Driven largely by the COVID19 pandemic, the UK has seen supermarket shortages and reduced offerings in recent weeks. The UK is not self-sufficient in food production, as such any disruption to the logistics infrastructure which supports the sector can have serious knock-on effects for the UK. The often-complex network of interactions of growers, manufacturers, retailers and freight organisations means that the current crisis is putting a strain on the agri-food sector.

KTN and partner organisations through V-KEMS, recently ran a one-hour session to explore what role that mathematical sciences might have in supporting the challenges faced. On the 28th April, around 100 participants from retail, manufacturing, policy, growers, researchers and technology providers came together to hear UK mathematical science academics introduce topics in operational research, risk modelling, statistical methods, network science, multilevel optimisation and supply chain & inventory modelling.

Chris Sturman (co-chair of the Retail & Food Logistics Forum at the Chartered Institute of Logistics and Transport), and Alan Champneys (Professor of Nonlinear Mathematics at the University of Bristol) followed the mathematical science presentations with a facilitated conversation on the role of the mathematical sciences, priority areas for intervention, and possible next steps. Chris asked the forum three key questions; the text below provides a shortened summary of the responses. Although the meeting was only scheduled for 1 hour, many participants were able to stay on the call for a further 50 minutes, leading to a wide ranging discussion, further sharing of experiences and an agreement on next some steps (see below).

1. **How can the mathematical sciences support cooperation versus competition at different parts of the supply chain?**

We should consider here the downstream and upstream aspects of the supply chain, and also the ancillary services which support them (for example packaging). 50 % of our food passes through the retailers, and we should recognise the competition which exists between them; how can cooperation respond to the panic buying we have seen in recent weeks? What about resource underutilisation; we have a food service sector largely out of action, how can we use them? We also have a transportation infrastructure overstretched in some sectors and broadly inactive in others.

In the mathematical sciences, there exist theories around optimising supply chains under the possibility of collaboration; so-called collaborative logistics aims to increase the utility of vehicles with compatible loads which are being sent to similar locations. Some projects have looked at collaborative logistics originally from a carbon footprint point of view, but these approaches may also inject some resilience into the system when the trucks aren't available to serve everybody which is the case we *see currently. Collaborative logistics involve multimodal transportation solutions which combine haulage with smaller companies for last mile deliveries.*

Some participants raised the question of modelling collaboration along the supply chain as a game theoretic challenge; simulating alternative types of games to model the interaction. Game theoretic models can often be stated as multilevel optimisation problems, so there is a connection worth exploring for modelling cooperation incentives in collaborative logistics.

Generally, it can be shown that collaboration in theoretical models improves performance, and the problems are realising it.

One challenge is in the cost of orchestration, suppliers don't know whether items are going to the same locations unless a retailer tells them. For retailer's, orchestration involves transaction costs and the benefits they see, which may be reduced congestion at the receiving location, may not outweigh the costs of orchestration. In the logistics world we have many small companies, so it may not be in their interest to collaborate. Another challenge is in data sharing – who shares data with who? If a third-party mediator is being used, then a retailer won't see a benefit until others join in also.

Legislation exists which prohibits certain kinds of collaboration. In a post COVID19 world we should look at what is optimal for the country. There may be an emerging opportunity to look at where collaboration may work best, both from a theoretical, and a practical point of view.

2. **How to design predictive models for upcoming bottlenecks, and using these to hit a dynamic target?**

COVID19 has shown weaknesses in resource use, supply chains and procurement. Some have been known about for some time and are in hand, but not acted on quickly enough. How can the industry be more 'agile' and how can we provide the evidence on which to provide this 'agility'?

Predictive modelling for hitting future, dynamic targets lends itself well to the concept of 'digital twinning'. In these 'twins' we feed real time data into the model, which might be a simulation or an optimisation model. Given that this twin is based on real time data, it means it is very appropriate to meeting dynamic targets. There are projects with the automotive sector and with hospital trusts, and there is no reason why these principles could not be applied to an agri-food supply chain.

