Flocking Dynamics in Multi-Agent Systems to Model Efficient Road Transport

P2 Proposal

APSC 200

MTHE

Section 208

Team 4

TA: Garrett Richardson

Liam Cregg, Mathew Jennings, Tristan Lawson

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Statement of Originality

Our signatures below attest that this submission is our original work.

Following professional engineering practice, we bear the burden of proof for original work. We have read the Policy on Academic Integrity posted on the Faculty of Engineering and Applied Science web site () and confirm that this work is in accordance with the Policy.

**Individual 1:**

Signature: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name : \_\_\_\_Liam Cregg\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ ID # : \_\_\_20054881\_\_\_\_\_\_\_\_\_\_

**Individual 2:**

Signature: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Date: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name : Mathew Jennings ID # : 20019342

**Individual 3:**

Signature: *\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_* Date: \_\_\_\_\_\_\_\_\_

Name : Tristan Lawson ID # : 20047729

Executive Summary

Current commercial vehicle traffic is highly inefficient due to the large air resistance on the front of large vehicles such as trucks, coach busses and large motorhomes. To reduce this and decrease gas costs for owners of these vehicles, this project suggests a method of creating “convoys” on the highway using flocking dynamics. This project would combine with autonomous systems on semi trucks, coach busses, and large motorhomes to create convoys of up to 5, that can travel together on the highway in proximity, and communicate instructions for breaking, accelerating and turning between the vehicles.

The goal of the project id to provide a system that could be implemented in large autonomous vehicles, and then be used easily on most highways with ease. The benefits of this would be that every vehicle that is not at the front would save on gas, as it has been seen in previous systems that trucks travelling in a 3-vehicle convoy reduce their fuel usage by 5.3% [4]. The vehicles would take up less space on the road, and accidents involving these vehicles will be greatly reduced. Traffic flow is an important consideration for all road users, so the convoy system must not require commuters to change their driving habits, which should not be an issue with this system.

Some expectations of the project are that the system must maintain traffic flow, the system must reduce accidents caused by truck driver error, and the system must have enough benefits to be a worth while investment for the target market.

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# Introduction

Fast and efficient transportation is incredibly important in modern society. With many online providers such as Amazon and Ali Baba offering same-day or express delivery on their products, consumers have begun to expect minimal delay. While this is convenient for the consumer, they are often not aware of the huge amount of logistics and transportation that go into making a delivery. The transportation of goods also has a huge environmental impact, as many large trucks run on fossil fuels, and furthermore the presence of these large vehicles on high-speed roadways can pose a threat to human safety. In fact, according to the US Department of Labour, truckers experience the most fatalities of all occupations, accounting for 12% of all worker deaths, and also lead in nonfatal injuries [1]. A report to Congress also found that about a quarter of all crashes involving large trucks were the result of improper spacing between vehicles (i.e. rear ends), and running off road or out of lane was the next largest source [2]. In order to deal with these safety concerns and to reduce the environmental impact of large transports, some companies have begun testing and implementing platooning techniques, in which several transports move in line in one lane, with equal separation and velocities. Research has indicated that such platooning (which is currently being tested in group of 3) can help reduce fuel use and congestion and improve air quality [3]. Moreover, 63-65% of all miles driven by large transports have been found to be good candidates for platooning, leading to a 5.3-17% fuel reduction, depending on the truck’s location in the platoon [4].

The properties of an effective platoon (i.e. equivalent separation and velocity among members, and a tendency to avoid collision) are naturally conducive to a flocking algorithm involving a multi-agent system. There are three primary principles of flocking [5].

1. Centering: Each agent should attempt to stay close to other flock agents. Also known as cohesion of agents.
2. Obstacle Avoidance: Each agent should avoid colliding with other flock agents. Also known as separation of agents.
3. Velocity matching: Each agent should attempt to match its velocity with other flock agents.

