Towards simulating the South African fruit export supply chain

Lente Schoeman[1], **Dr Stephan Nel**[1], **Dr Christa Searle**[2] & **Prof Joubert van Eeden**[1]

[1] *Department of Industrial Engineering, Faculty of Engineering, Stellenbosch University, Stellenbosch, South Africa*

[2] *Centre for Sustainable Road Freight, Edinburgh Business School, Heriot-Watt University, Edinburgh, EH14 4AS, UK*

Climate change has become one of the, if not the most, pre-eminent environmental issues threatening the human population and natural ecosystems. The extent of greenhouse gases emitted, mainly due to burning fossil fuels, has drastically increased due to the onset of successive industrial revolutions, increasing the likelihood of irreversible consequences. The greenhouse gas emissions of logistics processes and supply chain activities account for the majority of companies' overall greenhouse gas emissions and carbon footprint. Most of these emissions are engendered by logistics activities related to transportation. In particular, global food supply chains face amplified challenges due to their reliance on fossil fuels, exacerbated by volatile fuel prices, heightening vulnerabilities in transportation and distribution components within supply chains. This dependence showcases the increasing importance of understanding, quantifying, and better managing carbon emissions related to transport logistics activities within supply chains.

The carbon emissions from transportation logistics vary among supply chains and can be attributed to various factors. Given the perishable nature of food products especially fresh fruit, the transportation sector can have a significant impact on the food supply chain, as these goods often require long-distance shipment primarily *via* road, especially so within South Africa (the main case study of this research project). Furthermore, the distribution of fresh fruit necessitates temperature regulation throughout the process, leading to a higher rate of energy and fuel consumption when compared with non-perishable goods. Notable factors and trends contributing to fuel consumption — such as the transport mode, vehicle attributes, driver behaviour, environmental factors, and operations — ought to be considered when attempting to reduce the environmental impact of transportation activities. There is, however, a trade-off in respect of minimising cost and reducing carbon emissions — managing the financial implications associated with adopting sustainable practices and technologies is widely regarded as a complex endeavour.

Within the context of South Africa, the citrus industry is a vital component of the country's agricultural sector and has a significant economic impact. It is one of the largest citrus exporters globally, supplying fruits to numerous international markets. The South African citrus export supply chain relies heavily on road transportation to move citrus fruits from production regions to packhouses, cold storage facilities, and export ports — posing challenges related to the reduction of carbon emissions and the improvement of cost-effectiveness.

In this thesis, an agent-based simulation model of the real-world transportation conditions and decisions within the context of the South African citrus export supply chain is developed towards helping to address the aforementioned challenges. This approach incorporates the use of various frameworks and resources to aid in model development. The proposed solution methodology involves data collection and analysis to gather information relating to the current transportation system, including geographical locations of facilities, truck types, and associated costs. An agent-based model is developed, representing key entities such as production regions, packhouses, cold storage facilities, and the port of export. Each entity is represented by agents with spe-

cific attributes and behaviours, including transportation preferences, capacities, and consolidation strategies. Carbon emission calculations are integrated into the model to estimate emissions for different transportation conditions and decisions (referred to as scenarios) considering factors such as fuel consumption, driver behaviour, and truck types, to name a few. Cost reduction simulations are conducted to evaluate financial impacts and identify cost-effective solutions, accounting for fuel costs, and potential savings from consolidation.

The agent-based model is formulated in the AnyLogic Simulation Software environment enabling valuable visualisation of the physical movement of agents and graphical representations of cost and carbon intensity associated with different scenarios, during which predefined metrics such as carbon emissions, transportation costs, and logistical efficiency are compared. Based on the simulation results, recommendations are generated so as to provide decision support. These recommendations include adopting specific truck types, driver incentives, implementing consolidation practices, and suggesting modifications to the transportation network to achieve sustainability goals while balancing economic considerations.

The proposed agent-based model is subjected to systematic verification steps, ensuring the correct functioning and integration of its sub-components. Furthermore, the model undergoes evaluation under diverse operating conditions to gain a more nuanced understanding of the complexities and challenges within perishable supply chains, while validating its adequacy. In particular, parameter variation, sensitivity analyses, and scenario analyses are conducted, with subsequent face validation by subject matter experts.

The proposed agent-based model provides the groundwork for numerous avenues of future research, including both enhancements and extensions to the current model. Such follow-up work may entail considering a wider range of factors contributing to fuel consumption, as well as the application of mathematical modelling so as to aid decision support in respect of facility location (*e.g.* consolidation hubs) and vehicle routing.