Work Package 7: Urban Simulation & Modelling

Urban Simulation: Resource Competition and Service Performance Model

D7.3 & D7.4 Combined Report

April 2020

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Aims and Objectives

The main aim of this work is to define and better understand the benefits and spatially advantageous patterns of using AV to explore the deployment of Connected and Autonomous Vehicles (CAV) in Greater Manchester. More specifically this work aims to achieve the following set of objectives:

- Develop a spatial simulative resource competition model for a pre-defined specific geographic area.
- Explore/compare multi modes of transport: 'on demand CAV fleets' vs traditional mode (taxi)
- Explore the potential impact of using 'on-demand CAV fleets' on a number of attributes.

SYNERGY

Executive Summary

Synergy is a £5 million project funded by Innovate UK Autonomous Vehicles (CCAV2). The aim of this project is to further develop innovative technologies for connected autonomous vehicles to accelerate the adoption of driverless vehicles and allied technologies in the UK. This project has introduced innovative technologies to operate connected autonomous cars in a platoon formation from Stockport directly to the arrivals terminal at Manchester Airport. Concurrently, a platoon of three pods will transit passengers to and from a car park in the airport to the passenger terminals.

As a member of project Synergy consortium, Manchester Metropolitan University has been leading the delivery of WP7 with a focus on 'Concept Development and Urban Simulation'. The scope of the work consists of testing the innovative CAV technology from a human and spatial perspective through academic research and development of a digital simulation model.

This deliverable reports on combined findings of a resource competition (D7.3) and service competition urban simulation model study (D7.4), which tested a future CAV rapid personal transport system in Manchester Airport against the existing Taxi system.

Findings highlighted a distinct performance variance favouring different stakeholders. The existing Taxi system favoured operator interest such as minimising dwell time, deadhead time, average travel time and overall vehicle distance travelled. The CAV system seemed to favour the user and city stakeholders with better performance in measures such as user wait time, number of passengers waiting, total CO2 emissions and CO2 emissions per passenger.

Both systems were also run in parallel engaging in direct competition for the same passengers. Comparing the results of this competition run, the CAV system, with its better performance in passenger measures, achieved higher demand levels and overall passenger numbers than the Taxi service.

The report is structured to first highlight the aim and objectives of this work. Following the executive summary, the report begins with an introduction on Connected and Autonomous Vehicles outlining various levels of automation. The following section on CAV & Taxi system optimization and testing explains in detail, the model used to simulate various scenarios for both CAV and Taxi systems. Next, the simulation results are examined in detail, thus enabling an active comparison between both systems. The report ends with concluding remarks and a full list of references.

Introduction to Connected and Autonomous Vehicles

CAV is a term commonly used by the UK government which refers to a type of vehicles that are either highly or fully autonomous or connected, or both, connected and autonomous (The House of Lords Science and Technology Committee, 2017). Most commonly 'connected' refers to V2I (vehicle-to-infrastructure). It is important to note that automated driving does not require communication technology to perform the driving tasks, however, it is expected that many service providers will take advantage of this feature. Novel services such as Mobility-as-a-Service (MaaS) as well as other vehicle sharing and ride-hailing operations require vehicles to be connected, and they have often been brought up in discussions about the future of mobility (Jittrapirom et al., 2017; Sprei, 2018) and the future of autonomous vehicles (Gruel and Stanford, 2016).

Autonomous driving implies a technology that is capable of performing driving without human presence. Often in literature there is no clear indication of precise terminology when it comes to autonomous driving. In industry, the most commonly used classification is by SAE International (Society of Automotive Engineers) identifying six different levels of autonomy. Figure 2 summarizes the SAE classification. However, the level of autonomy is not always specified (especially, in media), which can sometimes result in unsubstantial assumptions of technology and its capabilities.

Figure 1. Autonomous pod by Westfield Sports Cars.

Earlier discourses about the future of autonomous driving saw the phasing in the levels of autonomy as steps in a logical progression. However, more recent research has shown that Level 2 and Level 3 autonomy might not be safe enough to be introduced in the market. In a study performed by National Highway Traffic Safety Administration (US) on partial automation revealed that it takes up to 17 seconds for the driver to obtain full control of the vehicle and cognition of surroundings, due to lack of attention paid to the road while in autonomous mode (Blanco et al., 2015). Therefore, in order to avoid compromising road traffic safety, the mainstream self-driving vehicles that will be introduced on the roads will most likely be Level 4 or Level 5. Even though Level 4 has the option for the driver to take control, the vehicle is capable of performing driving in assigned situation and does not require human monitoring. For example, such vehicle might not be able to fully perform in a street traffic situation but can operate independently in an airport setting in known surroundings.