These properties are up to interpretation but are nevertheless good general qualities of flocking dynamics and are also desirable qualities of a transport platoon.

The fundamental concept of flocking is to create an arrangement of agents (called an alpha-lattice) such that each agent has equal distance with each other agent and is moving at a constant velocity. This lattice is composed of *vertices* (i.e. the agents) and *edges* (i.e. the communication pathways between agents) [5]. Much of the research done in this field assumes that these lattices are bidirectional, that is, that if agent A can communicate with agent B, then B can communicate with A. This is also reasonable to assume in the case of platooning as each truck in the platooning would be technologically similar.

Such an alpha-lattice as described above can be implemented by considering the system of differential equations:

Where *q* gives the location of an agent and *L* is the Laplacian matrix. Essentially, the updated velocity of a given agent is given by multiplying the current velocity by the Laplacian matrix and the time increment, i.e.

The Laplacian matrix is dependent on the distance between agents (that is, the farther the distance from an ideal flock, the stronger the signal to regain flock formation) and other parameters [6].

Note that in many multi-agent systems, only implementing a velocity-consensus and a distance-based algorithm is not sufficient to prevent what is known as *regular fragmentation*. An image of regular fragmentation is shown in Figure 1 [5].

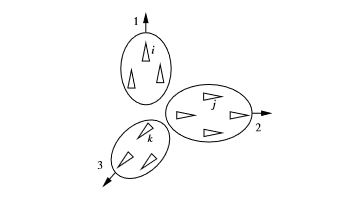


Figure - An example of regular fragmentation

Note that this fragmentation is because there is no group-objective term in the algorithm. This can be resolved by adding a term that considers the overall goal, which could be implemented in a platooning context by having the lead truck in the platoon move more independently, causing the other trucks in the platoon to follow it in a flocking fashion.

Ultimately, the algorithm used with have to take into consideration factors such as frequency of communication between agents, whether it is possible to change the lead agent (if the current lead truck must exit the platoon) and how exactly that would be implemented, and adjustments to following distance or speed in different road conditions.

# Stakeholders

This section will discuss the social, environmental and economic considerations for the project. It will also address three relevant stakeholders: truck drivers, transportation businesses, and highway commuters.

## Social Considerations

The trucking industry is related to two major issues that face citizens: commuting time and accidents.

Trucks travel more slowly than cars on highways, which causes congestion and longer commuting times. Americans spend 300 hours commuting in cars annually, a number that could be decreased by reducing congestion.[7] These excess hours spent in traffic can be put towards more productive and healthier activities.

Accidents are a less common, but much more devastating aspect of commuting. Social impacts include decapacitating injuries, loss of friends and loved ones, and trauma. 141,000 trucks were involved in crashes in America during a 33-month study from 2001 to 2003.[2] Jim O’Sullivan, the Highways England Chief Executive, believes that development of platooning will improve safety for all road users.[3]

## Environmental Considerations

Transportation is a large contributor to greenhouse gas emissions. In 2015, 1.8 billion metric tons of CO2 were emitted by transportation methods. 415 million were due to medium and heavy-duty vehicles, the focus of this report. This comprises 23% of the total.

Global efforts to reduce greenhouse gas emissions have turned towards commuting and transportation, with the recent development of electric vehicles and cars with improved fuel efficiency. Platooning is another method of reducing emissions. A 3-truck platoon uses at least 5.2% less fuel than the trucks travelling individually [8].

As mentioned above, platooning reduces congestion and commuting times. This will reduce emissions from all vehicles on highways. This induced benefit will curb the 1.1 billion metric tons of CO2 emitted by cars and light transport vehicles.

Finally, the sensor system must be environmentally friendly from manufacturing to disposal. However, this is not within the scope of the project.

