

CAN MATHEMATICS KEEP OUR FOOD SAFE TO EAT?

Keeping germs out of our food is a constant battle, but mathematical modelling can help us trace contamination and stop the spread. **Professor Renata Ivanek**, an epidemiologist at **Cornell University**, USA, has been helping keep food production facilities running safely and our food free from bacteria.



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Field of research

Epidemiological Modelling

Research project

Creating mathematical models to investigate epidemiology in the food industry

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When you get sick, do you ever wonder where you got the illness from? If you have a stomach bug, do you consider if any of the food you ate the day before was past its best-before date? If you catch a cold, do you think about who could have passed it to you? Bacteria and viruses causing diseases are an invisible enemy – as the pathogens are so tiny, it is hard to know for sure where you get them from.

Now imagine wearing a pair of magic glasses that lets you see bacteria. You could walk into your kitchen and see bacteria like in an advert for an antibacterial cleaning product – every contaminated piece of food and surface would glow! Professor Renata Ivanek, an epidemiologist at Cornell University, has not invented magic glasses, but she has been working on a mathematical equivalent. Her research is keeping our food

TALK LIKE AN ...

EPIDEMIOLOGIST

Algorithm — a set of strict, logical rules that can be followed by a computer

Epidemiology — the study of diseases and how they spread in a population

Food contamination — the presence of harmful chemicals or microorganisms in food

Mathematical model — a description of a system in terms of mathematical equations

Pathogen — a bacterium, virus or other microorganism that can cause disease

safe to eat by modelling the spread of a bacteria called *Listeria*.

How does *Listeria* get into our food?

Listeria refers to a group of bacteria. Not all of them are dangerous, but one species in particular (*L. monocytogenes*) is a pathogen that causes an infectious disease called listeriosis. People with listeriosis get a high temperature and feel achy or sick. Most get better after a few days, but it can sometimes be life-threatening or lead to miscarriages.

When there is an outbreak of listeriosis, epidemiologists try to determine where it began. The most common way to get infected is by eating food that has not been cooked properly or has been kept chilled for a long time. This includes cold meats and fish, pre-prepared fruits, sandwiches, salads and soft cheeses. By establishing who has gotten ill and what they ate, the contamination can usually be traced back to a specific food production facility.

L. monocytogenes finds its way into food production facilities because it is present everywhere – it is commonly found both in the country and in urban environments. A small slip in hygiene is therefore all it takes, and once *Listeria* is in the food facility, it is able to spread even inside fridges.

Can we keep our food safe from *L. monocytogenes*?

Food facilities test regularly for contamination by taking swab samples of various surfaces in the facility. They look for any bacteria in the *Listeria* group, as this will highlight places in the facility that have good conditions for dangerous *L. monocytogenes* to grow. However, there is no way to test every single surface in a factory every day, so *L. monocytogenes* sometimes slips through the net. This is where Renata's modelling work comes in.

With her team, Renata has created a tool called Environmental monitoring with an Agent-Based Model of *Listeria*, or EnABLE.



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It is a mathematical model that simulates the spread of *Listeria* in food production facilities. “In a nutshell, EnABLe recreates the unique food facility environment, equipment and practices, and serves as a digital twin of the facility,” explains Renata.

In EnABLe, the biology of *Listeria* is represented by equations. For example, an equation might state how quickly the bacteria replicate depending on temperature, moisture and nutrient availability. These equations are applied to a virtual copy of the food production facility. This ‘digital twin’ is like a computer-game version of the facility that includes the building and all of its equipment and workers. These simulated people and objects are the ‘agents’ that interact with each other to make up the agent-based model.

What can a model tell us about contamination?

Imagine, as an example, a chopping board. If a worker with *Listeria* on their hand uses the board to chop an apple, cross-contamination could occur. The bacteria might start to replicate if the board is wet and could contaminate any other food that touches the board until it is cleaned. By this time, *Listeria* could have spread all around the food facility, but where?

EnABLe keeps a tally of the bacteria present on every agent in the model every hour, so in this example, it would know exactly which surfaces need to be disinfected. In practice, companies can run the model to explore where in the facility *Listeria* contamination is most likely, and which control strategies would be most effective for reducing the risk of an outbreak. Furthermore, if *Listeria* is detected in the facility through routine swabbing of surfaces, the model can be used to figure out where the contamination likely came from.

How does worker health influence food production?

During the COVID-19 pandemic, we avoided being close to other people indoors, but this was often impossible for workers inside food production facilities. As a result, the virus could spread rapidly

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in these facilities, risking not only the health of the employees but also the security of food supply chains. Thankfully, Renata was able to help. Under the guidance of food industry leaders and the US Centers for Disease Control and Prevention, Renata and her team created a new model called Food Industry COVID-19 Control (or FInd Cov Control).

