Case study of unmanned logistics in Helmond

Xiaoyun Zhang[1], Steven Boerma[2], Robbin Blokpoel[3], Jaap Vreeswijk[4]
1. Researcher, Dynniq, The Netherlands
2. Traffic Architect, MAPtm, The Netherlands
3. Lead researcher, Dynniq, the Netherlands
4. C-ITS Traffic Architect, MAPtm, The Netherlands

Introduction

Road transport Logistic is a becoming more and more complicated because of the multiple dimensions involved. To name a few: its range of physical activities spreads and connects across the whole network, forming logistic chains and logistic networks to transport and deliver people, goods and materials from specific origins to destinations; its sheer increasing demand and requirements from customers and in return, the increased demand for complex information and communication control systems of today's global business environment; its unpredictable interactions with existing traffic flows on road, worsening traffic congestions with significant effects on the number of road accidents.

These complications of dimensions require synergistic optimization of infrastructure and application of innovative technologies, such as unmanned vehicles. Thanks to advanced sensors, vision and geo guidance technology, unmanned vehicles have already taken on a significant part of the logistics work process, mostly within restricted areas, such as closed roads in modern warehouses in airports, harbours, and yards. The current developments of unmanned logistics are reviewed in Section 9.4 of MAVEN D4.4, which presented the thriving field tests of unmanned logistic prototypes on open roads. Although it is far from full spectrum of unmanned logistics on the open road, the future of logistics is undoubtedly heading towards the direction of full autonomous with drastic developments.

The MAVEN project foresees that the first deployment of a significant fleet of automated vehicles will be related to public transport and logistics applications.

The current urban mobility system has one clear problem: there is a vast range of transport vehicles that are set out to bring goods and people between specific locations, which are rarely the same as their origin or destination. This misalignment between actual service locations and precise origin-destination is commonly recognized as the "first mile, last mile" problem of the transport network. Autonomous vehicles can solve these problems in the following ways:

1. Smaller pods can offer efficient last-mile transport because they only need to serve a few destinations, keeping detours at a minimum;
2. More on-demand, comfortable and seamless connections when a trip involves transfers among various forms of transport means;

When looking at traditional public transport, prioritization through dedicated lanes and high priority signal groups at intersections, reduce traffic capacity and intersection throughput if not optimally designed. This is potentially a problem with adding a larger number of smaller transport vehicles. On the other hand, the total demand of vehicles on the network will reduce due to a modal shift. The effects of these factors in the urban traffic network is mostly unknown and needs to be investigated. Therefore, the MAVEN project initiates an unmanned logistic use case targeting the following objectives to tackle these problems:

1. To study the performance of Helmond N270 corridor in two decades, when unmanned shuttles and pods are integrated in the evening peak traffic flow.
2. To investigate the impact of existing road infrastructure and intersection signalization strategies when unmanned logistics is incorporated.
3. To analyse platooning effect of unmanned shuttles and pods, and to balance the priority management strategy of unmanned logistics and other traffic flows.

MAVEN approach

In the MAVEN project, an overview on current developments of unmanned logistics is presented in Section 9.4 of D4.4. The study of current developments shows that the logistic process is becoming more and more complicated due to increasing demand and highly specific requirements of customers: In urban transport and distribution networks, goods, materials and people are handled using a vast range of equipment and transport vehicles from origins to destinations. The study also shows that autonomous vehicles in logistics have been playing a significant supporting role in the automated logistics process.

These findings not only give us specific trends that are applicable for the urban environment, but also inspire a new use case: unmanned logistics in urban area. This futuristic design encompasses autonomous shuttles and pods that coexist and replace buses. With the pods traveling below 25km/hr, using the bicycle lanes on the main roads and parking on pedestrian lanes/sidewalks. This use case focuses on autonomous transport, which uses the same infrastructure as cars, bicycles, pedestrians and Public Transport in urban areas. More general design details are listed below:

- Shuttles and pods are simulated as level 4/5 autonomous driving, unmanned vehicles, practically a new modality utilizing existing road design and infrastructure, such as road surface, signalized intersections etc.
- Shuttles are running as “intercity bus (mid/long-distance)” using the vehicle lanes while not requiring guided/dedicated bus lanes; pods are running on the vehicle lanes and on the bicycle lanes as “stop bus (short-distance)” - an alternative to bicycles, scooters etc., to battle the “first mile”/ “last mile” conundrum and bring persons and goods from door to door.
- Pods can commute persons or distribute goods through the network. A pod can pass from bicycle lane to pedestrian lane/sidewalks and deliver goods from door to door.
- Modal shifts from passenger car and bicycle to shuttle and pod can be expected. Willingness of acceptance (compliance rate) for the modal shift are presumed to be 68.9% of the available shuttle and pod capacity. The regular line buses are fully replaced by shuttles and pods with 100% modal shift.
- In the MAVEN simulation, the capacity of a shuttle is 20 persons and the capacity of a pod is 5 persons. The goods capacity highly depends on the form factor and weight of the transported objects.
- Shuttles and pods travel in a mixed traffic environment with other existing traffic flows, such as non-autonomous passenger cars, bicycles and pedestrians.