Dynamic predictive models need also to account for uncertainty; aleatoric (random) and epistemic (due to lack of knowledge). Risk modelling very much lends itself to predictive modelling; the networks that would be built to account for uncertainty have strengths in both diagnosis of weakness on a network, but also in terms of predicting possible futures. It is worthwhile to mention that there are *different processes by which we might build such models. These processes largely depend on the unit of analysis for the particular problem. One might imagine dealing with the uncertainty in a predictive model as a purely Bayesian network built by knowledgeable people, so that the structure of the uncertainty and evaluation are expressed as probabilities built by judgement. These can be powerful predictive thinking tools. These tools may not however have the granularity of some more data hungry mathematical approaches – such as digital twinning – which may be needed at an operational level; predicting delivery delays for example.*

3. **Designing optimal delivery systems which identify and prioritise vulnerable people?**

This has very much been in the news of late. What is needed is to know how to design an optimal system for vulnerable people; who they are? where they are? to what degree they are vulnerable? How can services (such as click and collect, home delivery) be developed more quickly?

The degree of vulnerability has to be measured, and it could use some of the indices that are being used in home healthcare. Knowing this then we can set some priorities and define a corresponding vehicle or path routing problem to best achieve this.

There is a complex optimisation aspect to this, if you want to optimise to ensure vulnerable people get food on time, this adds another variable. If, in a new world, we have legislation which allows collaboration to prioritise vulnerable people then the objective functions used by logistics companies change. When we talk about changing regulation, then models which are multi-level optimisation models - very close to game theoretic models - play an important role. It come back to how do we incentivise cooperation. If we talk about changing the rules by which to book delivery slots, how will people react? how to optimise to that reaction? What does this mean for vulnerable people who might have fewer options? How regulation trickles down might be interesting to model as multi-level optimisation models.

Chris Sturman (Co-Chair, Retail and Food Logistics Forum, at the Chartered Institute of Logistics and Transport) said of the meeting:

"The agrifood industry represents 15% of GDP, and logisticians in this sector rise to the challenge every day in ensuring the UK population is fed. Agility, flexibility and innovation in the face of external difficulties is a continuum. The dynamic debate amongst participants helped select and confirm three

most cogent and pressing challenges, where projects could make the greatest supply chain impact.

The contributors clearly demonstrated how mathematicians can come together with the agrifood industry and current logistics research to generate real time data that informs strategy and solution development to overcome the disruption caused by the previously unknown COVID threat. But let's not stop there - building on this initial work, they could also, in my view, be added agents for change by informing and contributing to some of the policy and regulatory change surrounding Climate Change, congestion and emissions reductions, and supply chain structures beyond Net Zero and 2035"

Next Steps

The organisers are grateful to those who were able to come and discuss for these topics. Slides from the session can be here: https://tinyurl.com/LOGISTICS-VKEMS-PRESENTATIONS and the background report discussed during the forum can be here: https://tinyurl.com/LOGISTICS-VKEMS-INITIAL.

We are also keen to hear how initiatives like this might support businesses, please do get in touch. The organisers are particularly keen to develop the three topics arising:

1. Using UK wide data on the agri-food supply chain to look at its robustness to shocks etc.
2. Working with various policy makers to learn how to prioritise vulnerable people in last mile food supply.
3. Looking at the practicalities of models of collaboration versus competition in the retail food supply market.

It was suggested that training sessions into some of the topics introduced might be of interest to business. Additionally, free, virtual, multi-day mathematical science study group sessions (see here for an example) can be arranged to tackle challenges in this space. please do get in touch.

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The Virtual Forum for Knowledge Exchange in the Mathematical Sciences (V-KEMS) is a collaboration between the Newton Gateway to Mathematics, Isaac Newton Institute (INI), International Centre for Mathematical Sciences (ICMS) and Knowledge Transfer Network (KTN) and various representatives from the mathematical sciences community (see https://gateway.newton.ac.uk/node/10190). Its main aim is to identify a range of virtual approaches that will help address challenges from business and industry, the third sector, and other groups outside academia. These challenges may be long-standing or may have arisen directly as a consequence of the present disruption to UK society.