FUTURE ROADWAYS

with

CO-OPERATIVE AUTONOMOUS VEHICLE NETWORKS

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Introduction

Co-operative Autonomous Vehicle Networks (CAVN) is a term used here to describe a dynamic roadway system, where individual driverless vehicles are efficiently directed in a way to minimise overall travel time and optimise use of road space. Although this concept is undoubtedly futuristic, the main purpose of this introductory paper is to demonstrate why it is an outcome worthy of concerted effort and investment to achieve. It is also intended to highlight the implications for potential reduced investment in transport infrastructure today, including large public transportation schemes.

Current roadways operate with individual human drivers acting and reacting to the presence of others as they are encountered, and rarely acting towards the greater good of the entire system. Instead, for safety and efficiency, drivers have to be managed via tools such as roundabouts or traffic signals (to slow and circulate, and time-manage conflicting movements respectively). These devices are very inefficient in terms of space, since moving vehicles need to keep safe operating distances between one another, to allow for human driver factors such as reaction time and gap acceptance. Vehicle deceleration and acceleration need to be accounted for, which also contributes to air and noise pollution.

CAVN as proposed here assumes the complete absence of human drivers, and would be operated in a way analogous to social animal organisms that demonstrate collective behaviour towards a better group outcome. Examples as shown in Figure 1 include fish swimming in schools, ants co-operating to form a bridge across an otherwise unnavigable gap, and birds flocking for aerodynamic efficiency. CAVN works on a similar principle, to achieve several times the efficiency of today's roadways in terms of transport of people and goods.

At a very basic level, the considerable advantages are quite self-evident for a driverless car scenario such as CAVN where each vehicle moves in a co-ordinated manner with others. For example, if gap acceptance values at intersections and following distances between today's vehicles (or headways) were halved, in theory the traffic capacity of a road network could approximately double.

Figure 1: Social animal examples of co-operative behaviour for mutual gain

Methodology

Intersection capacity is generally the most significant factor in the traffic carrying capacity of an urban street network. Given this assumption, some intersection scenarios using driverless vehicles were trialled using Invision, which is a visual simulation tool by Transoft for its Autoturn vehicle tracking software. The primary objective was to get some early indications as to how intersection capacity might be improved with CAVN, compared to the human driver road networks of today. Some video simulations are available to view at http://traffessionals.com/

A contemplation of vehicle type was also attempted, for both personal and goods transportation.

Personal transportation vehicles: how they could look and move

Current car fleets are heavily built in order to protect occupants in the event of high speed impacts. On the basis that CAVN would more assuredly avert conflict, a representative personal transportation vehicle with minimal sidewall protection is proposed, with dimensions akin to a 1970 Fiat 500 which is just 1.3 m wide (4 ft 3in). The idea of small lightweight vehicles is not unprecedented, and has previously been portrayed in science fiction movies such as 'Minority Report' (2002).

Figure 2: 1970 Fiat 500 next to a driverless vehicle from the movie 'Minority Report' (2002)

Small driverless vehicles operating with minimal clearances and headways, could multiply traffic capacity compared to today's roadways. Figure 3 at left shows a still picture of two conflicting CAVN traffic steams, travelling at a constant speed without acceleration or deceleration and minimal clearances. Even at just 20 km/hr, this represents an equivalent continuous throughput of some 1.0 veh/sec/lane[1], as compared to an equivalent traffic signal layout of today which caters for around 0.5 veh/sec/lane, and then only during green light periods (see Figure 3 at right). Figure 4 shows CAVN with simultaneous movements in all directions.

[1] This assumes two driverless vehicles could approximately fit side by side within a conventional 3.0 m wide traffic lane of today