- Shuttles runs on schedule and uses dedicated stops (long-distance between stops, e.g. 5-10km apart approximately). Pods runs on-demand and can theoretically stop anywhere, such as shuttle stops, container stops (to deliver goods), charging stations (to self-charge and maintenance) and even ad-hoc locations if deemed necessary.

  In the simulation, the transfers between shuttles and pods occur at Helmond train station square. Thus, the pods are in practice often synchronized to the shuttles, demonstrating seamless transfers between shuttles and pods.

Correlation to MAVEN use cases

The use case of this case study combines platoon management, queue estimation, signal optimization, signal priority and negotiation. These are implemented as follows:

[1] Platoon management:

Multiple shuttles with 5 seconds departure interval are forming platoons at the first intersection they encounter.

Pods of the same route are released in a platoon ranging from 2 to 4 except when a breakup is initiated due to safety for other surrounding traffic.

[2] Priority management:

In the baseline scenario, autonomous shuttles and pods have been given “zero priority”. They travel on the network as other traffic flows, such as passenger cars, bicycles, pedestrians.

In the priority scenario, they have been given a higher priority as the previous scheduled public transport such as regular line buses. This is to stimulate the modal shift with competitive travel time.

[3] Queue modelling:

The detailed information of the shuttles and pods was taken into account in the queue model of the intersection. Especially for the pods this is important, as their speed is significantly lower and the control algorithm would plan phases in advance of their arrival.

[4] Signal optimisation:

The scenario utilizes the existing intersections and as many as possible of the existing signal groups to minimize new conflicts that could increase intersection cycle time or reduce controller efficiency. This was a special point of attention when designing the transitions of the pods from a minor road to the cycle path of a major road.

[5] Negotiation

This is the cooperation between the priority, queue modelling and signal optimization use cases. Thanks to the extra information the vehicles provide, a specific control plan can be provided to them with minimal hindrance for other traffic.

Simulation setup

The simulation adopts the N270 corridor network with multiple intersections in Helmond city centre. Namely, intersections HEL701, HEL702, HEL704, HEL101, HEL102, HEL103 and HEL104 are distributed on this stretch of corridor. These intersections have similar intersection layout and road branches. The main east-west and west-east directions are dominant in terms of traffic demand due to the connection to the A270 to the west and the A73 and A67 motorways to the east. All intersections have pedestrian and bicycle traffic as well.

Besides similar intersection layout, this network cut-out covers the busiest trips (origin-destination pairs) and most POIs, such as central train station (connections to other cities), departure-terminal centre (e.g. public transport distribution plaza) on the south arm of HEL103. Ergo, current public transport routes are also heavily concentrated on this network.

Based on the aforementioned characteristics, this network is the most compatible for introducing new modalities, or eventually replacing current public transport system with upcoming public transport mode featuring unmanned shuttles and pods.

Figure 1 presents the layout of the simulation network. The 700-series and 100-series intersections indicated in this figure are controlled with adaptive controller ImFlow. However, only the four 100-series intersections: HEL101, HEL102, HEL103 and HEL104 are configured for the use case simulation experiment, replicating the current traffic controllers in real-time.

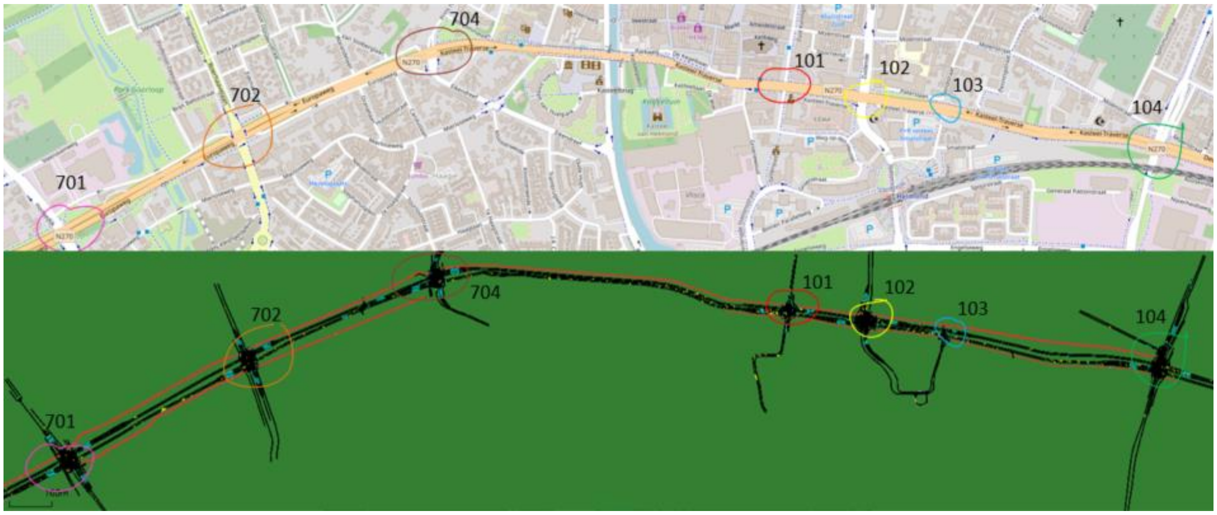

Figure 1: network of Helmond (top) and the simulation network in SUMO (bottom)

