Using an Agent-based Model to Explore Alternative Modes of Last Mile Parcel Delivery in Urban Contexts

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ABSTRACT

The scale of parcel delivery is increasing rapidly, with indications that it will continue to do so. This presents a challenge both to those in the industry who wish to understand how they might adapt and change their ways of doing delivery and the policymakers who would like to encourage this in order to positively impact urban areas in terms of traffic and pollution. We present an early implementation of an agent-based modelling framework of parcel delivery processes, flexible enough to be extended to explore a variety of scenarios. We apply it to a baseline case study to begin the process of exploring the effectiveness of switching to a different method of delivery.

CCS CONCEPTS

•**Computing methodologies** → **Modeling methodologies;** •**Applied computing** → **Transportation;** *Command and control;*

KEYWORDS

agent based modelling, freight, parcel delivery

1 INTRODUCTION

Freight traffic is rapidly increasing, hugely important, and relatively understudied [Bates et al. 2018]. Certainly the first of these is obvious to many casual observers, but the scale is important context: an estimated 1 billion parcels were delivered in 2015 across the UK, with annual growth at around 15.7% [IMR 2015]. E-commerce and online shopping are partially fuelling this rise, which is forecast to continue at 10-12% per annum until 2021 [Mintel 2016]. This in turn drives the 16% of total road vehicle activity attributable to parcel freight transport in UK urban environment [Allen et al. 2017], and their associated 15% of the UK's transport emissions [for Transport 2015],[for Transport 2016]. Considering the trajectory of congestion and freight demand, urban centres look to be the victim of a tragedy of the commons when it comes to the delivery of parcels as individual companies battle it out for parking spaces and customers. Given, then, that a sizeable portion of the safety, health, and traffic concerns which are associated with freight traffic are a function of the parcel industry, it is an increasingly important question for researchers of urban systems.

Parcel delivery is a challenging topic to address, however, given that it plays out in a market saturated with players under extreme stress. Individual companies need to see clearly how they might be impacted by any proposed changes to their operating procedures, and policymakers need a rigorous understanding of the same. Among freight service providers, there are substantial perceived risks associated with transitioning to new practices, lest any disruption to service translate into dissatisfied customers and the advantage of competitors. Policy makers are also wary of implementing changes they perceive to have potential negative economic effects, even with existing strong arguments relating to environmental impacts. Engaging these diverse end users with analysis is challenging because of this extreme risk aversion. As such, providing them with a tool which allows them to interrogate different elements of the system in familiar terms makes the problem more accessible and more tractable, as well as giving them confidence in the outcomes of any such tool.

Agent-based modelling is a tool which has the potential to bridge the gap between academics, industrial partners, and government agencies. Simulations can provide us with ”artificial laboratories” to test ideas and hypotheses about phenomena which prove to be ”wickedly” complex in the real world [Gilbert 2007]. Combined

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with increasingly available big data, it can help tailor systems in order to give more specific information (see [Heppenstall et al. 2016]). In particular, some promising work of this nature has already taken place (see [Chen and Chankov 2017], [Starý 2012]). In order to capture the behaviourally-informed, spatio-temporal process of parcel delivery, we have constructed an agent-based modelling framework which allows us to visualise how different approaches to delivery and cooperation can translate into different outcomes for our industry partners as well as our urban spaces more broadly.

2 METHODOLOGY

In this work, we model the interactions of different entities within the parcel delivery sector in order to simulate the system at the level of the movement of individual delivery personnel and their vehicles throughout the day. Parcel delivery personnel can be on foot, in a van, in a larger heavy-good vehicle, and so forth. The availability of different parts of the transport network to the personnel are correspondingly varied, as are the possible speeds. Individual parcel delivery personnel determine how to make their deliveries, although in certain scenarios they may be informed by company-specific metrics or requirements. The model framework is built in Java, using the MASON simulation toolkit, an open-source multiagent simulation library [Sullivan et al. 2010]. In the simulation, the environment is captured at a $5m^2$ resolution, and the temporal scale of the model is calibrated so that one step of the model represents one minute in real time. These granularities are set based on units of time and space relevant to a mix of pedestrian and vehicle movement within an urban environment. The code for the simulation is available on GitHub (https://github.com/swise5/SimpleDriverDemo/), although the data that supports the validation section is proprietary. The following sections present the model environment, the individual entities, and the behaviour of the various entities, with each section giving insight into the way different scenarios can be represented in this context.

2.1 The Environment

The model presented here represents the environment in which the delivery personnel act as a network of multimodal transportation connecting potential delivery points and depots. In the instance presented here, the model combines OpenStreetMap data on roads and pathways in Central London. The road network includes parking restrictions drawn from OpenStreetMap, showing where driven vehicles are prevented from stopping to unload, as well as parking spaces tagged with information about their suitability for different sizes of vehicle.

