smaller companies may

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FIELD OF RESEARCH
Mathematics

RESEARCH PROJECT
Creating mathematical models of global supply chain networks to protect them from disruptions

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fit into a network and they gather additional data from other sources. For example, as transportation networks play a key role in moving goods and materials from suppliers to customers, Zach hopes to integrate models of global transportation networks into his models of global supply chain networks. "This will be a quantum leap forward in terms of realism," he says.

ASSESSING SUPPLY CHAIN RESILIENCE

Once Zach and his team have created a model of a supply chain network, they run simulations to assess how resilient the network might be when faced with disruptions. For example, if the ChemCo factory shuts down, how will this impact PencilCo's production of pencils?

Interpreting these simulations can be difficult. Historically, mathematicians have analysed aspects such as how closely connected all nodes are in a network. "But this is far too simplistic," says Zach. On the other hand, supply chain practitioners try to calculate the actual flow of goods between each node. "But this is hard to do with networks containing thousands, or even millions, of companies," he says.

Zach's team is developing a compromise between these two extremes. "We keep some of the micro-supply chain insight, while simplifying the approach enough that we can make statements about large and diverse supply chains."

WHY IS IT IMPORTANT TO ASSESS THE HEALTH OF SUPPLY CHAIN NETWORKS?

Supply chain networks are prone to disruptions which can have widespread consequences. "Most daily supply chain disruptions are from very mundane things, like a truck breaking down or a vendor running out of stock," explains Zach. While these issues are usually trivial, disruptions to one link or node of a supply chain can propagate throughout a network, resulting in a 'cascading failure' that impacts the entire network. Zach is investigating these large-scale disruptions.

For example, in March 2021, the cargo ship *Ever Given* became stuck in the Suez Canal in Egypt for six days, blocking one of the world's busiest trade routes and causing disruption on a global scale. During the COVID-19 pandemic, factories were shut down and national borders were closed, preventing goods from being manufactured and distributed, resulting in supply shortages around the world.

Global supply chains are still recovering from the cascading failures caused by these disruptions. "Governments and companies want to do something," says Zach. "But it is not very clear what actions will be most helpful and practical, or how to prevent similar issues from happening again. I'm trying to build mathematical tools and models that make it possible to produce good advice that we can have confidence in."

LOOKING TO THE FUTURE

Zach's next step will be to investigate the best recovery strategies for different kinds of supply chain disruption, while also continuing to refine his models to make them even more realistic. "I am also interested in bringing more researchers from diverse fields together in this discussion," says Zach. "There is a lot of expertise spread across the world that can contribute to solving these complex problems."

This multi-disciplinary approach may prove to be crucial. As we move deeper into the climate crisis, many global supply chains are at risk of disruption from extreme weather events, crop failures and new disease outbreaks. Researchers from all disciplines will have to work together to find solutions to these problems, and mathematicians like Zach will have a big role to play.

ABOUT MATHEMATICS

Mathematics is the incredibly broad field that covers numbers, shapes and formulas. There are many branches of maths, including algebra, geometry, calculus and statistics. Pure mathematicians study mathematical concepts in their abstract forms, while applied mathematicians use maths to solve problems in the real world and are, therefore, an essential part of many other disciplines, such as the natural sciences, engineering and finance.

WHAT DOES A DAY IN THE LIFE OF A MATHEMATICIAN LOOK LIKE?

Zach spends his working days doing a variety of different tasks. He teaches classes of university students, works on research problems, writes up his findings and mentors students as they complete their own research projects.

HOW CAN MATHS SOLVE REAL-WORLD CHALLENGES?

"There are so many applications of math!" says Zach. "For pretty much any big problem in the world, there is probably a group of mathematicians out there working to fix it." Zach is applying his mathematical skills to address a range of challenges beyond supply chain networks. He is working with psychologists and neuroscientists to understand how people recover from bad habits, with genealogists to help people find information about their ancestors, and with artificial intelligence researchers to make smarter algorithms for advertising. "Math really is everywhere!" says Zach. "If you know math, it gives you incredible power to contribute to all kinds of fields."

HOW CAN MATHS HELP US IN EVERYDAY LIFE?

Having a good understand of maths and numbers can help you in many areas of your life. For example, knowledge of maths can make you better at handling your money and help you avoid scams. "Most of these things are not taught directly in classes," says Zach. "But having a good quantitative head will make you more confident in many areas of life where it is necessary to judge the size or likelihood of something."