- Intersection 701, Hortsedijk/ Europaweg
- Intersection 702, Boerhaavelaan/ Europaweg
- Intersection 704, Prins Hendriklaan/ Kasteel-Traverse
- Intersection 101, Zuid Koninginnewal/ Kasteel-Traverse
- Intersection 102, Zuidende/ Kasteel-Traverse
- Intersection 103, Penningstraat/Smalstraat/ Kasteel-Traverse
- Intersection 104, Burgemeester van Houtlaan/ Kasteel-Traverse

The current public transport routes and flows are replaced with shuttles and pods, which have a total capacity to carry 320 persons and 64 pods full of goods (only dispatch at a pre-defined container stop in the experiment) across the network (from west of HEL701 to east of HEL104 and vice versa. Since the amount of passengers is significant, the related traffic flows are recalibrated according to the modal shift mentioned previously according to the OD pairs replaced by the shuttles and pods. The other “normal” traffic, such as passenger car flows (except for the two OD pairs due to modal shift), bicycle flows and pedestrian flows have been kept the same as current situation.

Actors and relations

As unmanned logistics use case paints the picture of traffic situation of Helmond city centre in two decades, a few new actors and the associated relations among all actors need to be examined and addressed.

- Unmanned shuttles: As this category of actor requires no manual action, unmanned shuttles act as fully automated and autonomous bus (level 4 or 5). In this use case, they are designated to drive on vehicle lanes; follow two pre-defined routes and load/unload passengers at pre-defined shuttle stops; they use the traffic signals of existing vehicles and the PT traffic signals in the PT distribution centre.
- Unmanned pods: Pods are automated driverless vehicles that can provide rapid transit to persons and goods and they can self-charge (at electric vehicle charging points) during out-of-service time. They use existing road network and infrastructure instead of building new and extensive infrastructure. With a maximum speed of 25km/hr, they are able to drive on bicycle lanes, vehicle lanes within an exclusive area (such as a PT distribution plaza), and they can ride-on/park on pedestrian lanes or perform curbside stopping. They use mostly the traffic signals of bicycles and the PT traffic signals in the PT distribution centre.
  One of the future features of pods is that they can operate on-demand to provide swift travel service in congested areas. In the simulation experiment, the full scale on-demand feature has not been fully simulated. In the short term, the simulation experiment features transfers between shuttles and pods at pre-set locations that are concentrated on the PT distribution centre behind Helmond train station.
- Shuttle stops: similar to current bus stops (but longer distances, ca. 5~10 km, between stops), there are in total four shuttle stop locations configured on the simulation network of Helmond. One on the furthest location on the westernmost link, one on the furthest location on the easternmost link, and two stopping bays at the PT distribution centre where passengers and goods can change modalities with the most possibilities in a centralized manner. In reality these would be further away (e.g. the motorway exit of Nuenen to the west and the intersection with the N279 to the east), but due to the size of the network they were placed at the edge instead.
- Pod stops, container stops, charging stations: These three types of stops are designed for pods to achieve the following functions.
  - Pod stops: embark, disembark of persons and goods. Two pod stops are currently set-up in the PT distribution centre, targeting the transfers among modalities mostly.
  - Container stops: deliver, gather goods. One container stop is configured on the pedestrian lane (next to the bicycle lane) between intersection 103 and 104, which is intended to deliver goods to door.

   ○ Charging stations: Pods can perform self-charging autonomously in the charging station when the electrical power is below a threshold. These pods are in the "on-call" mode, which means they are off to service if needed. One charging station is configured in the PT distribution centre in the simulation network. All pods in this simulation experiment perform a full charge at this station before picking up passengers.

The current traffic flows and infrastructure of Helmond city centre are composed of the followings:

- Existing vehicles: passenger cars and trucks travels on the road surface and use the traffic signal for vehicles.
- Existing bicycles: bicycles of generalized bicycle category that travel on the bicycle lanes with a maximum speed of 25km/hr.
- Existing pedestrians: pedestrians walking on pedestrian lanes/curbside. Shuttles and pods can perform collision avoidance actions autonomously when they are interacting with pedestrians.
- ImFlow traffic controllers: Intersections 700-series and 100 series on N270 of Helmond are controlled with ImFlow traffic controllers. Customized changes can be made to configure different scenarios.

Routes and schedules of unmanned shuttles and pods

To see the impact of different types of automated public transport units – namely shuttles and pods, 35 shuttles, 64 pods and 320 persons /goods following designated PT routes are simulated. The shuttles and pods are following a pre-configured schedule, in specific a time table with flexile time windows.