Like any other mathematical model, FInd Cov Control works by programming in a set of inputs, and it then generates a set of outputs. The inputs to FInd Cov Control include the number of employees, their age, infection status and vaccination history, as well as details about the food production facility, such as worker hierarchy and shift schedule and the types of COVID-19 control strategies in place (e.g., testing or physical distancing). The output is a prediction of when workers will get ill and how this will affect food production. Using these predictions, companies can determine the best way to protect their workforce and keep their production line open.

What is the best way to control COVID-19 in the food industry?

“The analysis with FInd Cov Control is ongoing,” says Renata, “but there are several valuable insights we already have about COVID-19 control in the

food industry.” The model has found that intensive testing for the virus is very effective, but also costly. Cutting costs by slightly reducing the amount of testing, however, is a bad idea. If the testing rate is high enough to send lots of people home because they test positive, but not high enough to eradicate the outbreak, then there is likely to be both a shortage of workers and the infection will continue to spread, causing more potentially life-threatening illnesses. “Cost-effectiveness is not just a function of cost and worker availability, but also the protection of public health,” says Renata.

Another effective approach, according to the model, is to enforce intensive physical distancing and hygiene measures. In practice, though, this approach is unpopular and difficult to maintain. In the long term, Renata suggests “the most cost-effective approach is maintaining a vaccinated workforce to prepare for a new outbreak”.

In the future, Renata’s models could be used for other diseases or workplaces. “The model can be adapted by changing the parameters of the employee population, restructuring the work module or incorporating the epidemiology of a new infection in the disease module,” she says. Her research can therefore help all industries to protect their workers while maintaining production.



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ABOUT EPIDEMIOLOGICAL MODELLING

Where do diseases come from, who is at risk from them, and how do they spread?

These are some of the underlying questions that epidemiology tries to answer. To do this, researchers not only zoom in to the microscopic scale of pathogens to understand their biology, but also zoom out to analyse the patterns of disease in communities and populations around the world.

Why is computer modelling so important in epidemiology?

Epidemiologists aim to predict the spread of diseases through a population, but this is a complex problem. Even if an infection's spread follows a simple rule, the numbers can quickly get out of hand. Imagine a disease where every infected person passes it on to two other people each day. It starts with one case, the next day there are two new cases, and the day after

that there are already four new cases. At this exponential rate of spread, after three weeks there would be over 2 million cases! To get more realistic predictions for the spread of diseases, epidemiologists consider how long a person remains infectious, how sick they get, how many people they come into contact with, and how easily transmissible the disease is.

Keeping track of this complexity by hand would be impossible, so epidemiologists build large-scale computer models. Epidemiological computer modelling requires collaboration: some researchers will be experts on how certain infections behave, while others will use their mathematics and coding skills to turn this knowledge into algorithms. Finally, research teams can experiment with their models to find out the best ways to slow the spread of a disease and help healthcare systems prepare for outbreaks.

Who is working in Renata's research lab?

Renata's research team includes people with a wide range of backgrounds. At the moment, her lab members come from Chile, China, Croatia, Turkey, the US and Zambia. They are at a range of stages in their education or career – some are high school students, some are university undergraduate students, some are graduate students, and others are postdoctoral researchers. They also come from different disciplinary backgrounds, and so bring expertise in veterinary medicine, food science, public health, mathematics and statistics to the group. "This diversity is important because our different experiences contribute to the lab mission in unique ways," says Renata. "Our diversity helps us to identify and solve meaningful problems. We are different, but what we all have in common is an interest in mathematics, food and health."

Pathway from school to epidemiological modelling

• As an interdisciplinary field, there are a number of routes into epidemiological modelling. "In my research, people typically fall into one of three groups," says Renata:

1. Those who studied mathematics, statistics or computing, but have little knowledge of health or food
2. Those who studied epidemiology, public health, medicine or food safety, but have no computer coding skills
3. Those who, like me, know just enough about mathematics, food and health that they can effectively collaborate with people in groups one and two.