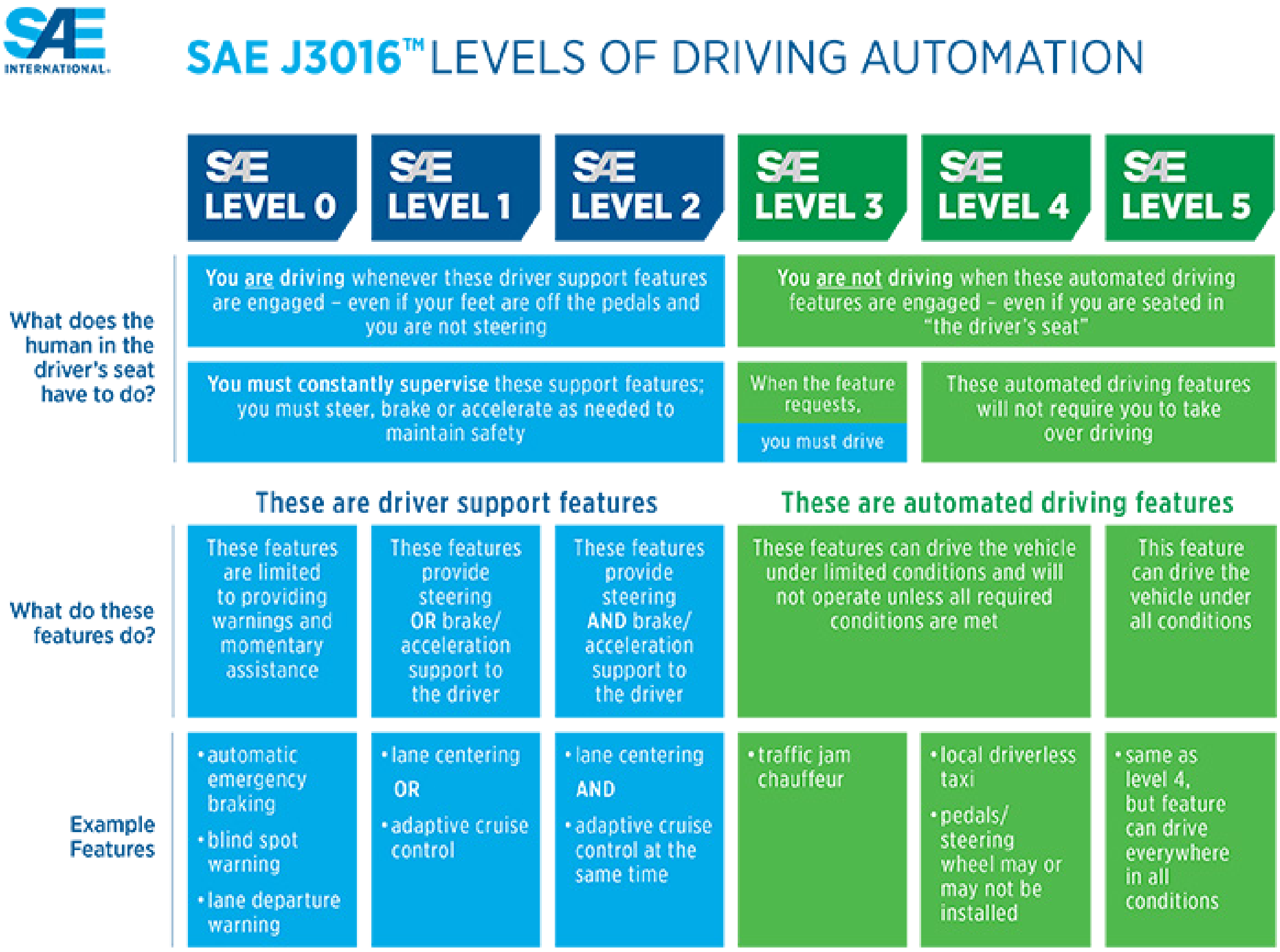

Figure 2. SAE Levels of automation, source: https://www.sae.org.

Scope

This work builds on the findings from the study on 'Connected and Autonomous Vehicles: The Opportunity in Greater Manchester' (February 2019) carried out by Atkins for TfGM. The Atkins study explored a number of potential scenarios for CAV adoption based on CAV usage and the penetration of CAV technologies on the roads' network. These scenarios include: Elite CAVs, Private CAV society, shared CAV fleets and Autonomy rejected. Stakeholder engagement in Greater Manchester resulted in a clear preference for CAVs to be integrated within existing public transport as part of a collective, shared mobility system. Close examination of these scenarios clearly indicate that the 'shared CAV fleet' scenario provides the largest potential for CAVs to be offered as a fleet service, integrated within the wider, shared mobility system in Greater Manchester. In such a scenario, end-users will be able to book a shared CAV as a sole rider or sharing with others. In addition, CAVs will also be used to support public transport systems including rail and metro link.

In addition, the Atkins study identified a number of use cases to explore CAV deployment and potential applications in Greater Manchester. The list of case studies includes: first/last miles for passengers, on-demand CAV fleets, segregated CAV corridors, automated regional public transit and first/last mile for freight.

Following the above study, a decision was made to select 'On-demand CAV fleets' as a case study for the digital simulation model since stakeholders' engagement in November 2018 revealed that it was the most preferable case study with the highest potential for CAV deployment. The 'On-demand CAV fleet' case study deploys CAVs as a shared mobility system fleet operate within a specific geography area and an extended environment to include urban, suburban as well as rural areas. This case study will utilise pods, shuttles and cars, operating in a shared mobility system.

Location & Model Set-Up

The geographical area for the simulation covers Manchester Airport and some of its surroundings as illustrated below (Figure 3).

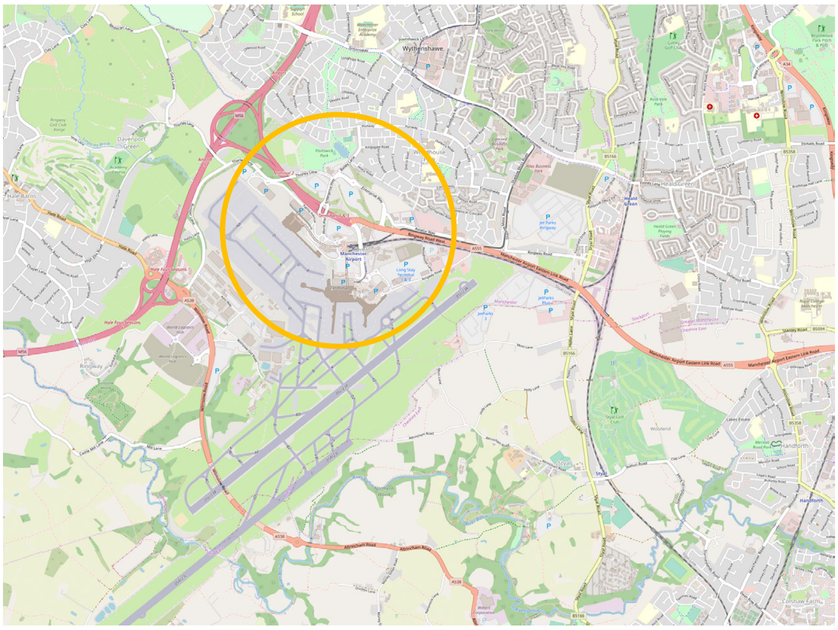

Figure 3. Map of Manchester Airport and adjacent surroundings.

The geographic area of the simulation model includes the airport zone as a pre-defined area for the competition model, existing road network including a number of pre-defined passenger pick up locations.