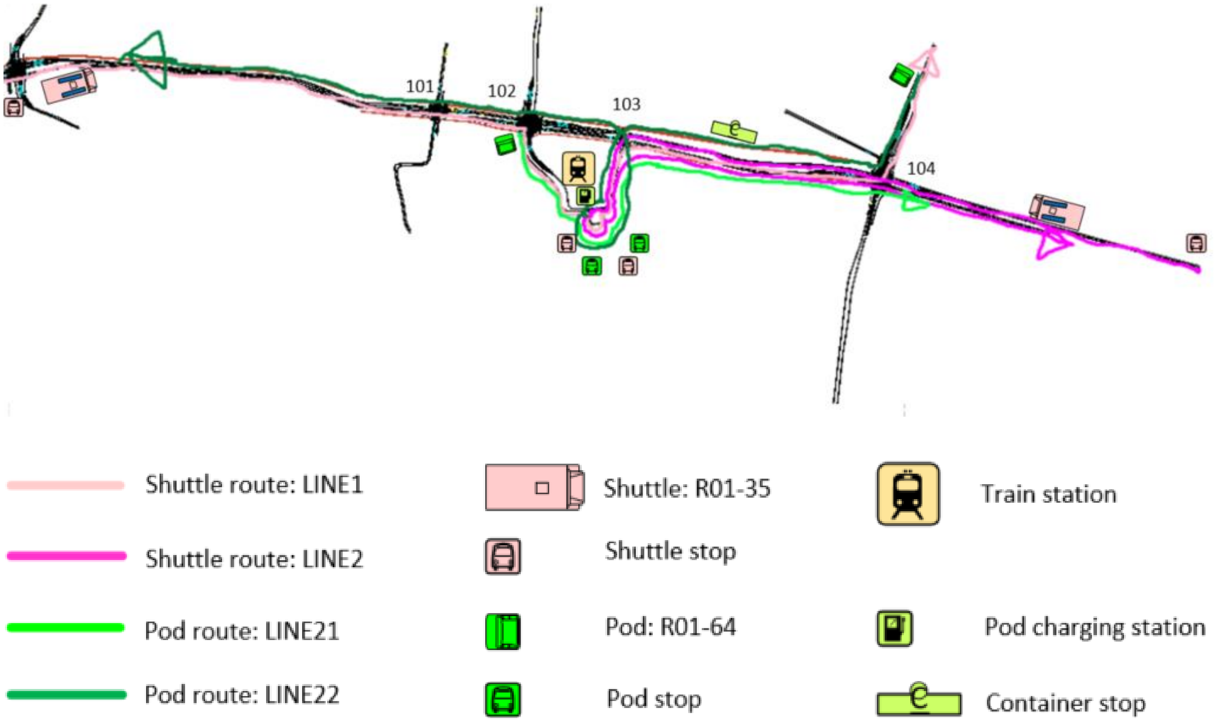

Figure 2: Overview of shuttle routes, pod routes and important POIs.

The top half of Figure 2 intends to show the general ideas of shuttle/pod route map, while the bottom half listed the legends. As presented, the strategic objective of unmanned shuttles and pods is to orchestrate a barrier-free door-to-door trip. Shuttles serve as intercity travels and pods serve the “first and last mile” of a trip. Note that the shuttles ride only long distance with scheduled stops approximately 5-10 km apart.

In the simulation experiment, we expect there should be a high amount of transfers, for example: persons and goods transfer from train to pods/shuttles, from shuttles to pods, and vice versa. Therefore, shuttle and pod stops are clustered on the PT distribution centre behind the train station, as shown in Figure 3 (A zoomed-in snapshot from SUMO simulation).