In addition to the transport network, the physical environment also gives details about the location of parcel depots. The road network has been designed to allow for the incorporation of SCOOT (Split Cycle and Offset Optimisation Technique) data showing traffic flow information, although this data was not yet available to the researchers at the time of writing. Other external data includes parcel delivery data. This data, colloquially known to freight companies as their "manifest", can be either fed into the model or else synthetically generated for the area in question. This informs the locations to which the individual delivery personnel will have to make their deliveries, shaping their movement within the environment.

2.2 Entities

Broadly speaking, there are three kinds of entities within the system, of which only the individual delivery person can be said to be a full agent. The two "passive" agents are depots and parcels. The parcels are no more than objects with a location, a target destination, and weight and size dimensions. Optionally, a parcel may also have a delivery time slot, which specifies a time window within which the parcel must be delivered to the target location. Depots are similarly relatively passive, responding to the arrival of a individual delivery person by providing them with a batched set of parcels. The manner in which the depot batches the parcels is one of the major aspects of scenario selection. Indeed, both the target delivery points and the process by which parcels are generated at the depot can be configured to explore more nuanced examples of new approaches to freight. The case study will ignore aspects of weight and size, as do the systems of the freight companies with which we have partnered in the past.

The delivery personnel are the heart of the model. They are individuals with a location, a certain knowledge of the transport network, and potentially a vehicle of some description. The personnel are also endowed with a particular method or heuristic by which they choose to deliver their parcels. Taken together, these attributes determine their wayfinding, speed, and parcel delivery process.

2.3 Agent behaviours

As described above, the only true agents in the simulation are the delivery personnel. They are characterized by a number of behaviours, which interact with one another and potentially shape the decision-making space within which their fellow personnel act. Our design and implementation of delivery personnel behaviour is drawn from interviews and ride-alongs with working delivery drivers [Bates et al.].

Firstly and perhaps most importantly, the personnel are characterised by a method of choosing the next parcel they intend to try to deliver. This behaviour is modularised to facilitate the exploration of a variety of behaviours, including greedy algorithms, true optimisations, heuristics, and so forth. Agents can be dynamically responsive to changes in traffic or parking availability, or they may be unchanging in their ordering. They have been designed to be easily modified, allowing the user to propose new modes of decision-making as appropriate for their own context.

Having chosen which parcel to attempt to deliver, the delivery person will plot a route to the target delivery location, attempting to minimise travel time. This route will be informed by their own knowledge of the environment, which may be good or bad depending on how familiar they are with the target area (this helps to capture the cost of relatively untrained delivery personnel and their impact on their coworkers). Arrival at the point may incur a time penalty, depending on the mode of transit (e.g. the time to park a vehicle). In particular, delivery personnel in vans may find the nearest parking spaces already in use by other personnel, and be required to either divert to a further parking space or to undertake a holding pattern, waiting for parking to become available.

Upon arriving as close to the location as their chosen mode of transit will allow, the delivery person will attempt to deliver the parcel, potentially failing to successfully complete the delivery and therefore being required to retain the parcel. This failure rate is currently drawn from a global variable, but could similarly be specified as a function of building type, parcel dimensions, or some such metric. An important note is that depending on the next-parcel-selection method, the delivery person may attempt to deliver multiple parcels simultaneously, or to plan a shorter walking route around an area doing deliveries on foot. In this case, the chance of failure is applied to each individual parcel. A failed parcel delivery incurs an extra time cost, to reflect the need to generate documentation of the failed delivery (e.g. leaving a "card" for the intended recipient of the delivery to notify them how to proceed).

Having either succeeded or failed to deliver the parcel, the delivery person will continue to attempt to deliver parcels until they have either successfully delivered all parcels, attempted delivery of all parcels, or run out of time in their shift, at which point they will return to the depot. If they return to the depot in order to pick up more parcels, they will be required to wait for an open space at the depot in order to fill up their bag or vehicle.

3 CASE STUDY

We present a case study showing the difference in road usage and personnel time in the case of both the standard operating procedures of a group of independent parcel delivery companies and in an instance where they each adopt a portering-informed delivery approach. The work helps to explore how moving parcels out of vehicles and into different forms of delivery might impact the overall profile of delivery in London. In must be emphasised here that this work is preliminary and carried out as a proof of concept. Our purpose is to develop the model in conjunction with external, non-academic partners, getting feedback and adjusting the model accordingly throughout the process. This rapid prototyping will allow our partners to feel confidence in their understanding of the workings of the model, without requiring them to participate in writing code or analysing data themselves. Having established this relationship, we will have the freedom to explore more varied forms of delivery without fearing that our work will be understood as that of outsiders with little grasp of the problems our partners face.