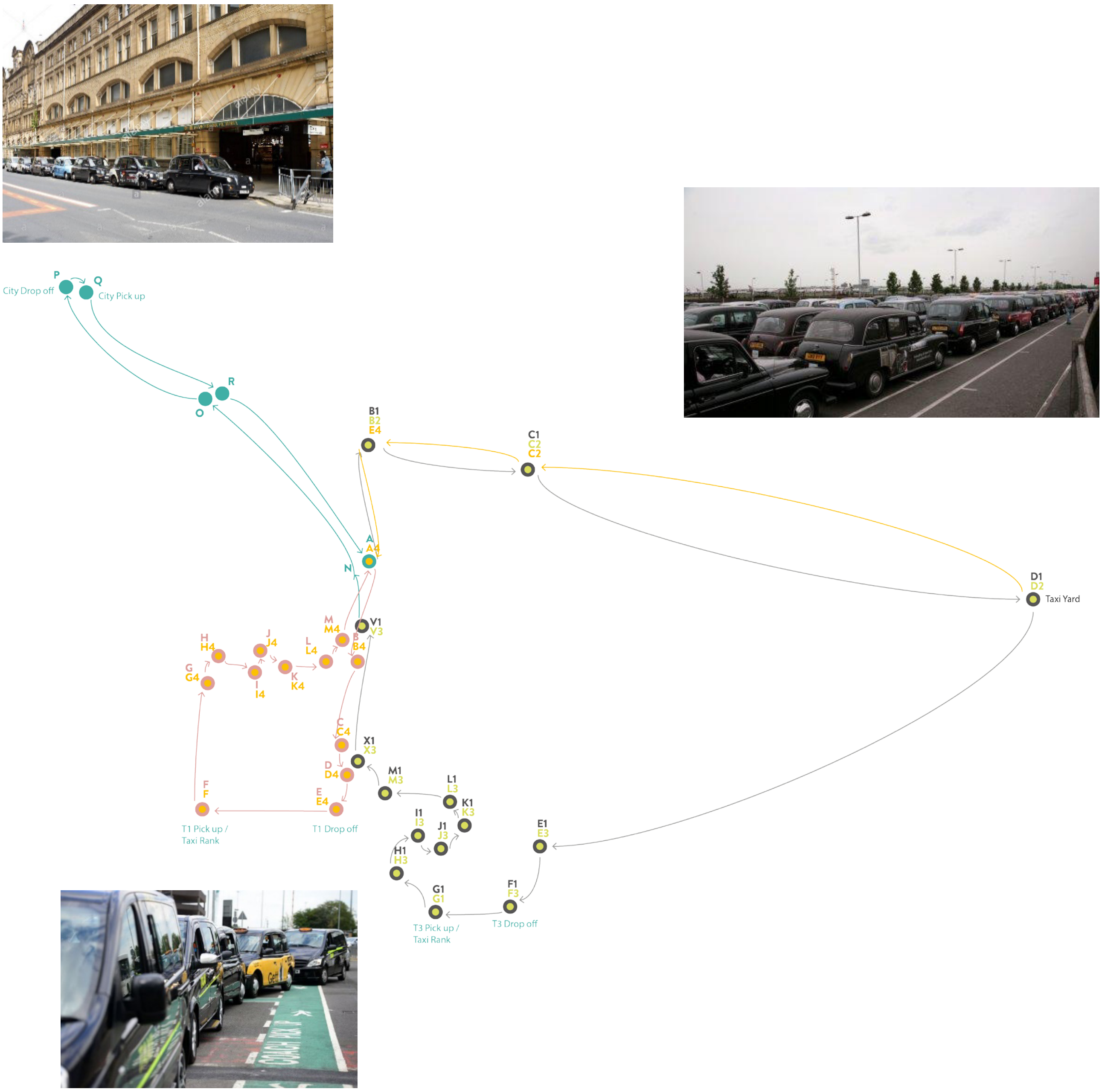

Figure 4. Taxi and CAV routes from Terminals 2 and 3 to and from a city center location in the simulation model.

CAV and Taxi Profiles

The digital simulation model was designed to explore the behaviour of both transport systems: CAV and a traditional one (Taxi). The agent (vehicle) characteristics defined for the CAV system is based on the assumption that all vehicles are part of a centrally controlled network. Decisions and actions in this case, are dependent on other vehicles to maximise collaboration. However, in the case of the traditional Taxi system, behaviour is conceived on the assumption that all vehicles will act individually and decisions made by one vehicle are independent of other vehicles, operating a more random system.

Service: Shared

Passengers: Max Capacity when possible

Control Type: Top down

Leave when Car is full or travel distance between car infront / car behind is above x or below y metres

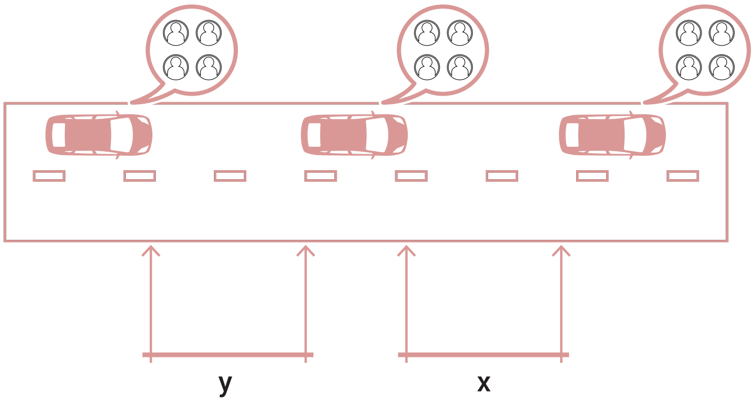

Figure 5. CAV Pick-Up Behaviour

Service: Individual

Passengers: First come first served (between 1-max capacity)

Control Type: Bottom up

Leave when Car has a passenger on board.

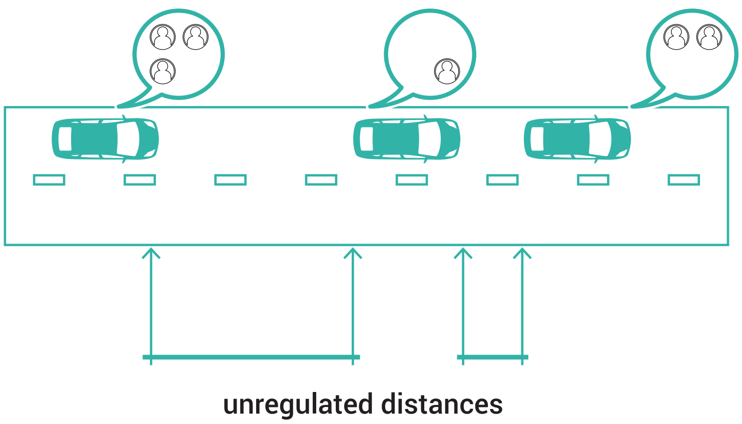

Figure 6. Traditional Taxi Pick-Up Behaviour

All cars act as part of a centrally controlled network. Their actions and decisions are controlled and dependent on other cars. This enables the system to be rigid with maximum collaboration between all units.

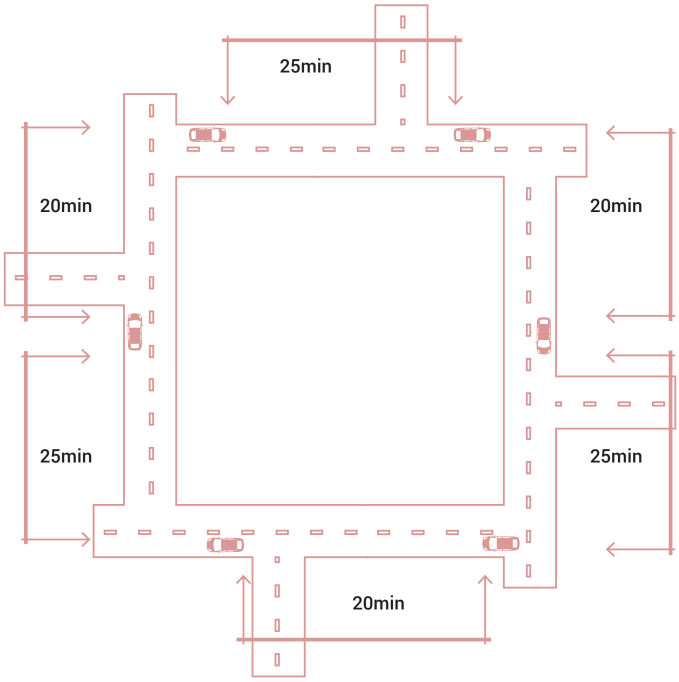

Figure 7. CAV System behaviour: Top Down

All cars act individually, their actions and decisions are independent of other cars. This enables the system to be more random with no control over the overall systems running.

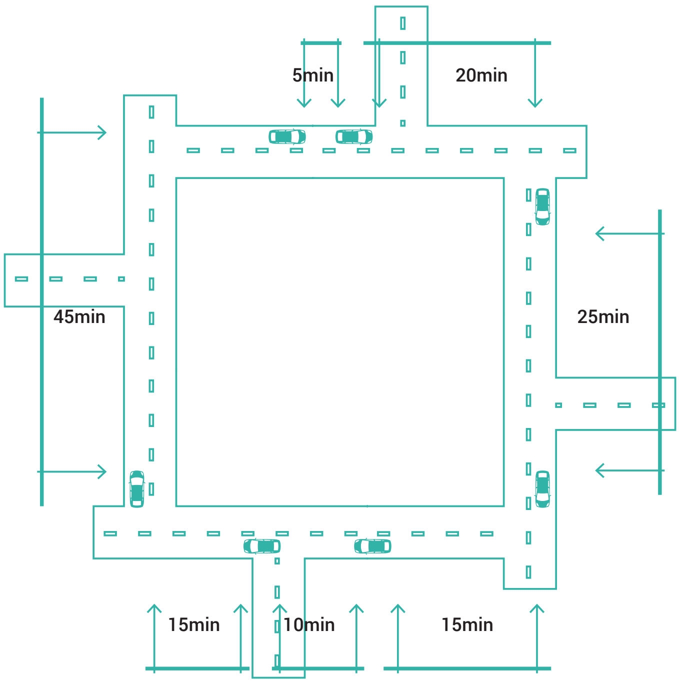

Figure 8. Traditional Taxi System behaviour: Bottom Up

CAV & Taxi system optimization and testing

This part of the simulation situates each transport service, CAV and Taxi, in a range of scenarios in order to test their performance. The scenarios make use of changing parameters for each system that are set differently for each test. The model run 12 times with a different combination of changing parameters for each system. This section outlines all the test runs carried out and presents/analyses the results.