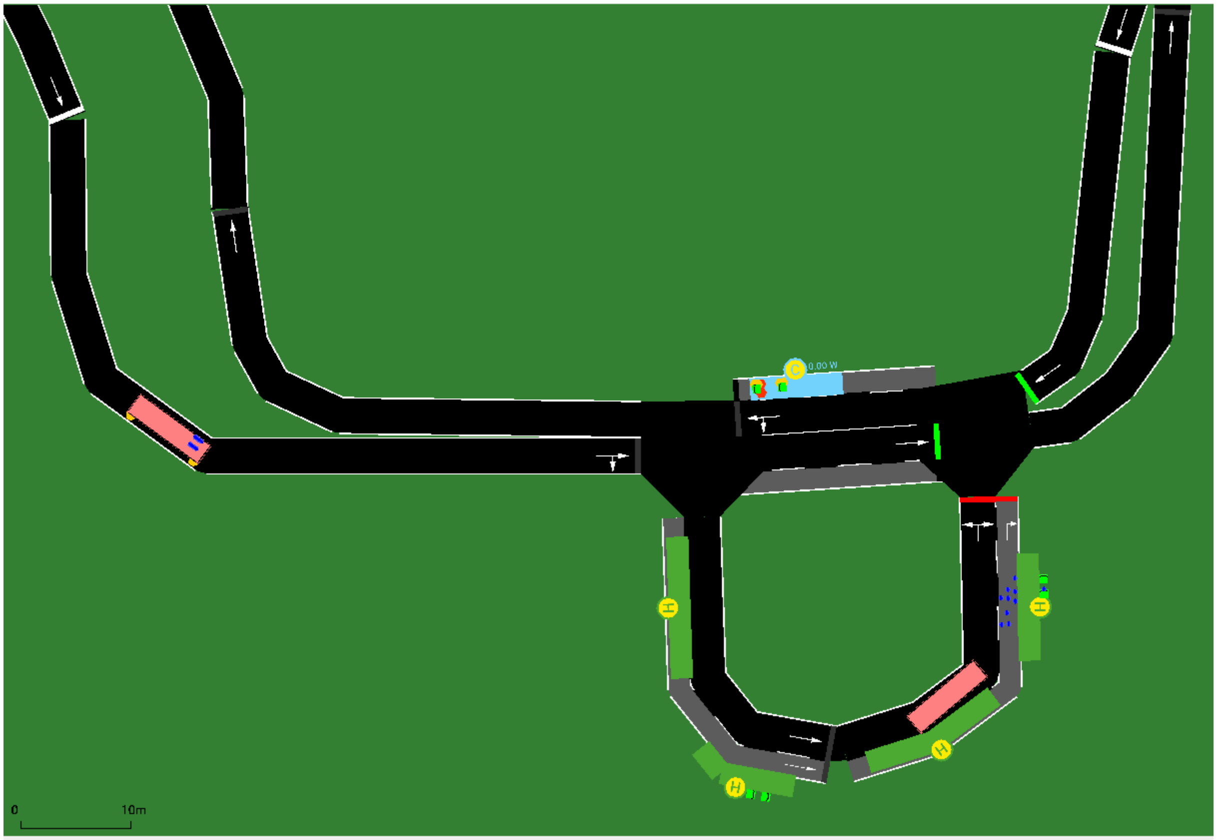

Figure 3: The trip transfers (blue dots represent persons or goods) at the distribution centre

This figure shows passengers and goods from potentially long shuttle ride disembark and move to the pods (parked at the pod station east one minutes ago) to finish the last short trip piece to reach their final destinations.

Although public transport routing using multi-modal travel means has been studied for years, its models and solutions are still limited and case-specific for most of the situations. Therefore, the shuttle routes are set to fixed routes, so are the simulated pod routes, in order to deflect from dynamic routing uncertainty.

The shuttle schedule has 35 shuttle trips of LINE 1 and LINE 2, departing every 5-10 minutes. The 64 pods of LINE21 and LINE 22, run on-demand. This is implemented by programming every pod to be on time on the pod stop and wait for the arrival of their designated persons or goods to arrive at the pod stop. After embarking the pod will do the last mile delivery.

Simulations of the other use cases in MAVEN (reported in D7.2) were performed mainly on three simulation locations. These are the current real-life networks of the cities: Helmond, Prague and Braunschweig. Keeping on using SUMO and ImFlow, this use case adopts the simulation approach of the previous single/combined use cases built up on Helmond. In order to ensure the validity of the results, each simulation experiment follows the following approaches:

1) Using real-world data collected in Helmond network, each simulation scenario was thoughtfully planned, monitored, analyzed and calibrated in order to minimize the discrepancies between real-world and the corresponding simulation experiment.
2) Each simulation scenario (with a configured parameter setting) was performed 10 times with a different random seed (two hour evening peak simulation each). The results were averaged over these 10 runs to ensure a statistically significant outcome.
3) It should be noted that while the network includes seven intersections, only four intersections (HEL101, HEL102, HEL103 and HEL104) are evaluated and have the use case configured. This is because the signal groups of these four intersections are heavily used by the unmanned shuttles and pods. Signal groups that are frequently used by shuttle and pods are shown in Figure 4 below.
4) Special detectors are added on SUMO and ImFlow. First, the simulated traffic is detected in SUMO, then the information of these detected shuttles and pods are sent back to ImFlow to calculate and optimize the signal timing plan. After making the decision of which plan to choose, ImFlow sends back the chosen plan to SUMO to continue the simulation.