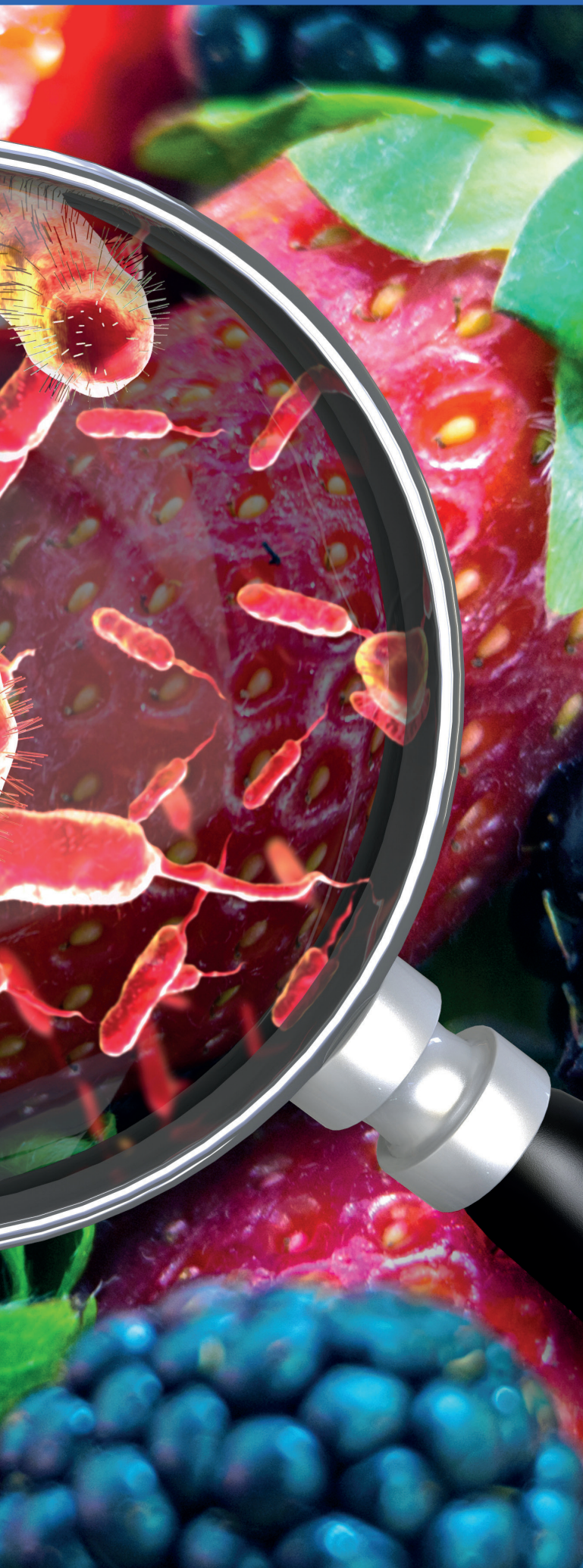
• "It doesn't matter which subjects you start with, people with knowledge of any related field are valuable in our research," says Renata. "Follow your interests and curiosity to find your path to epidemiological modelling."

• If you are most interested in how diseases work, then consider degrees in human or veterinary medicine, biomedical science, public health or epidemiology.

• If you love the idea of modelling, you may prefer to study mathematics, statistics or computer science, and then apply these skills to epidemiological challenges.

Explore careers in epidemiological modelling

- Public Health Degrees provides information about how to become an epidemiologist and the areas of epidemiology you could specialise in: www.publichealthdegrees.org/careers/epidemiologist
- There are a number of paths you could follow to work in the food safety profession: foodsafetycareerguide.com/2018/08/17/how-to-get-started-in-food-safety
- The Centers for Disease Control and Prevention has information about what epidemiologists do and epidemiology-related lesson plans and classroom resources: www.cdc.gov/careerpaths/k12teacherroadmap/epidemiology.html
- Coding skills are important for epidemiologists. Use online courses such as Code Academy (www.codecademy.com) or Free Data Camp (www.freecodecamp.org) to teach yourself. Then, when you are ready to explore infectious disease modelling, visit MIDAS (www.midasnetwork.us) to find modelling projects to work on.



Q&A

Meet Renata

How did you end up becoming an epidemiological modeller?

When I was younger, I loved animals so I wanted to become a vet because I had the naïve idea that I could heal and save all creatures. I also developed a love of solving math problems at an early age thanks to my excellent first math teacher.

I studied veterinary medicine at university, where I discovered the epidemiology of infectious diseases. But I was blindfolded by my goal of becoming a vet, so I didn't pursue epidemiology at the time. Later, during my master's degree in veterinary epidemiology, I realised how big a role math plays in epidemiology and that I could combine my interests in math and health in a single discipline.

My PhD united these interests, and I became an epidemiological modeller. Food is essential to health, so it was natural to focus my epidemiological knowledge and modelling skills on problems at the health-food interface.

How did you learn computer modelling?

I learned computer modelling simply by doing it. In research, I often find myself at the very edge of my comfort zone, where solving a problem requires something I don't yet know. Being at the edge was how I started incorporating computing into my research, one small step at a time and learning along the way.

While I studied epidemiology then learned computing on the job, you could approach epidemiological modelling in the opposite direction and train in computer modelling then apply your skills in epidemiology. I think that either direction has its challenges. I also think that irrespective of the direction, having strong skills in one discipline before learning another is helpful, because it gives you confidence that you are doing something right.

What motivates you at work?

I am very curious and love learning new things. I also enjoy working with students who are curious, creative and have the drive for research. In my research lab, we are addressing real problems faced by society, and we strive to make a difference by developing new and sustainable approaches for improving the health of human and animal populations, and optimising food production systems.

Renata's top tips

1. Don't be afraid of dreaming big and working for it!
2. You may not always land where you had hoped. But success is more likely if you have a vision of where you want to land.
3. Remember that failure may open a new door for you that you never even considered before.