EXPLORE CAREERS IN MATHEMATICS

- "Mathematicians tend to find themselves in jobs that are perceived as technically challenging, where a little extra ingenuity can generate a lot of value," says Zach. These include stock market analysis, artificial intelligence, supply chain optimisation and medical engineering, but mathematicians can end up working anywhere!
- The Mathematical Association of America has many resources for high school students who are considering a career in mathematics: **www.maa.org/member-communities/students/student-resources/high-school**
- The Society for Industrial and Applied Mathematics has resources for schools, information about mathematical careers and lists maths-based internships in industries: **www.siam.org/students-education/resources/for-k-12-students**
- Prospects lists some of the wide range of careers available for those with a degree in maths: **www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/mathematics**

PATHWAY FROM SCHOOL TO MATHEMATICS

- Zach recommends taking as many maths classes as you can throughout your education. Linear algebra, statistics and computer programming are particularly useful. "If possible, take a proofs class, as learning to structure your thinking and spot logical gaps will be important in all areas of your life," says Zach.
- Join the maths club at your school and participate in maths competitions. Teach yourself coding using online tutorials and take part in a Kaggle machine learning competition (**www.kaggle.com/competitions**). These activities will all hone your skills.
- Most universities offer degrees in mathematics or related fields. The Top University Guide provides information about different maths degrees and what courses cover: **www.topuniversities.com/courses/mathematics/guide**

HOW DID ZACH BECOME A MATHEMATICIAN?

HAVE YOU ALWAYS BEEN INTERESTED IN MATHEMATICS?

I was interested in math from a young age. I was good at it, so many teachers provided lots of encouragement. But I had very broad interests. I had the hardest time picking a college major as everything interested me. Many of the classes I took didn't end up directly contributing to my career. I don't think that's a problem though, especially when you are young and building a broad foundation for who you are going to be.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

Mostly, I'm proud to have been able to carve out a niche for myself where I can do what I love, work with students, grow personally and do work that it is useful to the broader community.

YOUR LAB GROUP IS UNUSUAL AS IT PREDOMINANTLY CONTAINS YOUNG UNDERGRADUATE RESEARCH ASSISTANTS. WHY IS IT IMPORTANT TO GIVE STUDENTS RESEARCH EXPERIENCE EARLY IN THEIR STUDIES?

I'm trying to provide opportunities for people who are just starting out to experience the joy of diving deep into problems and to acquire the self-guided learning skills that they will need in the rest of their lives. I can point them in good directions and help them work through the frustration, and then when they make progress, they know they did something amazing, something beyond anything most of them would ever do in a class. I just love to see them grow and succeed.

ZACH'S TOP TIPS

1. Don't get discouraged by setbacks. Everyone experiences challenges and rejection, so you may as well do what you enjoy!
2. Make sure you live a balanced life. Take time to look after your soul and your relationships, especially with your family. These things are more important than any math you could do.
3. Go for it and have fun!

WHAT DO YOU ENJOY DOING IN YOUR FREE TIME?

I spend a lot of time with my kids – playing, coaching soccer, that kind of thing. I also play a fair amount of racquetball and do yoga.

MEET JASON

Jason Vasquez is an undergraduate student working with Zach on his supply chain network research.

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

I have always been interested in math. Even back in 3rd grade, I was part of my school's math club. I also have a love for history and trivia, I have played the piano for 14 years, and I am captivated by cryptography and code breaking.

WHAT INSPIRED YOU TO STUDY MATHEMATICS?

When I was younger, I loved math. But for some reason I didn't think that I could study it because I thought it wouldn't lead to a job. Turns out, I was wrong. I took a physics class in high school and thought that might be a good application for my interests. However, when I got to college, I realised that what I loved about physics was the math behind it. I started to look into careers in math and I realised that there are so many options.

WHAT IS YOUR ROLE IN ZACH'S LAB?

I am conducting my own research relating to cascading failures of supply chains and I am currently writing a paper about this work. I have also helped Dr Boyd with a paper about supply chain networks, which I will be a co-author of.

HOW ARE YOU BENEFITTING FROM THE EXPERIENCE OF WORKING IN A RESEARCH LAB AS AN UNDERGRADUATE STUDENT?

I have learned so much since joining the lab. I knew next to nothing about research or what to do when I started, but Dr Boyd has mentored me every step of the way. I feel like I have the experience that I need to grow my breadth of research and to apply for graduate schools when the time comes.

WHAT ARE YOUR HOPES FOR THE FUTURE?

I hope to attend graduate school – I am specifically interested in studying machine learning. I would love to work in industry for a tech company, but I am also considering obtaining a PhD and working in academia in this area.