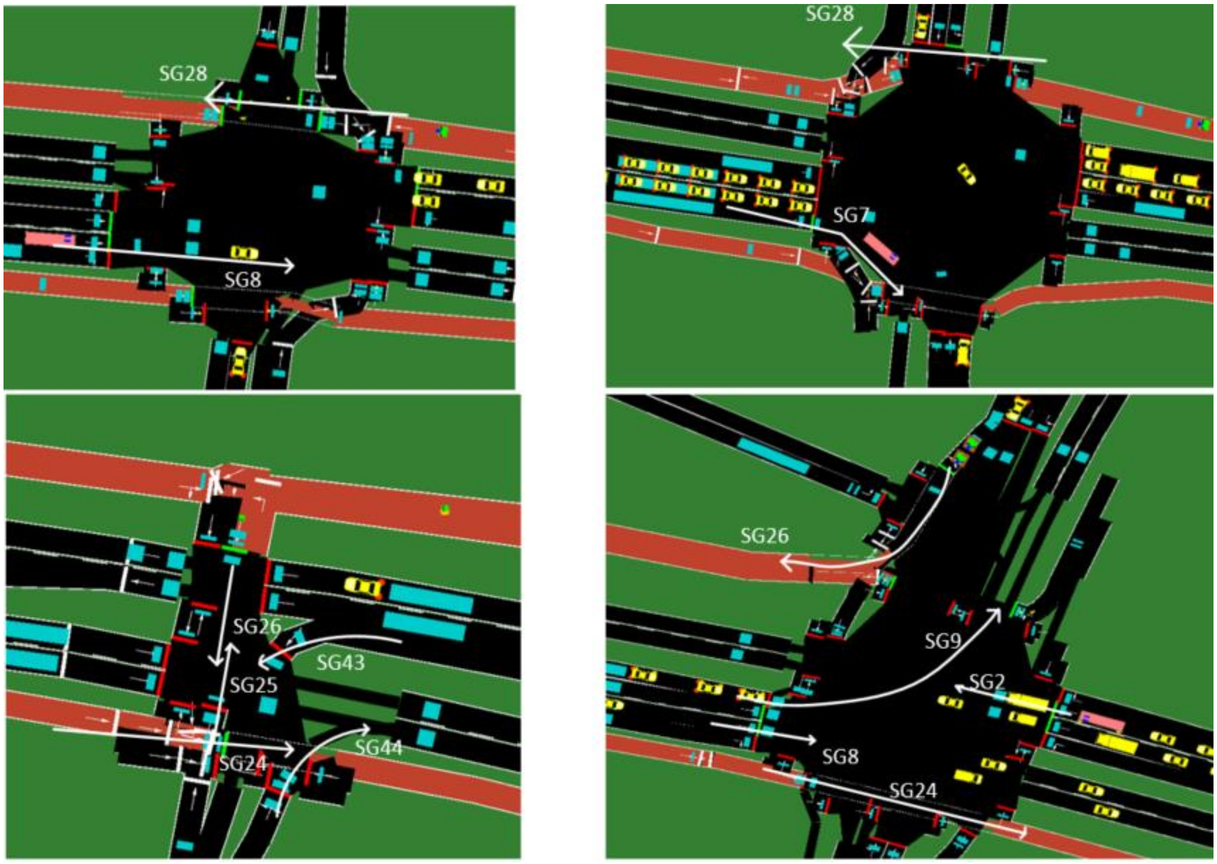

Figure 4: Snapshots of HEL101 (top-left), 102 (top-right), 103 (bottom-left) and 104 (bottom-right) during simulation; white arrows and text indicate SGs that are used by shuttles and pods

Simulation scenarios and KPIs

Three scenarios are set up to perform the simulation experiments:

1 *Scenario baseline*: scenario baseline simulates the current traffic conditions in Helmond. The original ImFlow configuration is used at the traffic lights. The demand is set to the normal workday evening peak hour levels.

2 *Scenario future*: Scenario future paints the same network as baseline, but with unmanned shuttles and pods fully operated as unmanned transport as it could be in two decades. Intersections are handled as scenario baseline with the same ImFlow configuration on current road. Due to the high amount of persons transferred with unmanned shuttles and pods, the demand and eventual traffic flows of the related OD-pairs are recalibrated. The goods are generally already transported by vans and trucks stopping at multiple addresses. Some shopping trips by car may be saved, but this is not taken into account for the simulation.

3 *Scenario futurePriority*: Scenario future priority is based on scenario future and adds the traffic management strategies of MAVEN, which is most notably the priority for the shuttles

and pods. The corresponding policy plans and routes are configured on top of the current ImFlow configuration.

Through SUMO and ImFlow, simulation experiments are performed according to above mentioned sections. Raw results are generated and written in output files. Based on the objectives and expectations summarized above, a list of KPIs is provided here, which have also been used in the MAVEN project in previous use cases to evaluate the impact (see D7.2).

1) KPI 1 Average impact

A measure of effect introduced in MAVEN D4.4 indicating the performance of the traffic network is an impact. It can be defined using the following formula:

$$impact = \frac{\sum_{i=0}^{i=I} delay_i + 8\, stops_i}{I} \qquad (1)$$

The formula sums over all traffic participants (I) to calculate the average overall impact. The average impact can also sums over participants of a special interest vehicle category or a specific signal group of an intersection. The value 8 in the formula is often used as a rule-of-thumb factor by traffic engineers. It is based on CO_2 emissions and road user comfort of not stopping.

2) KPI 2 CO_2 per run (kg)

The CO_2 emission of all vehicles/special group vehicles of one run. Ten simulation runs were performed in the simulation experiment and KPI 2 is an average over the 10 runs.

3) KPI 3 Throughput (veh)

Throughput is defined by the number of vehicles passing the intersection for a specific (set of) turn direction(s). It can be acquired from the simulation output on the network level and per signal group level.

The above mentioned KPIs will be compared in two levels for results analysis and impact assessment purposes:

Network average level: including whole network and all vehicle categories in order to verify the effect on all users, including the ones not directly involved in the use case;

Per signal group per vehicle class level: only consider shuttles/pods and the specific SG they have passed (labeled special interest group). In specific, it means that all impact, delay, stops and throughput that incurred to a vehicle upon entry of the network up to the passage of the first traffic light, will be attributed to the signal group it just passed, so on so forth for the next signal group when the vehicle goes through the next passage.