Test Runs Outlined

Changing Parameters for the model

The 12 simulations utilise a range of changing parameters. These range between system type, rate of passenger generation, fleet size and pick-up behaviour.

System Type includes a switch between CAV and Taxi systems. Each system has their own unique characteristics outlined below:

- CO2 emissions per km
- Capacity of Vehicle
- Route followed
- Route decision algorithm
- The rate of passenger generation change aims at testing each system against changing demand patterns from massive spikes to steady stream. The parameters for this include:
    - Number of passengers at T1 / T3
    - Interval of passenger arrival

Fleet size involves the number of vehicles a service has available for completion of work. This is between 10 – 20 cars.

Pick-up behaviour involves the characteristics laid out as law to be followed by service vehicles when entering a passenger pick-up zone. This includes the minimum number of passengers needed to be picked-up before leaving the zone. This does not apply for Taxis due to the personal transportation aspect of the system, which is inherently not shared unless the passengers themselves negotiate this between each other.

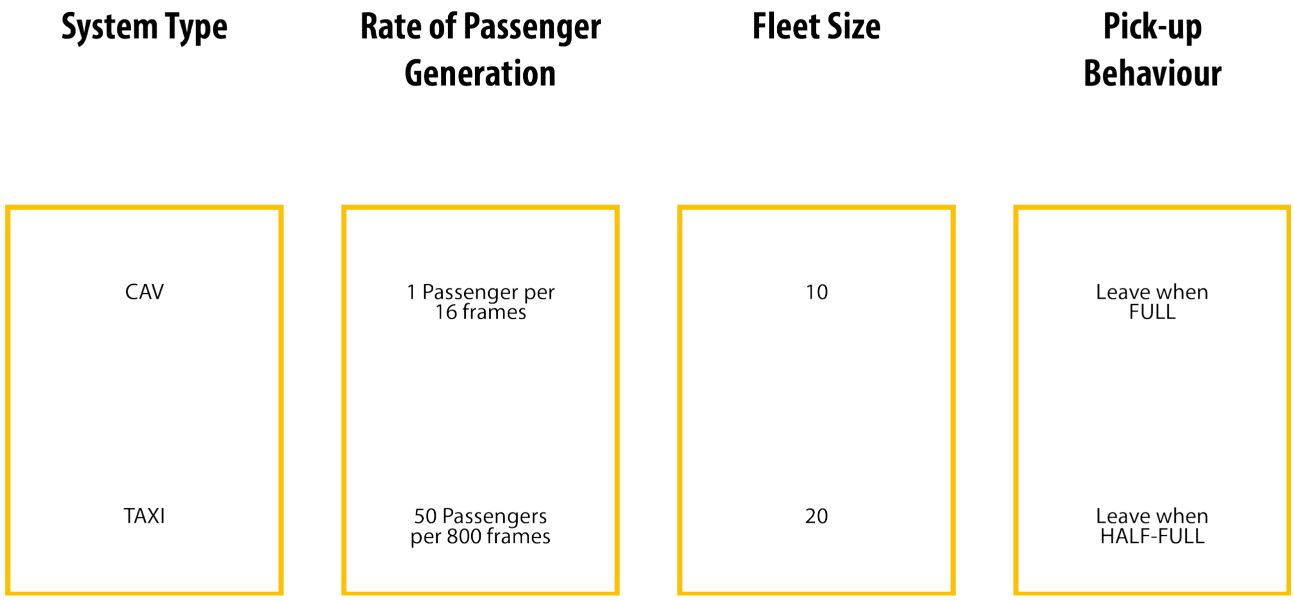

Figure 9. The diagram showcases the different variable changes for each simulation run

Number of runs and variables

The model run 12 times with all results recorded. The 12 runs had the following combination of changing parameters

- Taxi System
- CAV System
- 1 Passenger generated per 16 frames
- 50 Passengers generated per 800 frames
- 10 vehicle fleet size
- 20 vehicle fleet size
- Pick-up behaviour of only leave when at full capacity
- Pick-up behaviour of only leave when at minimum half-capacity

Results of Runs

Performance criteria identified for recording results

The tests record a number of performance criteria as real-time data outputs that make up the results of the simulation. These criteria include:

Number of Passengers served
This includes all passengers serviced by a fleet vehicle during the run

Passengers in simulation
This includes the total number of passengers generated in the simulation and is used to understand the percentage of passengers serviced out of the total thus determining the capacity of the system

Distance travelled by all vehicles in the simulation
Each vehicle in the fleet is tracked in real-time in the simulation and its distance travelled is measured to understand the number of passengers serviced against distance travelled

Total vehicle dwell time/idle time
Vehicles in the simulation can dwell at pick-up points or the taxi yard while awaiting passengers. This is called dwell time and is used to understand the inherent inefficiency of the system

Vehicle deadhead
Deadhead is a measure that incorporates total vehicle time spend driving around without any passengers inside. This is a measure of system efficiency.

Passenger Distance Travelled
This performance criterion is a measure of the total distance travelled by passengers. The measure determines how the system layout/route followed affects the service provided

Total Passenger wait time
Passengers generated have their waiting times, from the moment of generation to the moment of pick-up, tracked in real time. The total is given as an output

Average waiting time

The average waiting time for each passenger is also recorded to understand how the total number of passengers generated affects service performance

<u>Total passenger travel time</u>

Passengers' travel time, from the moment they are picked-up to the moment they are dropped-off, is recorded in real time and added up as a total

<u>Average travel time per passenger</u>

The average travel time is also recorded in order to understand how the system is affected by changing demand

<u>Total CO2 emissions estimate</u>

Each vehicle in the simulation has their real-time CO2 emissions tracked based on their distance travelled. This allows for the total CO2 emission of the system to be recorded as a result informing on the environmental performance of the system.

<u>Estimated CO2 emissions per passenger</u>

The total CO2 emissions does not allow for an accurate comparison of environmental performance as it fails to include the total number of passengers serviced in the calculation. Therefore, the emissions per passenger are also measured.

<u>Estimated CO2 emissions per passenger distance travelled</u>

This measure builds on the emissions per passenger by allowing for the distance travelled being included in the calculations. This enables a comparison of the system's performance in both passengers serviced and the distance travelled to complete journeys.

