An agent-based approach towards modelling cost versus CO_2 emission trade-offs in multi-modal middle-mile logistics.

Dominic Huskisson[1], Jan van Vuuren[1], Christa Searle[2] & 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*

The Internet has become an inherent part of our society. The increasingly high quality of online platforms are showcased by their attributes of convenience, reliability, and high-speed connection, creating a world of opportunities for businesses and customers alike. More specifically, one of the more visible trends in the world of *electronic commerce* (e-commerce) is the unrivalled usage of mobile devices, accounting for more than 70% of all retail website visits worldwide, in 2022. This, of course, allows for incessant access to online platforms wherever and whenever necessary. An online platform is capable of sustaining a much higher volume of virtual foot traffic than a physical brick-and-mortar store which is subject to physical constraints. This advantage affords online platforms the opportunity to reach millions of people via a single website.

An increase in online shopping equates to an increase in parcel orders. This increased load poses a challenge to both e-commerce and omni-channel[1] businesses alike, but of course the potential to curb these challenges attracts such companies. In particular, for a parcel order to be fulfilled, it must be delivered from a depot, to the doorstep of an end-consumer. This requires the critical tasks of vehicle routing, scheduling, and delivery execution.

The middle-mile of a retail supply chain in which customers can place online orders for commodities entails delivering parcels from a brick-and-mortar store to end-user retailers. This portion of the supply chain poses particularly challenging logistical problems related to the pursuit of acceptable trade-offs between operational cost minimisation (as a result of eliminating middle-mile delivery inefficiencies) and minimising the environmental impact of traditional commodity delivery modes (as a result of CO_2 emissions and the consumption of fossil fuels).

The aim in this project is to showcase the design of a decision support framework for managing the multi-modal middle-mile delivery logistics of a depot. The working of the framework is based on an agent-based simulation-optimisation model which takes as input

- time-stamped commodity demand volumes for a number of retailers pertaining to a single depot,
- time windows during which the aforementioned demand has to be satisfied at retailers,
- details about a set of delivery modes available to service retailer demand,
- data describing the fleets of available delivery vehicles for each of the aforementioned modes (including fixed and variable costs, rates of CO_2 emission, vehicle speeds, and vehicle capacities), and

[1] An omni-channel business employs multiple channels to communicate their sales options to customers, such as online channels, as well as in-store.

- information related to the delivery transport infrastructure and expected travel times within this infrastructure for each of the aforementioned delivery modes.

The delivery modes include lorries, electric vans, cars of incentivised, exogenous delivery agents, and motorcycles. The model produces as output an assignment of vehicles of the appropriate transportation modes to service the set of retailers in pursuit of the objectives mentioned above. The model also suggests delivery routes and schedules to be followed by each of the delivery vehicles. The project includes a demonstration of the working of a computerised instantiation of the framework which is capable of analysing the solutions returned by the agent-based model formulated over a rolling planning horizon (discretised into multiple planning periods) during which both retailers and delivery vehicles are modelled as stochastic agents exhibiting autonomous behaviour (in terms of subjective preferences and agents' perceived value of time). The instantiation includes a virtual, real-time bidding platform for registering and evaluating delivery alternatives and corresponding driver agent incentives offered.