Collecting the data per signal group is to perform deeper analysis between scenario future and scenario futurePriority. Since these results of per signal group should exhibit a similar trend but can also be considered stand-alone, only interesting findings of special interest groups (e.g. the average results of the special interest category is defined to the average results of shuttles and pods when they pass the SGs) will be reported to keep the discussion concise yet comprehensible.

Results

The results of all simulations for the three scenarios are exported and results analysis is performed using evaluation scrips, both on the network level and on a per signal group level as aforementioned.

Network level

On the network level, the average impact, CO2 emissions and total throughput of all vehicles are extracted and plotted in this section. Figure 5 shows the average impact of all vehicles for the three scenarios: baseline, future, futurePirority.

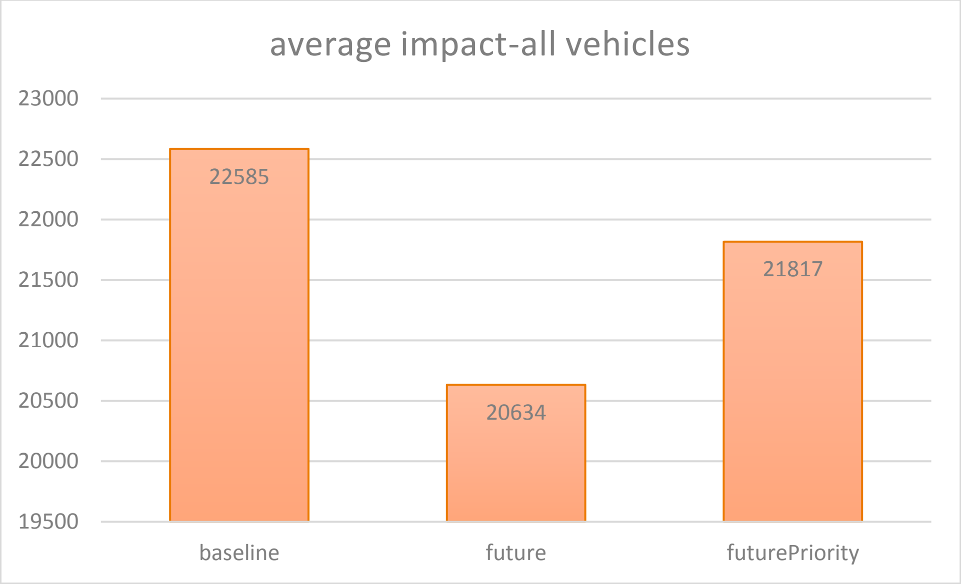

Figure 5: average impact of all vehicles on the network

From scenario baseline to scenario future, the average impact decreases by 8.6%; from scenario future to scenario futurePriority, the average impact increases by 5.7%.

The decrease from scenario baseline to scenario future is as expected and it confirms the positive effect of unmanned shuttles and pods on the network performance, when the compliance rate of modal shift from passenger car to shuttle/pod is 68.9%.

The increase (5.7%) of average impact from scenario future to futurePriority is also as expected based on experience. Since scenario futurePriority gives a high priority to all shuttles and pods when they approach existing traffic signals. However, the performance is still better than in the baseline.

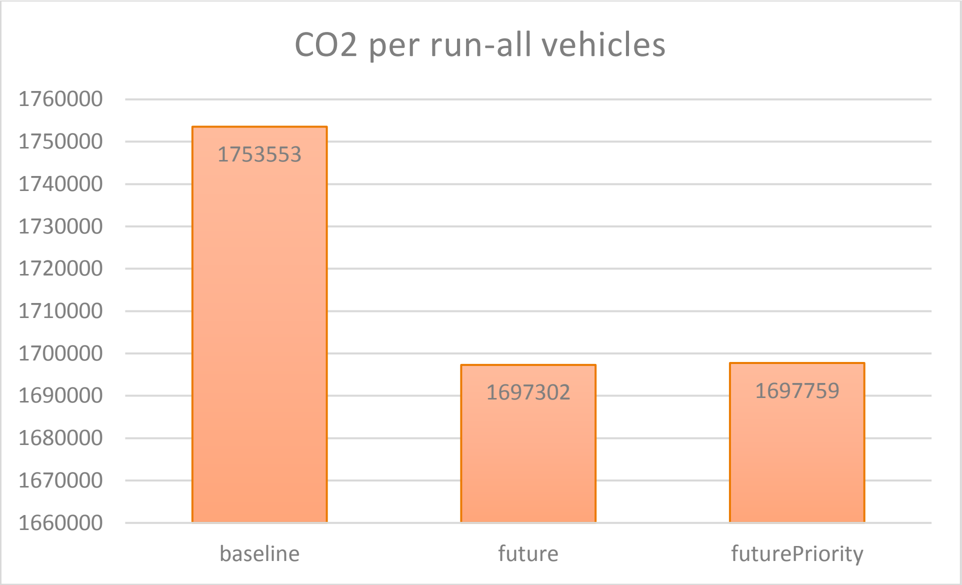

Figure 6: average impact of all vehicles on the network

Figure 6 shows the CO_2 emission of all vehicles during ten runs for the three scenarios: baseline, future, futurePirority. From scenario baseline to scenario future, the CO_2 emission decreases by 3.21%; from scenario future to scenario futurePriority, the CO_2 emission insignificantly increases by 0.027%.

