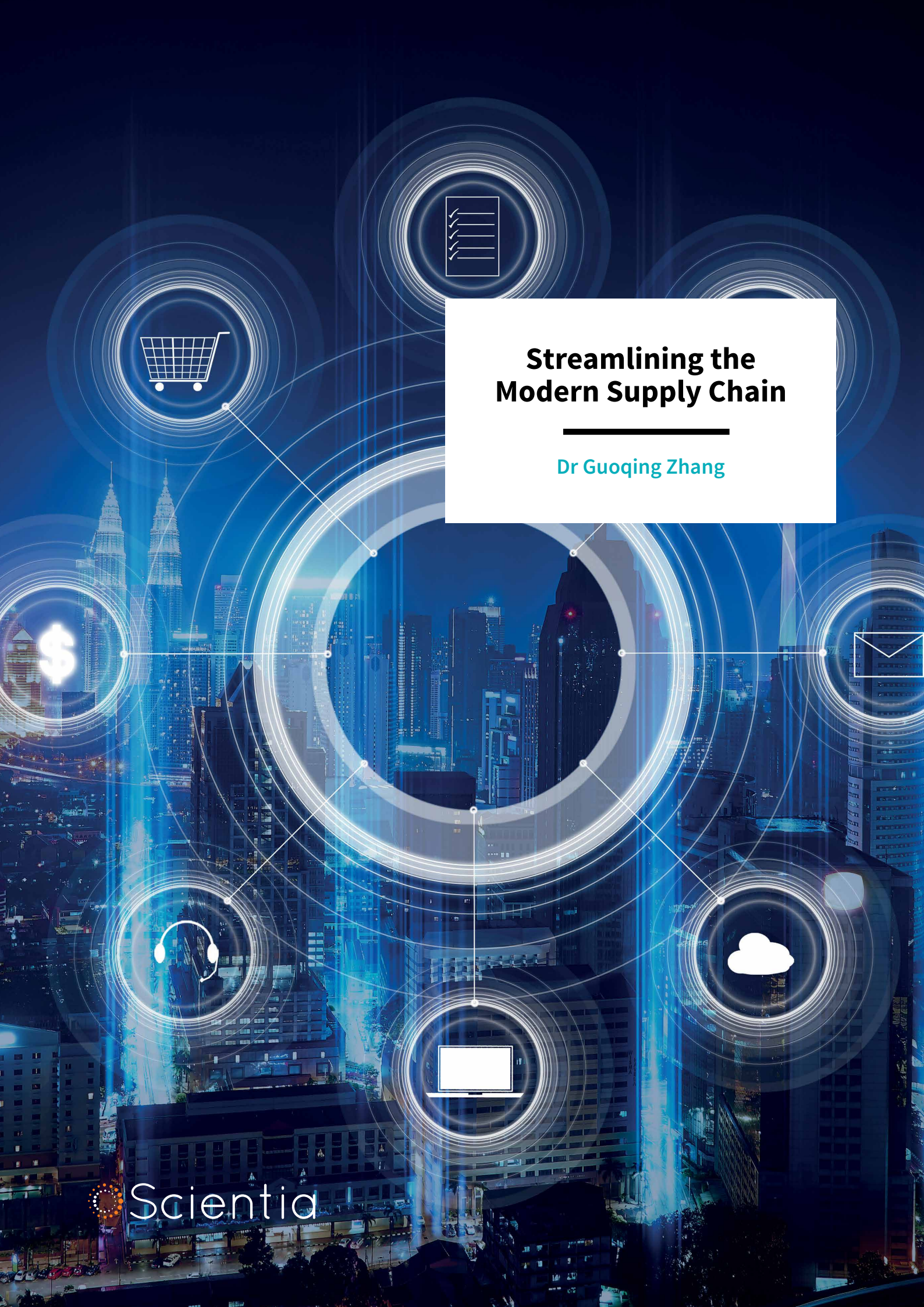

Streamlining the Modern Supply Chain

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Scientia

STREAMLINING THE MODERN SUPPLY CHAIN

The digital age has seen a profound shift in how we consume products. Not only have many of us shifted to doing most of our shopping online; new technologies are also transforming how products are produced. These shifts have brought about similarly monumental changes to the supply chains that bring products to the doorstep, presenting significant new challenges to the complex networks of groups involved. In his research, **Dr Guoqing Zhang** at the University of Windsor in Canada uses the latest computational techniques and optimisation algorithms to present smart solutions to these issues.

Profound Change

In little over two decades, the ways in which most people in the developed world buy and consume products has changed almost beyond recognition. Previously, our only option to shop was to visit a physical store, whereas now, most of us frequently go online to buy products ranging from food to the latest technologies. Throughout the COVID-19 pandemic, online shopping has allowed millions of people to obtain essential supplies while remaining in the safety of their homes, helping to curb the spread of the virus.