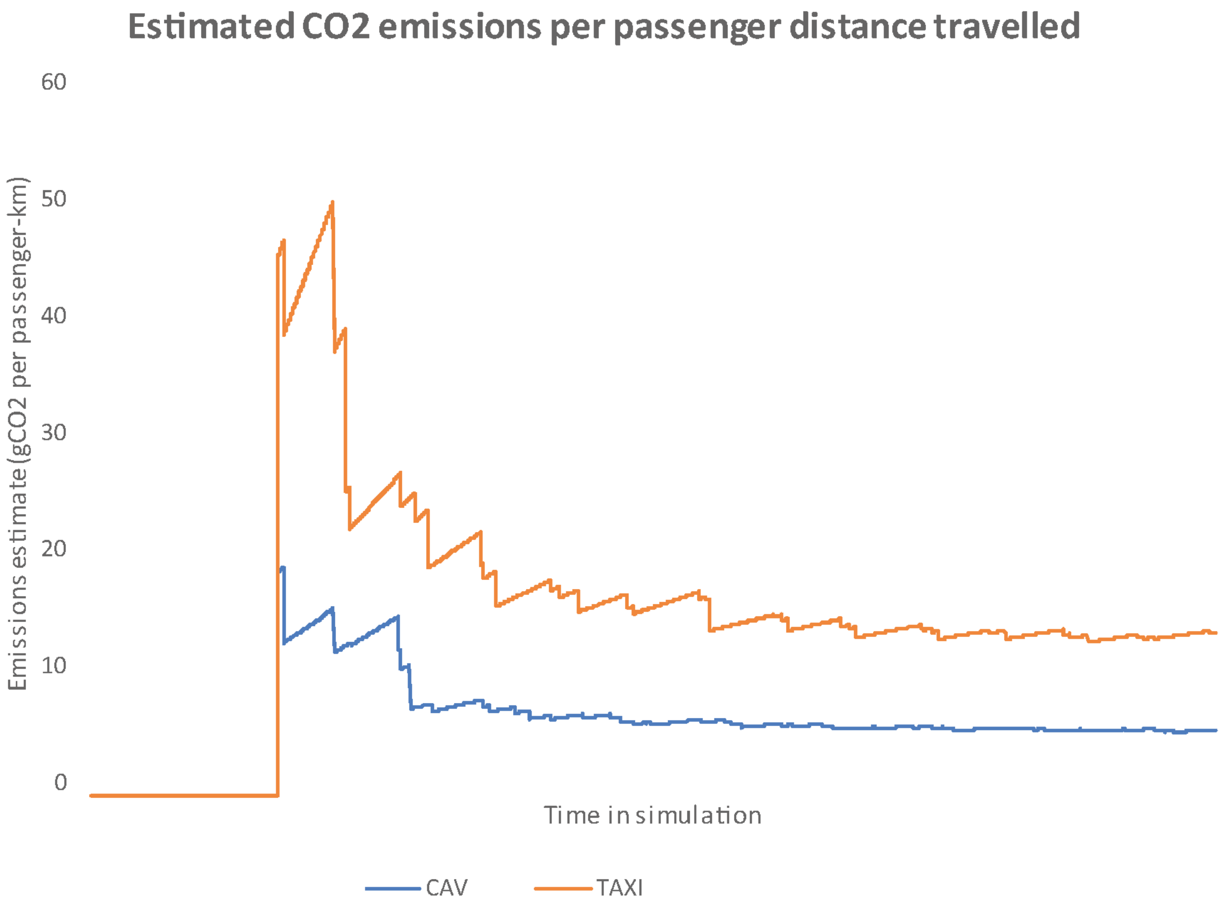

Figure 10. Data is collected in real-time from the simulation allowing for graphical comparisons between runs and mobility systems

Results

Each test run had its parameters labelled as the name and the results recorded in real time as a csv file allowing for graphical outputs. This enabled a direct comparison between each run for every single performance criteria allowing for the ranking of each test/system setting.

The results of this comparison were collated into a graphic displaying the performance of each run against every other run. The labels used to identify the scenarios include the system (T for Taxi and C of CAV), the generation rate of people (A for 1 per 16 frames and B for 50 per 800 frames), fleet size (10 and 20) and pick-up behaviour (F for leave only when at full capacity and H for leave only when at minimum half capacity).

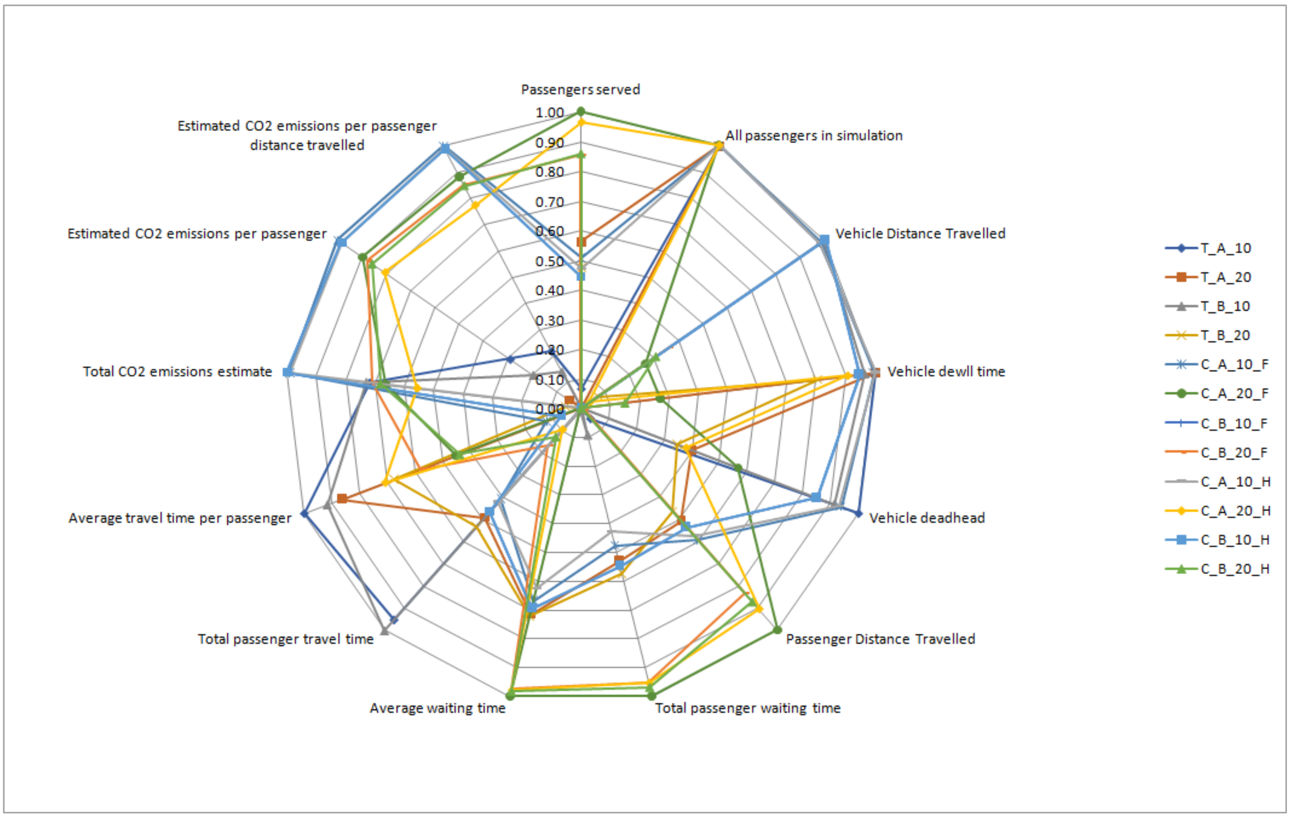

Figure 11. All runs have a multitude of performance metrics recorded and analysed in a ranking order as showcased in the figure above.

Analysis of Results

Understanding value to each stakeholder

In order to understand the results, we must consider what each performance criteria means to the different stakeholders of this system. How do their unique interests influence which system and system configuration is more beneficial for them? The stakeholders mentioned split into three groups. These are:

Operators

The operators include the companies responsible for operating the different mobility services as well as the individual taxi drivers that have a general independence from company control. These operators are concerned primarily with reduced dwell time and deadhead time for their vehicles.