These results are corresponding to the positive average impact exhibited in the previous figure. On the one hand, the decrease of CO_2 emission is quite promising on the network level even with the fact that only Pods are considered fully electrical with zero emissions while shuttles are following the PHEMlight model for bus in SUMO. In the future, the shuttles should actually produce less CO_2 emissions comparing to bus. On the other hand, the slight increase from scenario future to futurePriority is quite insignificant, which verify our assumption that the network performance is not deteriorated by giving a higher priority to shuttles and pods.

The total throughput is 180 vehicles lower in the future scenario's compared to the baseline. Between the future scenarios there is no significant change, which ensures that there is no congestion forming.

As mentioned in the section about simulation scenarios and KPIs, the latter are analysed for both the total network and for specific vehicle classes per signal group. This resulted in a total of 13 special interest vehicle class/ signal group combinations that were part of any shuttle or pod route. The results of these 13 special interest groups are examined one by one. The results are shown in Figure 7:

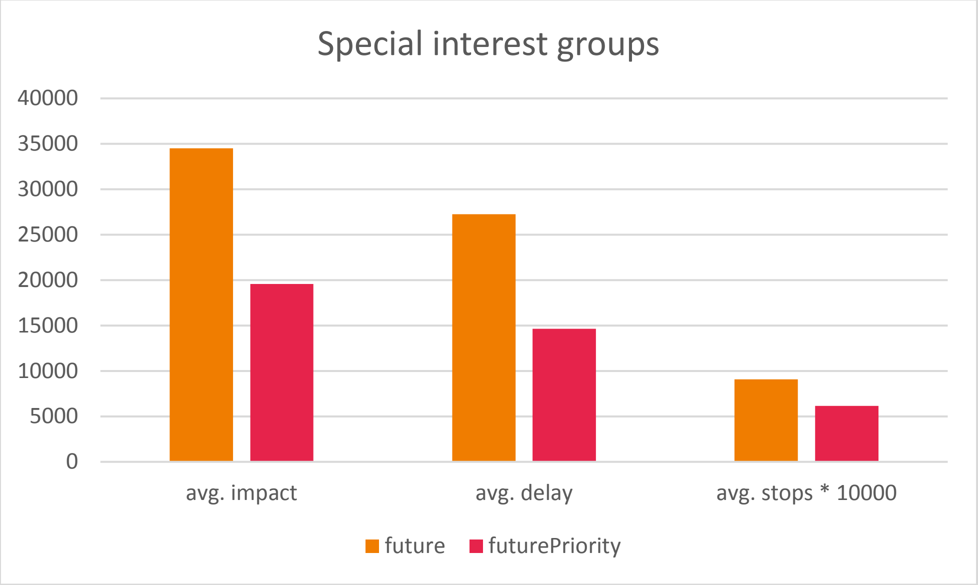

Figure 7: average impact, delay and stops of all prioritized traffic

A decrease of 43.3% on average impact is observed from scenario future to scenario futurePriority, which shows the significant positive effects of priority targeting special interest groups with pods and shuttles, which should stimulate the envisioned modal shift. The average amount of stops were multiplied by 10,000 to make them visible in the graph (decrease from 0.9 to 0.6).

Conclusion and further research

The average impact and the CO_2 emissions on the network level (all vehicles) are significantly decreased with 8.6% and 3.21% respectively, from scenario baseline to scenario future. When adding the priority the average impact increases with 5.7% while the CO_2 emissions don't change significantly.

The decrease of 43% for the impact on prioritized vehicles demonstrates it is possible to give a large advantage to these vehicles with traffic management policies. This shows that a 68% compliance rate for the modal shift from private vehicles to unmanned shuttles and pods would be realistic. At the same time, the overall performance is still better than in the baseline without shuttles and pods, making this solution beneficial for all traffic participants.

The case study showed a clear beneficial application of the MAVEN use cases to a realistic future situation. Thanks to the combination of the use cases, an effective priority could be given with minimal impact on other traffic participants.

The future of logistics on the public roads will undoubtedly head towards the direction of full automation. In this paper a first glance is given on the foreseen impact of unmanned logistics on road transport in an urban area. Whereas unmanned logistics is a new kind of transportation, further research regarding the logistical organization, forms of distribution and also steering from the government is desirable. For instance, in this case study commuting persons and delivery of goods are combined in one transportation system, which has a positive impact on the performance of the traffic system. On the other hand, the requirements of a traveller or a package to be delivered are different, such as punctuality, travelling time of day, costs etc. So different approaches and strategies can be developed and weighed on their impact on our resources. This can give us more insight expected benefits and possible side effects and will be able to act on beforehand.

Acknowledgement

The paper presents some preliminary results of the EU-funded project MAVEN (Managing Automated Vehicles Enhances Network), which is funded by the European Commission Horizon 2020 Research and Innovation Framework Programme, under Grant Agreement No. 690727. The content of this document reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.