In the US, the convenience of online shopping meant that total sales reached almost $350 billion in 2015 – a figure which was then predicted to grow annually by 6% until 2020. This profound shift spurred many companies to migrate from physical retail alone, to an approach that combines both physical and online channels.

Although this has largely occurred behind the scenes, such a significant transformation in behaviour has had a large influence on product supply chains, which encompass broad networks of people, companies, activities, information, and resources. Throughout their operation, these systems take in raw materials; transform them into finished products over successive stages; and finally, deliver them to consumers. This intricate process can be severely disrupted if any changes are not implemented effectively. In turn, this has required a substantial rethink amongst industries about how the movement and storage of materials and final products should be managed.

The Modern-age Newsboy Problem

Although this is a distinctly modern problem, Dr Guoqing Zhang at the University of Windsor shows that links can be drawn with the far older 'newsboy problem', which considers how managers need to make decisions about their inventory over limited periods.

In the past, news vendors faced constant uncertainty in the demand for their products. To deal with this problem, they needed to make smart decisions about how many papers to buy from a supplier each morning: if they bought too many, their leftover products would be worthless the next day; but if they bought too few, they would miss out on crucial opportunities to make more profit.

For modern industries, this problem becomes highly relevant when considering how multiple products should be sold – a situation that has now been widely studied for decades. In a 2008 study, Dr Zhang developed an algorithm that offered new solutions to this problem, accounting for factors including budget constraints, which limit the number of products that can be sold, and promotional price discounts, which would diminish profits if not enough products are sold. Since then, Dr Zhang has expanded on these advanced algorithms and mathematical techniques to explore how solutions to the newsboy problem can inform the supply chains of the digital age.

Recently, he also used a newsvendor model to formulate some supply chain risk management problems, and analysed the impacts of a manufacturer

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or retailer's risk attitude (such as risk-neutral or risk-averse) on ordering and marketing strategies. His team then developed an optimal capacity strategy for new product development with risk consideration, and applied it to the automotive industry.

Closed-loop Supply Chains

In a 2013 study, Dr Zhang became the first to consider how the newsboy problem is simultaneously affected by both supplier discounts and budget constraints: a situation that required an entirely new approach to analysis compared to previous approaches to the newsboy problem. His proposed algorithm was extremely effective in solving the problem on both small and large scales, even when it was extended to consider multiple realistic constraints. In particular, he considered 'closed-loop' supply chains – which involve products and materials travelling both forwards and backwards among networks of actors.

In this research, Dr Zhang investigated the characteristics of such a system made up of multiple interconnected plants, collection centres, demand-generating markets, and products. His methods led to a model that minimises the total costs for these supply chains, and that could be extended to consider external factors leading to unexpected variations in their operation. In addition, it could account for the impact of uncertainties in demand along both directions in the chain. To achieve this, Dr Zhang needed to incorporate elements of randomness into his models – a factor that would be crucial in his subsequent research.

More recently, his team studied production quantity, pricing and collection network decisions for manufacturing enterprises under either the 'take-back' or 'carbon emission capacity' regulations, and applied it to electronic waste collection and a tyre closed-loop supply chain.

Handling Two Channels

The dual physical and online channels described by Dr Zhang have brought about significant new challenges to the operation of modern supply chains. Together, they need to handle customers who can be distributed across wide geographical regions; deal with large volumes of orders that are often very small; and achieve short, flexible delivery times, often at night. As in the original newsboy problem, variations in demand across both of these channels can create significant uncertainties regarding how they should be operated.

Following on from his previous findings, Dr Zhang next aimed to analyse the impact of this type of commerce and 'omni-channel' commerce (referring to retailers with both a physical and digital presence to provide seamless shopping experience) on the management and logistics of supply chains, and to provide concrete solutions to how they should be configured effectively. In doing this, he used his algorithms to design new approaches to dual- or omni-channel commerce with random demand, which consider factors including facility locations, inventories, warehouse storage, and transportation. Through this approach, he hoped that his findings would provide key guidance to retail and manufacturing industries as they shift their operations to incorporate dual-channel supply chains.

Managing Warehouses and Inventory

Through a subsequent study, published in 2018, Dr Zhang drew on these cutting-edge techniques to suggest how optimised supply chains could be specifically designed to account for modern behaviours. To do this, he examined the inventory policies for newly emerging dual-channel warehouses, which are uniquely divided into two areas: one for fulfilling online orders; and the other for both storing products and fulfilling offline orders.