## Economic Considerations

Platooning is a recent development that is enabled by self-driving research in the transportation industry. However, its social and environmental benefits have caught the UK government, who invested 8.1 million pounds in 2015 to research and develop and convoy system that will be applied to their transportation industry.[3]

The implementation will reduce the expenditure on fuel for all road users, including truck drivers and commuters. It will be capital expenditure for transportation businesses that implement the technology on their fleet but will reduce operation costs by improving the fuel-efficiency of their journeys. However, the initial cost must be small enough to encourage companies to install the technology on their fleet.

## Truck Drivers

Truck drivers are highly susceptible to injury on the job. They account for 12% of all worker deaths in America. 87% of crashes involving trucks are due to driver error. When a car and a transport truck are involved in an accident, 45% of the time the error is due to the truck driver.[2] Platooning can reduce the likelihood of an error causing an accident by both truck drivers and commuters.

Platooning allows trucks to travel in a more predictable manner. This will reduce the potential for error on the commuter side. On the truck driver side, the self-driving aspect will prevent avoidable collisions. However, it may also contribute to inattention behind the wheel. This reduces the driver’s ability to retake control of the vehicle if the self-driving mode fails. A design element to ensure attentiveness would be beneficial for the safety of the truck driver and others on the road.

The truck drivers are the primary user of the platooning algorithm, so it must be tailored for their needs. It must be easy to use and improve the safety of the drivers.

Finally, it must be acknowledged that truck drivers have financial incentive to surpass the speed limit. Many drivers are paid by the load or by the mileage, so speeding directly increases their income, especially due to labour laws that restrict their time spent on the road in a day. The speed of the convoy must balance following the speed limit with average truck speeds. Alternatively, companies can promote following the speed limit by paying hourly wages, however this may not be in their best interest either.

## Transportation Businesses

Fuel is one of the major operational costs for transportation businesses. As a result, many large companies would have incentive to invest in technology to allow platooning. There would be an up-front cost to install the technology, but this would be offset by the savings on fuel in the future.

As mentioned in the economic considerations, the cost of installing the platooning system must be low enough to encourage it to be adopted by transportation businesses. On the other hand, many countries are adopting carbon taxes and other policies to reduce emissions. These may raise fuel costs and add to the necessity for efficient driving.

## Commuters

Commuters incur fuel costs, excess time spent idling in traffic, and a risk of accidents. As mentioned in previous analyses, all these factors are reduced by the adoption of truck platooning. The largest potential issue with installing platooning is that it will force driving habits to change. By the nature of the platoon, cars cannot merge into lanes as easily, since they cannot pass in between trucks in the platoon. This issue may be addressed by limiting the number of vehicles that can travel in a convoy. Current testing by the UK Department of Transportation uses platoons of 3 lorries.[3]

# Problem Definition

There are many considerations to be made in this problem, including the interests of each stakeholder as well as what is reasonable and ethical. For example, the safety and legality of certain travel speeds must be considered, but this must be balanced with the economic interests of the truck drivers. Overall the goal is to increase overall trucking safety and efficiency while reducing economic and environmental cost. This will be done using multi-agent flocking dynamics, with the solution being an algorithm that can effectively manage a platoon of transports to maintain equal spacing and speed, while one leader car operates relatively independently. Other desirable features are the ability to replace the leader truck and the capacity to adjust the parameters of the algorithm based on factors like road conditions.

# Design Criteria and Specifications

The main priority of the system is to not disrupt traffic. This is a social consideration that directly aligns with the needs of commuters and other truck drivers on the road. This may require limitations to the length of convoys and will also require them to travel at a consistent speed and remain in the same lane.

Similarly, the algorithm must prevent collisions. This involves maintaining a sufficient stopping distance in front of the vehicle, and not changing lanes unless the area is clear. The stopping distance can be dependent on features such as road conditions, but for the purposes of this project it will suffice to manually change the parameters of the algorithm such that an appropriate stopping distance is reached; the algorithm does not have to itself find this stopping distance, simply follow the distance indicated by the driver. Collisions caused by other vehicles are more challenging to avoid, and an algorithm may cause a larger crash. This issue is best left in the hands of the drivers until self-driving vehicles are more advanced.