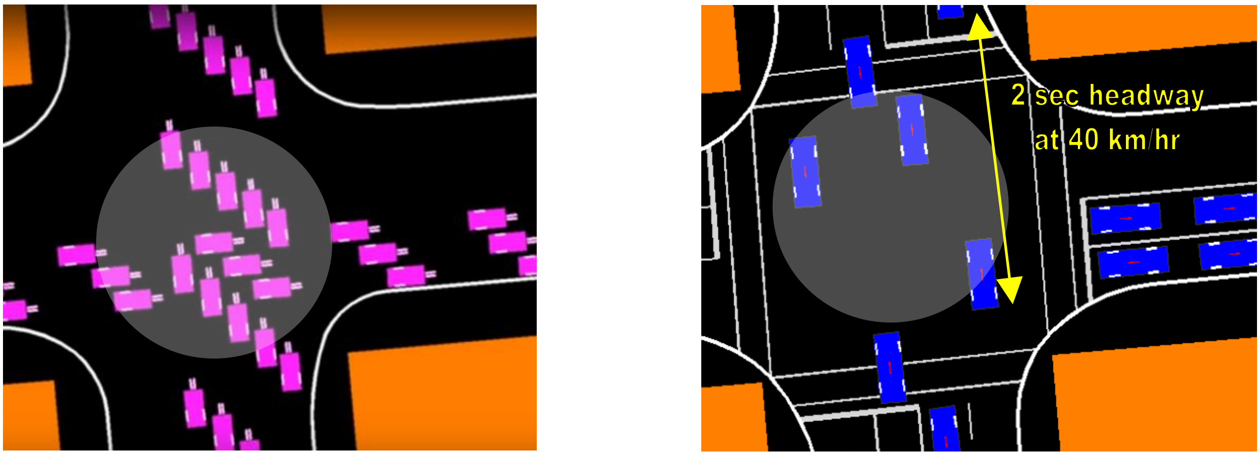

Figure 3: Left shows two simulated continuous streams of driverless vehicles[2]. At right is a same scale traffic signal with a north-south stream of today's vehicles during the green light period.

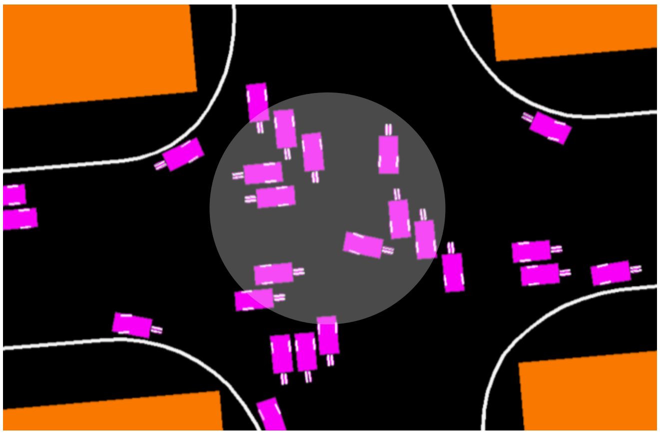

Figure 4: CAVN example with simultaneous turning movements in all directions[2]

Co-operative vehicle behaviour can hugely improve the utilisation of intersection space available. Compare the much higher space efficiency of the CAVN mechanisms in Figures 3 & 4, in terms of proportional area occupied by moving vehicles (sample areas circled). Because of this, even at lower speeds CAVN can achieve several times the vehicle throughput. Vehicle speeds between major intersections could of course be much higher, and with greater confidence intersection speeds could be increased to proportionately improve capacity even more.

In effect, the traffic carrying capacity of a road network could multiply several times over with CAVN, even with low speeds at major intersections. The future challenge will be to come up with intersection layouts and CAVN operating mechanisms to optimise space efficiency for different turning vehicle combinations. Roundabouts for example, could potentially use a rotary arrangement of the mechanism shown in Figure 3. Catering for human users such as pedestrians and cyclists will also be a critical consideration.

[2] Video simulation available to view at http://traffessionals.com/

Goods transportation vehicles: how they could look and move

It seems reasonable to continue using the ubiquitous 8 ft wide (2.4 m) shipping container, since they number in the millions worldwide and can be accommodated on most urban two-way roads.

Road trains like those used in the Australian outback are not feasible for urban roads today, since their turning path requirements are considerable and driveability questionable in confined spaces. However, larger goods vehicles generally correspond to reduced transportation costs and increased economic prosperity, and quite conceivably could be accommodated within a dynamic CAVN system.

Figure 5: The 8 ft wide shipping container, and a road train as used in outback Australia

Figure 6 shows the swept path for a triple-unit road train at a small intersection of two carriageways 14 m and 12 m wide respectively. Such disruptions are feasible with CAVN which could temporarily divert conflicting traffic streams to other routes, or simply cease conflicting flows for a short time at a safe distance. Even though turning road trains might be restricted to quieter periods in order to maintain major directional flows, the potential is clear enough.