Passengers

This group of stakeholder make up the customers using the service that are primarily concerned with the efficiency and speed of service and minimal wait times for service

City

These stakeholders make up the local authorities that are primarily concerned on optimising road usage and minimising air pollution/CO2 emissions.

All of the different operators have their performance interests identified and categorised (Figure 12). Some performance criteria have shared interests between two or more stakeholders such as average travel time per passenger reduction being of interest to both the operators (as they maximise their journeys) and passengers (as they get to their destination faster).

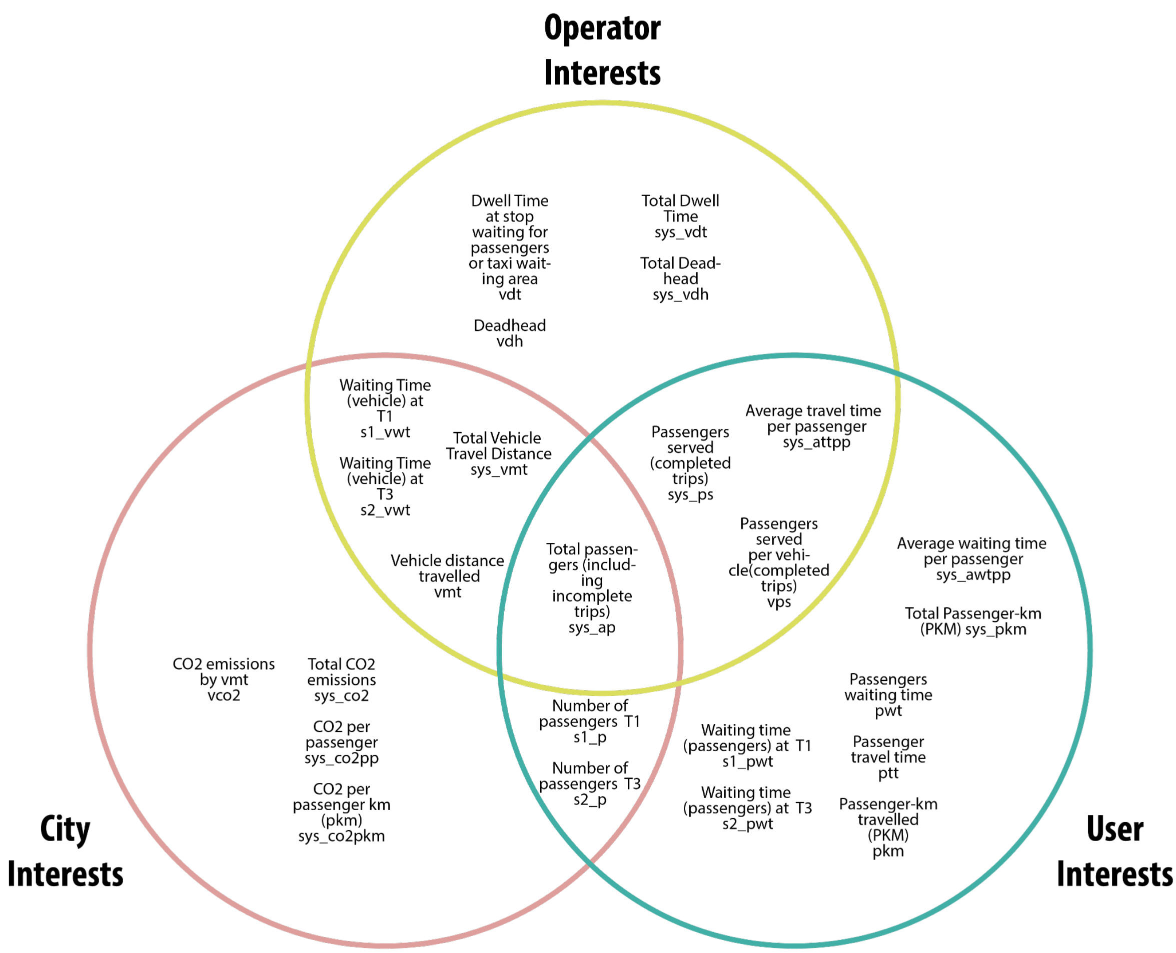

Figure 12. Illustration of three main stakeholder groups (operators, users and the city/government) and their performance interests concerning the provision of personal rapid transport services.

Given the performance interest of each group, the results analysed reveal a pattern when it comes to the two systems of Taxi and CAV. The run that scored highest in the operator's performance criteria range that include dwell time, deadhead time, average travel time for vehicles, passengers served and vehicle distance travelled, was set to a taxi system with the fewer fleet size. According to the simulation, the Taxi behaviour and increased demand favours greatly the operators.

Meanwhile the run that scored the highest in User interests and City interests ranging from average wait time, passenger distance travelled number of passengers waiting at terminals, total CO2 emissions and CO2 emissions per passenger involved a CAV system at max fleet. This creates a contrast between which system to implement, as operators seem to benefit more at the expense of users and government.

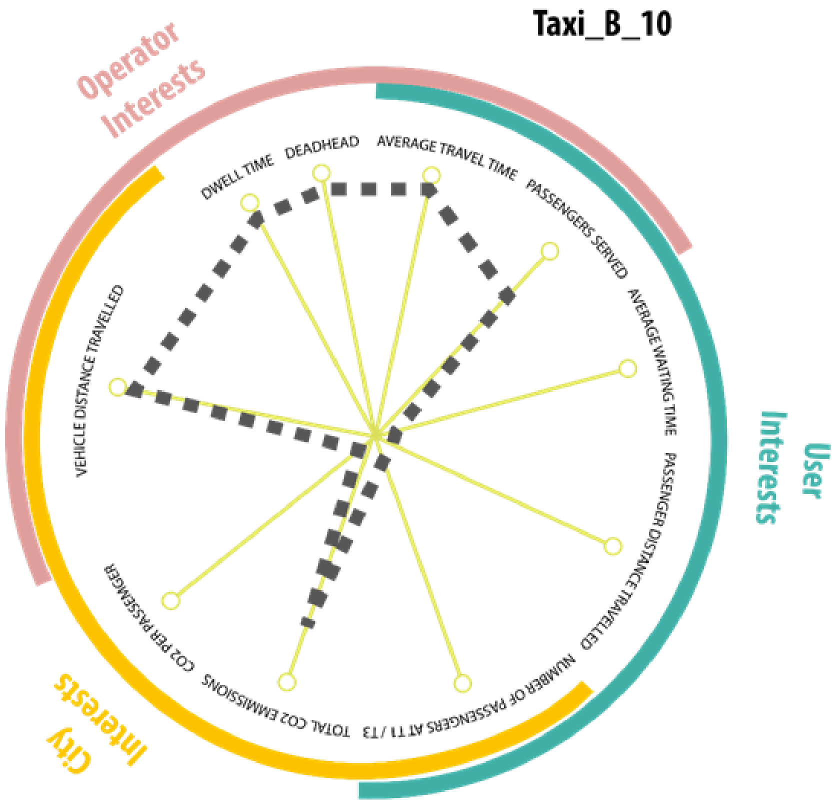

Figure 13. The performance of a Taxi run is recorded and analysed in terms of stakeholder benefits. The analysis clearly shows the majority of benefits clearly favour the operators in a Taxi system.