There are many more advanced features that can be implemented in a flocking algorithm, such as obstacle avoidance by treating obstacles as separate β-agents, or splitting-reformation tactics for increasing travel efficiency [5]. While very interesting, these features will likely be beyond the scope of this project, which will be primarily focussed on simply satisfying the 3 rules of flocking dynamics from Reynold’s mentioned earlier along with a flock leader. However, if these methods prove to be a viable for this project, they can certainly be pursued.

In summary, the system must:

* Travel at an appropriate speed, constant among the platoon members
* Convoys must have a length limitation
* Trucks under self-driving must not complete a maneuver that induces an accident (if other drivers cause an accident, the human driver of the transport can react accordingly)

# Project Plan

This project will include a few phases going forward in order to maximize productivity. The first Phase consists of Spending 5 days on research, while simultaneously preparing the project proposal. Research will continue into the rest of the project as necessary. During the second phase of the project, the solution will be modelled. This will be done in phases, with each group member focusing on one aspect of the solution. A progress repot will be created at the same time. After the completion of the modelling, the team will review the model and discuss possibilities for improvements and a second progress report will be written. After the completion of the review, the final draft of the model will be created and edited by November 21st, 2018. At this point the team will begin creating and editing the final report and the final presentation. These should be completed by November 30th, 2018 and submitted on December 2nd, 2018. Finally, the team will spend 3 Days preparing and practicing the final presentation. Part of the plan is for the team to meet every Tuesday, and Wednesdays as necessary. This will provide the team with dedicated time to discuss their work and provide each other with progress reports, which can be used to assign roles for the upcoming week.

# Gantt Chart



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[4] “Truck Platooning Evaluations | Transportation Research | NREL.” [Online]. Available: https://www.nrel.gov/transportation/fleettest-platooning.html. [Accessed: 02-Nov-2018].

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[6] B. Gharesifard and S. Kyle, “Group Formation in Multi-Agent Systems.” .

[7] T. F. Times, “Americans spend 300 hours a year driving in their cars,” *Business Insider*. [Online]. Available: https://www.businessinsider.com/americans-driving-300-hours-a-year-2016-9. [Accessed: 04-Nov-2018].

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# More information that we have discussed

## Implementation of the design:

Technology available to communicate between vehicles:

* Adaptive Cruise Control: detects distance/speed of the vehicle in front and adjusts speed based on that
* Cooperative Adaptive Cruise Control: ACC with the addition of transmission of information between vehicles. For example, the lead vehicle may transmit their speed to the other vehicles in the convoy. This allows for smoother transitions and movements but requires extra equipment in the vehicles for communication. This makes the design more expensive
* Note on ACC vs CACC: sometimes more information is not better, because the main thing you want the trucks to be focused on is aligning themselves between the vehicles ahead and behind themselves. A secondary priority is keeping the convoy together (rather than having a truck trail behind or speed ahead). ACC does a perfectly fine job at the first goal but has no control over the spacing of vehicles that are separated by another vehicle. CACC can help with this. However, it will be problematic if the vehicles are being influenced too heavily by non-adjacent vehicles, resulting in constant speed adjustments that are not necessary. This directly conflicts with another goal of the convoy system: predictability of movement. This criteria is important because it will ensure that other road users are comfortable, and prevent accidents.

Program:

* If statements will be used to prevent collisions and make the vehicles travel in an appropriate convoy. This includes things like *If distance to agent n – 1 is less than 4m, slow down*

## Ways to evaluate solution

1. Does it maintain traffic flow?
   1. All agents travel in a steady convoy at a mostly-constant speed
   2. Spacing between agents is minimized
2. Is it safe?
   1. Agents do not come within 4m of one another
   2. Convoy travels in a smooth, predictable manner to prevent mistakes or crashes by other road users
   3. Agents never exceed 120km/h