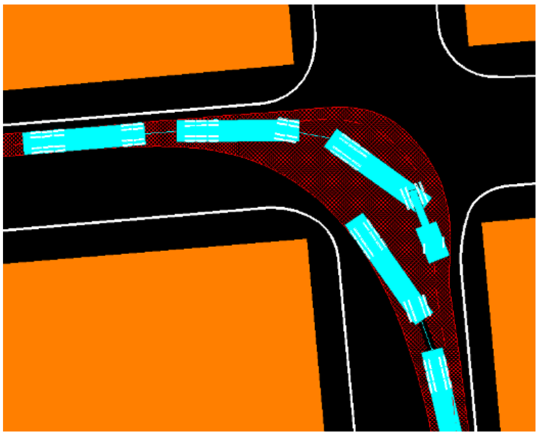

Figure 6: Swept path of a triple road-train at a small intersection[3]

[3] Video simulation available to view at http://traffessionals.com/

Strategic operation of CAVN

CAVN strategic direction will need to be flexible enough to allow for on-site influencers such as road surface conditions, and less predictable human interrupters such as pedestrians and cyclists.

It is envisaged CAVN would incorporate the following dynamic variables:

- Directional flow – streets could vary flow direction based on demand, and one-way street links can allow for simplified intersection operation to maximise traffic capacity. For example, Figure 7 shows how a local network with tidal flow characteristics might operate morning and evening peak periods.

- Diversions – temporary street diversions could be enacted due to downstream interruptions such as conflicting traffic platoons, turning road-trains (described above), or human interrupters such as pedestrians or cyclists.

- Vehicle speeds – maximising intersection capacity will be a key objective during peak demand periods, where operating speeds may have to be temporarily reduced for safety reasons. Mid-block speeds between major intersections can afford to be much higher all of the time.