Dr Zhang also studied warehouse layout problems where both horizontal and vertical travel costs need to be considered, and developed several algorithms to solve these complex issues. Motivated by a real-world case, he also proposed an integrated strategy to combine production planning and storage layout, and analyse the impact of the 'Internet of Things' (IoT) on warehouse operations, in the first research to combine these two problems. His strategy ensures the availability of warehouse space, and saves costs during production and warehouse operation.

Realising Smart Supply Chains

Since the time of Dr Zhang's earlier research, an almost bewildering array of new technologies have emerged, including the internet of things, cloud

computing, and artificial intelligence. Although these terms can encompass widely varying systems, they are united in their ability to bridge the gap between advanced computational architectures, and everyday situations in the real world. Therefore, each of these technologies can be integrated into 'smart' supply chains to make them more cost-effective, share information more effectively amongst networks of companies, and better account for random uncertainties in the external environment.

However, these supply chains inevitably bring new challenges due to the manufacturing and business models they entail, and the high risks of uncertainty involved with applying new technologies. Therefore, it is critical to study how smart supply chains can be made to connect networks of companies and individuals with relevant technologies, and how industries can reconfigure and optimise their existing networks. Ideally, these systems would even have the capacity to intelligently plan, control, and adjust the systems to match supplies with ever shifting demands in real time.

Developing Optimisation Algorithms

To realise these capabilities, Dr Zhang and his colleagues are now working towards the development of advanced optimisation algorithms – which can find the best possible solutions out of all possibilities. This has involved exploring a variety of techniques and case studies. In his earlier research, Dr Zhang developed a software package for solving large-scale linear optimisation problems, which can be applied to various fields of study. Leading on from this, his team used these techniques to determine how the operation of a world-leading airline's vast cargo network could be optimised. From analysis of real data, the researchers solved routing problems, which would have once taken over 450 hours of calculation, in just 7 minutes.

More recently, Dr Zhang developed novel optimisation algorithms for solving diverse problems, including healthcare supply network issues and supply chain problems, such as warehouse layout and operation. Through their optimisation algorithms, his team showed how the operation costs of complex warehouses could be reduced by 26%.

Incorporating New Technologies

In his upcoming research, Dr Zhang will rigorously study the challenges faced by the supply chains of the digital age, resulting in new frameworks and optimisation algorithms for smart supply chains. In particular, he will focus on four key areas. Firstly, he will study the impacts and opportunities for new digital technologies like the internet of things and cloud computing, and will design new business models that can incorporate them effectively. Secondly, he will develop new concepts and methods for smart supply chain manufacturing – focusing on problems as wide ranging as uncertainty, tactical planning decisions, procurement, distribution, sales, and smart warehouse operation.

Thirdly, Dr Zhang will develop data-driven optimisation models, methods, and algorithms, which will enable him to study how modern data analysis can be combined with classical optimisation techniques to solve complex management problems. Finally, he will work with partners in real industries, including car manufacturing, energy, retailing, food, and medicine, enabling him to effectively solve the problems which arise for real-world supply chains, and to verify the solutions which have already been proposed.

Recently, Dr Zhang has also proposed an IoT-assisted randomised storage layout policy, and developed an integrated strategy to combine this with production planning. Through rigorous analysis, the IoT-assisted randomised storage policy can reduce operation costs by up to 28% and increase space utilisation by up to 17%.

Ensuring Success in Future Supply Chains

Through over a decade of research into how modern supply chains have been transformed by the digital age, Dr Zhang has made important advances in our understanding of how industrial practices have adapted. In the coming years, the technical landscape now looks set to transform in more profound ways than ever before – meaning his results have never been more relevant. By fully integrating the latest technologies and optimisation algorithms into the systems we rely on to bring products to consumers, while fully accounting for rapid improvements, Dr Zhang's methods could soon ensure that modern companies will not fall behind.

Meet the researcher

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Dr Guoqing Zhang achieved his PhD in Management Sciences from City University of Hong Kong in 2000. He has since worked at a variety of institutions worldwide, including as a postdoctoral fellow at McMaster University in Canada, a visiting associate professor at the University of Pittsburgh in the US, and a JSPS fellow at Osaka University in Japan. He joined the University of Windsor in 2002 as an Assistant Professor, then became an Associate Professor in 2005, and has been a Full Professor since 2011. His current research interests include smart supply chain and logistics management, the design of intelligent decision support systems, and optimisation algorithm design and development. He has earned numerous awards for his important findings in these areas, including the first practice prize of Canadian Operational Research Society in 2015 and the Outstanding Paper Award at the IEEM International Conference in 2014. He has also developed an effective optimisation software for solving large-scale linear programming.

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FURTHER READING

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