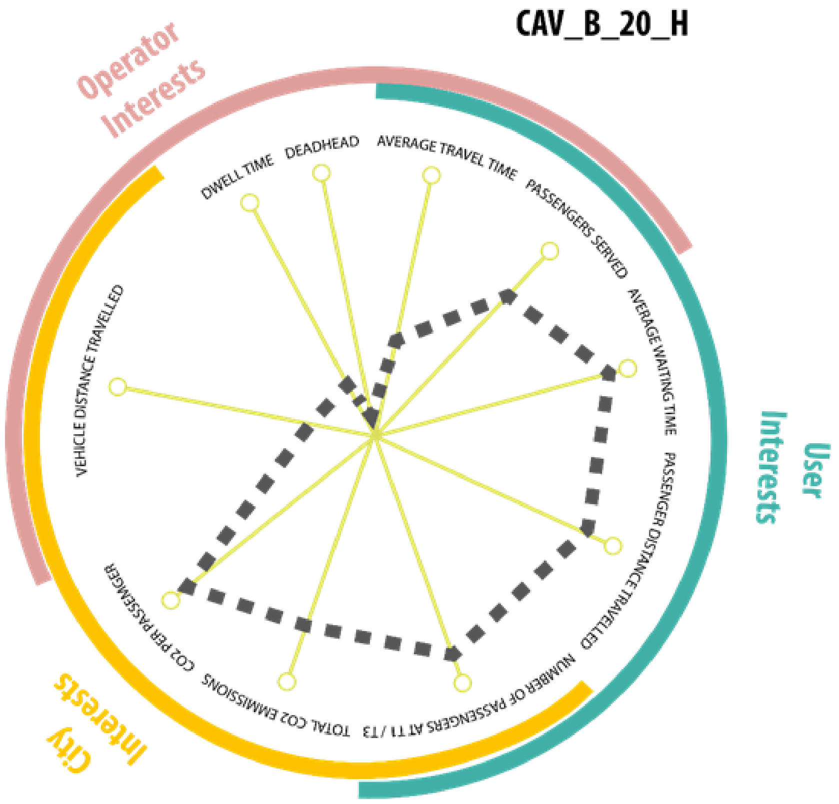

Figure 14. The performance of a CAV simulation run is recorded and analysed in terms of stakeholder benefits. Users and the City stakeholders are clearly favoured more in a CAV system.

Resource Competition Modelling

The previous simulation run each system separate in order to compare them in any given scenarios. In this section, we run both systems in parallel using the same scenario allowing passengers to make a decision as to the mode of transport they preferred. This enabled an active competition between the two systems and enabled the testing of CAVs as an integrated service with current Taxi system.

Setting up test runs

Passenger's Decision-Making algorithm

Running both systems in parallel, allowed passengers from one system to choose to que up for the other mobility system. The reasoning behind the change in these simulation runs focuses primarily on both the individuals wait time for the service and the average wait time for passengers at the stops.

Each passenger generated in both simulations is tracked and its wait time recorded. After a certain amount of time, the passenger may choose to change mode of transport as they are unhappy with the amount of time spend waiting to be serviced by their initial mobility system decision. This then allows that passenger to remove himself from waiting for one service and move into the que of the alternative service.

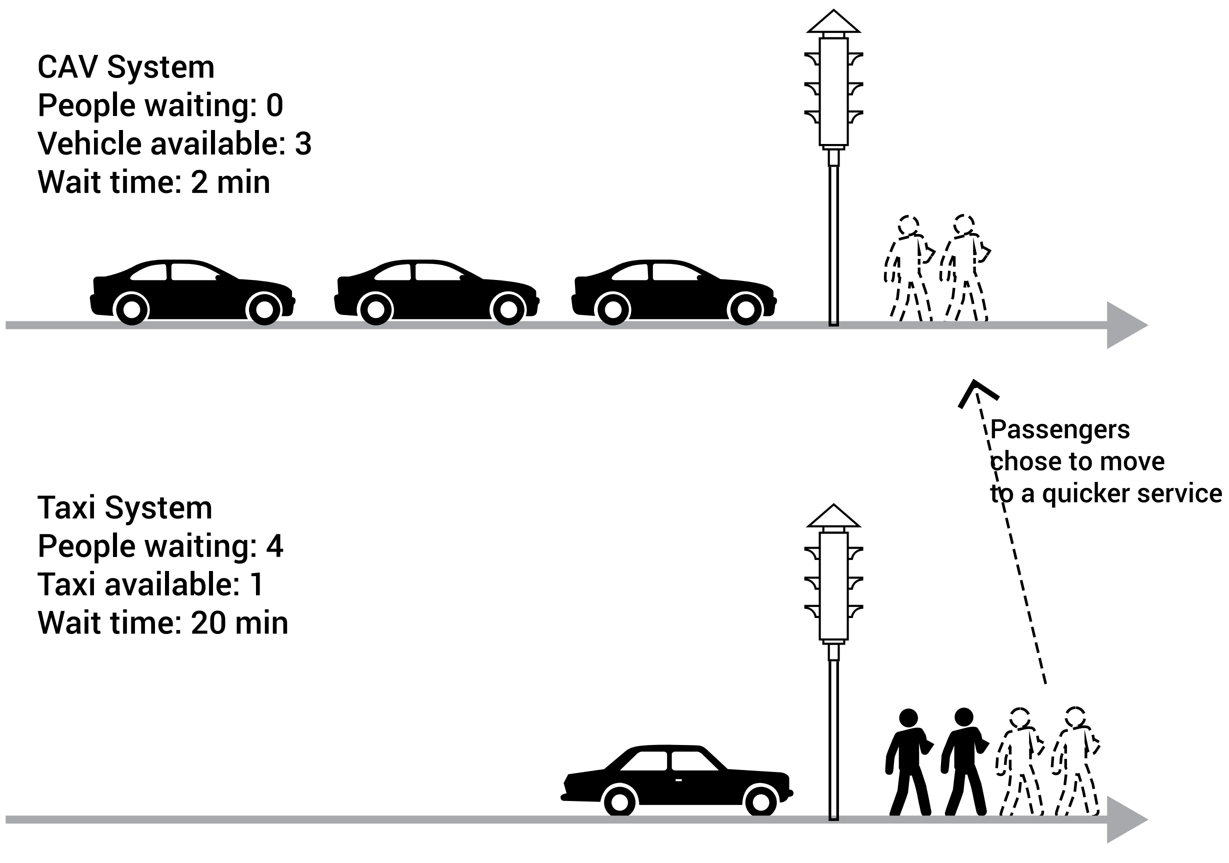

Figure 15. In the resource competition simulation between the Taxi and CAV system, passengers have the ability to chose between the two systems and change service if they believe it is faster/better.

Test runs

The model ran with the best performing system configurations for both services as their respective parameter combinations. These included:

Taxi System

- 50 Passengers generated per 800 frames
- 20 vehicle fleet size

CAV System

- 50 Passengers generated per 800 frames
- 20 vehicle fleet size
- Pick-up behaviour of only leave when at full capacity
- Pick-up behaviour of only leave when at minimum half-capacity

Results

Evaluating results from simulation

After both systems run in parallel for the allocated 10000 frames period, the results for this particular test focused solely on the passengers serviced in each system and the total number of passengers in the given system. This is due to the number of passengers serviced and the total number of passengers choosing one service over another forms a practical measure for the most demanded service and most effective/efficient service.