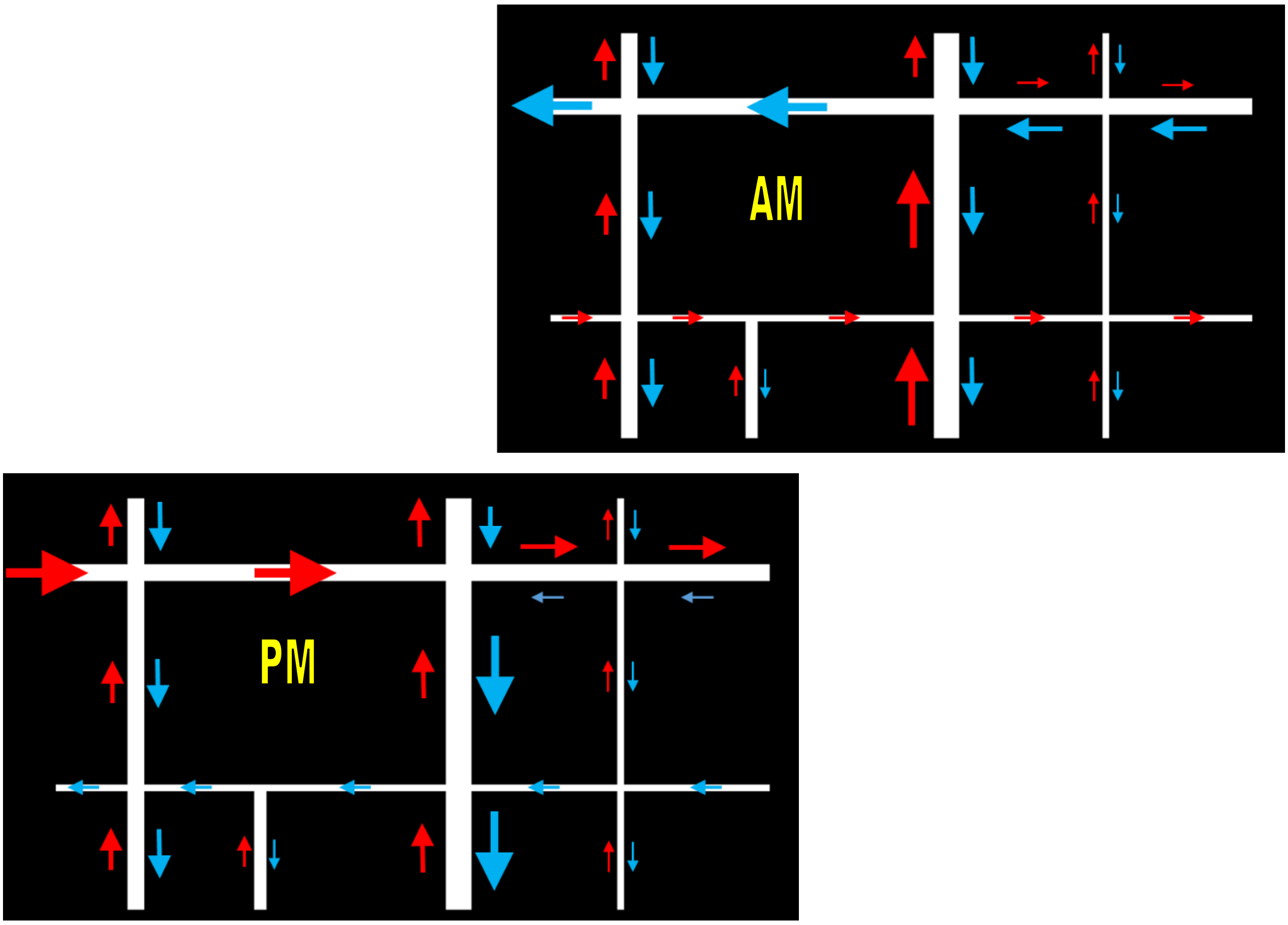

Figure 7: CAVN example of a local street network, with varying flow and direction by demand during morning and evening peak periods

CAVN and human users

As can be imagined, human drivers in large and relatively heavy vehicles present an unpredictable, potentially dangerous, and considerable interrupter to CAVN. Today, CAVN to the total exclusion of human drivers is more easily imagined within inner-city areas, and perhaps some higher speed motorway connections. The most challenging question for the future will perhaps be:

Where, how and when should human drivers be permitted on a road network, if at all?

Pedestrians and cyclists might be more readily accommodated within CAVN. Lightweight vehicles, low speeds at intersections, and autonomous vehicle technology capable of reacting to unexpected interferences – a dynamic CAVN system could possibly handle them quite well, though intersections during busy periods will still be a challenging prospect. In addition, a major corollary to a compact CAVN with very high traffic capacity, is that existing road space could be relinquished for dedicated use by pedestrians and cyclists.

Riders of small and relatively lightweight motorised scooters or motorcycles, since they pose more of a hazard to themselves than others, might possibly be permitted in some form or other on CAVN (for example on separate corridors).

A driverless network would also obviate the necessity for every household to have their own personal transportation vehicle, with potentially considerable implications with respect to urban space currently allocated for carparks and on-street parking (ITF 2015).

Discussion

Preliminary findings from this introductory research, show CAVN gives potential for:

- Space efficient, safer intersections with very high capacity and lower conflict speeds
- Smaller, lightweight vehicles justifiable by a more predictable and safer road network
- Road trains for more economic transportation of goods

The idea that the traffic carrying capacity of today could be undertaken in a fraction of the space with CAVN, is also a significant inference that should not be ignored in terms of transport infrastructure being invested in today. Should CAVN come to pass in a manner approximate to that described in this paper, and since it would offer such a superior travel option compared to alternative modes, then much of the infrastructure being built today – including large public transportation schemes - could tomorrow be redundant, and even a burden to maintain. Conceivably, existing road and urban space would also be relinquished for other purposes, such as for pedestrians and cyclists.

Conclusion

CAVN has enormous potential for a high capacity and low casualty road network, with major disadvantages yet to be determined. But CAVN is clearly a futuristic proposition with many challenges, and would require very considerable investment and commitment to even have a chance of succeeding. In the opinion of this author, the rewards could be so great that this path is well worth exploring.

"We can't solve problems by using the same kind of thinking we used when we created them"

Albert Einstein

References

International Transport Forum (2015),<http://internationaltransportforum.org/cpb/projects/urban-mobility.html>

Traffessionals video simulations available at http://traffessionals.com/

Photo credits: Figure 1 – Fish and ants care of shutterstock.com, canadian geese care of John Benson; Figure 2 – Fiat 500 care of Kyle Smith, shutterstock.com; Figure 5 - Road train care of Thomas Schoch