As such, we begin here with a simple case study situated in central London. We draw the manifest data used here from synthetically generated data, informed by real manifest data provided by our industry partners. This randomisation of true data allows us to ensure that demand is being accurately modelled, while not compromising the anonymity of the clients who ordered the rela parcels. Similarly, the depot location is informed by real depots as they existed in 2016. Data on the manifest locations as well as GPS traces of vehicle movement in central London were collected in September 2016, and are here used in this context to calibrate the model.

In particular we calibrate the "baseline" model as a form of "verification" - that is, the process of ensuring that the implemented model matches the designed model. North and Macal [North and Macal 2007] define this as the case in which the code produced as part of the work correctly carries out the processes described by the authors. Verification decreases the risks of code and data artefacts, and makes for more rigorous science. It is often contrasted with validation, or the determination whether the modelled processes produce results that resemble the real data (as per [North and Macal 2007]). In this instance, we compare the routes generated by our synthetic delivery personnel with the real traces of drivers to assess whether their actions are adequately realistic to be of research use. See 1 for an example of the true personnel trace information.

4 CONCLUSIONS

In this work, we present a model framework which allows us to posit how delivery personnel carry out their responsibilities, and to explore in detail how these decisions and actions translate into larger patterns of road usage, traffic congestion, and unintended interferences with the work of their peers. By seeking to show how different combinations of approaches to delivery operate, we can gain a better understanding of how effective certain changes could really be, both in the case of perfect and imperfect adoption. Focusing on behaviours and knowledge allows us to divorce the patterns from the noisy, imperfect data we have collected.

Future work will hopefully include more diverse modes of transit, as well as a greater range of methods by which agents choose which parcels to deliver. Increasing availability of data drawn from the smart cities movement will further extend the useability of the model. In particular, the ability to include collection data into the model represents an enticing option. The model also does not, at this time, incorporate information about public transit routes, although this would potentially be of interest in exploring the movements of delivery personnel through alternative modes of transit. Further, richer data about parking locations and restrictions could prove a promising avenue for investigation, especially if explored in conjunction with local council colleagues with an eye toward creating special drop-off zones.

The work presented here represents a first step toward producing a tool which will allow for more informed conversations about parcel delivery and how it might work under a variety of conditions. The need for such findings to be accessible and responsive to end user concerns cannot be overstated. Subject matter experts who feel that their experiences are not reflected in the behaviours of the delivery personnel, or the functioning of the depots, or even the distribution of parcel sizes, are not going to be compelled by our research findings. Allowing them to look inside the model and understand all of its workings builds trust and rapport, and ultimately invests them with the power to make their own decisions based on our work.

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Figure 1: *Example of real routes taken by different parcel delivery companies*

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REFERENCES

ALLEN, J., BEKTAS, T., CHERRETT, T., FRIDAY, A., MCLEOD, F., PIECYK, M., PIOTROWSKA, M., AND ZALTZ-AUSTWICK, M. 2017. Enabling the freight traffic controller for collaborative multi-drop urban logistics: practical and theoretical challenges. Tech. rep.

BATES, O., THORNTON, L., MCLEOD, F., CHERRETT, T., AND WISE, S. Menzies distribution report based on visit to inverness depot (9-12 july 2018). unpublished.

BATES, O., FRIDAY, A., ALLEN, J., MCLEOD, F., CHERRETT, T., WISE, S., PIECYK, M., PIOTROWSKA, M., BEKTAS, T., AND NGUYEN, T. 2018. Ict for sustainable last-mile logistics: Data, people and parcels. In *ICT4S2018: 5th International Conference on Information and Communication Technology for Sustainability*, B. Penzenstadler, S. Easterbrook, C. Venters, and S. I. Ahmed, Eds., vol. 52. 49–67.

CHEN, P., AND CHANKOV, S. M. 2017. Crowdsourced delivery for last-mile distribution: An agent-based modelling and simulation approach. In *2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 1271–1275. doi: 10.1109/IEEM.2017.8290097.

FOR TRANSPORT, D. 2015. Transport statistics great britain 2015.

FOR TRANSPORT, D. 2016. Transport statistics great britain 2016. Tech. rep.

GILBERT, N. 2007. Agent-based models.

HEPPENSTALL, A., MALLESON, N., AND CROOKS, A. 2016. fispace, the final frontierfi: How good are agent-based models at simulating individuals and space in cities? *Systems 4*, 1.

2015. 2015 metapack uk delivery index report. Tech. rep.

MINTEL. 2016. Online retailing fi?! uk. Tech. rep., July.

NORTH, M., AND MACAL, C. 2007. *Managing business complexity: Discovering strategic solutions with agent-based modelling and simulation.* Oxford University Press, New York, NY.

STARÝ, J. 2012. *Agent-based Model of Parcel Logistics.* PhD thesis.

SULLIVAN, K., COLETTI, M., AND LUKE, S. 2010. Geomason: Geospatial support for mason. Tech. rep., Department of Computer Science, George Mason University, Fairfax VA.