The results recorded in the graph below show an obvious edge to the CAV system that managed to service the higher number of passengers in the given period while keeping wait time low thus maintaining higher levels of demand and poaching passengers from the Taxi service throughout the simulations duration. The only exception to this is the first third of the graph that shows the initial response of the Taxi being more effective than the CAV. Once all Taxis were engaged in service however, the CAV's bottom up system behaviours proved more efficient in the long run given their unique pick-up behaviour and ability to maintain smooth service levels.

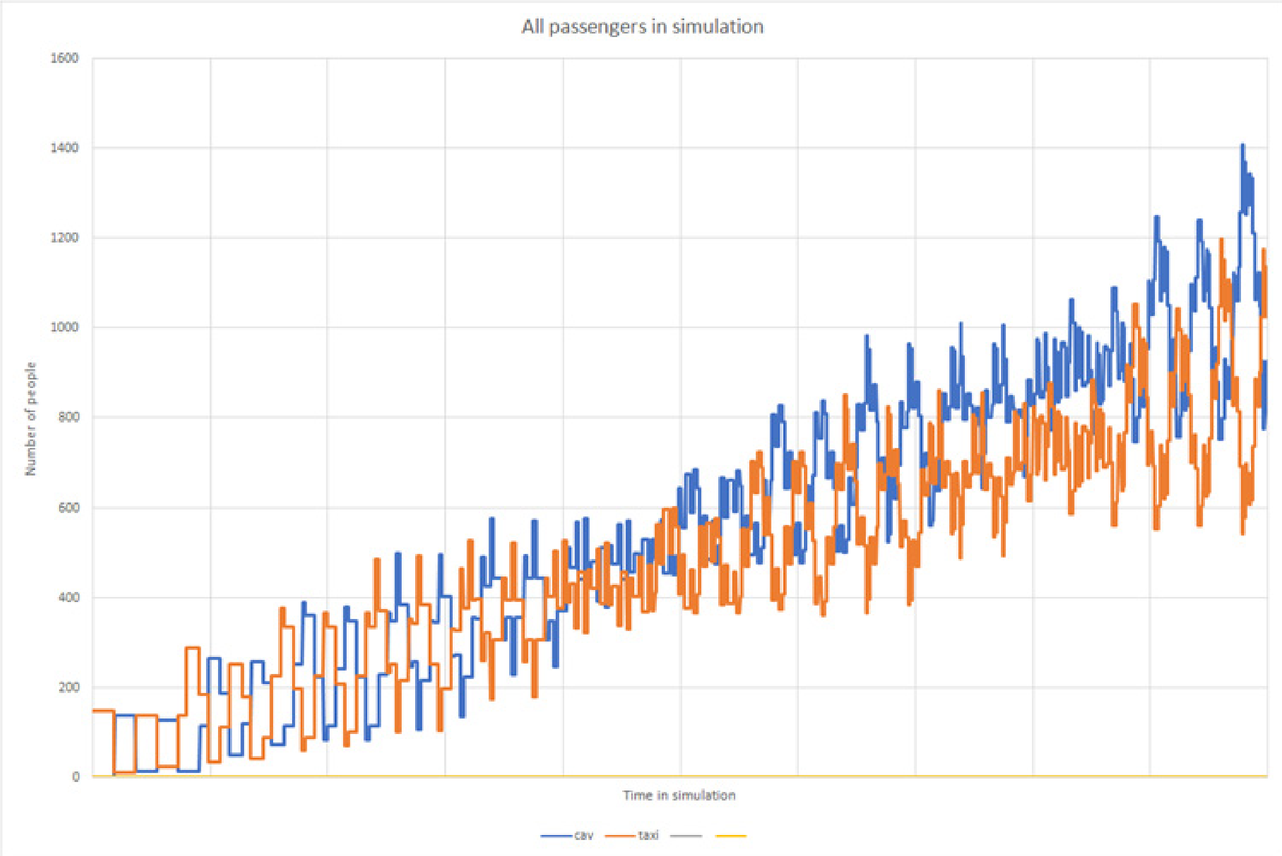

Figure 16. Passenger choices of CAV or Taxi service is recorded in real time allowing the comparison of what passenger choices are made at each point. The graph shows a clear trend of CAV being a more chosen option with passengers switching over to them.

Conclusions

Using a simulation-aided approach, a future CAV rapid personal transport system was tested in Manchester Airport against the existing Taxi system. From the analysis of the simulation run results, the conclusions drawn highlight a distinct performance variance favouring different stakeholders.

The existing Taxi system favoured operator interests such as minimising dwell time, deadhead time, average travel time and overall vehicle distance travelled. The CAV system seems to favour the user and city stakeholders with better performance in measures such as user wait time, number of passengers waiting, total CO2 emissions and CO2 emissions per passenger.

Both systems were also run in parallel engaging in direct competition for the same passengers. Comparing the results of this competition run, the CAV system, with its better performance in passenger measures, achieved higher demand levels and overall passenger numbers than the Taxi service.

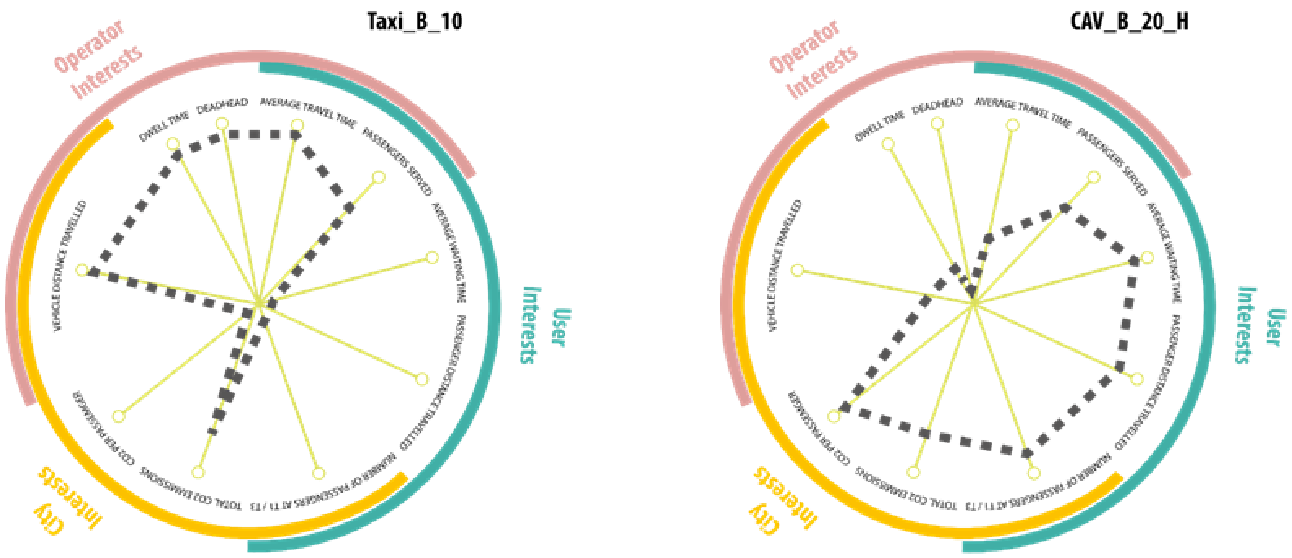

Figure 17. Comparison between Taxi and CAV mobility systems in terms of stakeholder benefit shows a clear divide between the heavily operator beneficial Taxi system and the user and city beneficial CAV system.

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SYNERGY