

Path Finding and Joining for Truck Platoons

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Abstract- Road transportation is a chief mode of freight transportation for any business. Freight agencies seek safe and rapid means to transport their goods between places. In this paper, we focus on trucks platoons as one of the main solutions in the road freight transportation. We discuss the need for using truck platoons and offer scheduling algorithms for forming initial platoons as well as merging of two platoons. We have developed a few algorithms for platooning and to determine when they platoons may merge into larger ones.

Keywords- platoon, distance, path, scheduling.

I. Introduction

Distribution of produce and food products are time critical and rely on burgeoning commercial trucking that is part of the larger road freight supply chain. Commercial road freight requires the most efficient and the most economical use of their fleet of trucks that must travel road segments with varying prevailing weather and traffic conditions. We are exploring an application of trucks platooning where a few trucks maintain to be a proximal distance to each other and travel together as a unit. Platooning can be accomplished by wireless communication among vehicles to form cooperative adaptive cruise control (CACC).

Platooning is a solution that can achieve road use efficiency goals. A platoon can be defined as two or more vehicles that are driven in a vector at similar velocities. Loftus, et al. define the platoon as a coordinated operation of two or more trucks via cooperative adaptive cruise control [10]. Figure 1 shows the nominal notion of the platoon [5]. In this paper, we apply platooning to achieve efficient road freight.

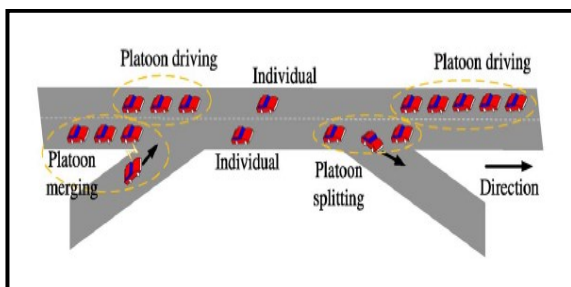


Figure 1: Platoon pattern

In order to build a platoon, trucks in a platoon need to be provided with specific technologies in order to communicate with each other and to achieve safety and stability as well as saving cost and energy through all their travels. Such technology is divided into two types: software and hardware. Software technologies are control algorithms. The control algorithm can monitor the distance between trucks and establish constant spacing among trucks. Another example of software that needs to exist in trucks is a communication network; which will facilitate exchange of important information among trucks that are useful for their trips. On the other hand, hardware technologies may include sensors, radars, cameras, etc.

Using a platoon system in transferring products has many benefits for the road traffic and the companies that are using it as well. The benefits include enhancing highway safety, improving traffic capacity, and reducing fuel consumption [14]. As Elisabeth Uhlemann mentions in [7], there are some experiments that show truck platooning can realize up to 10% fuel savings and reduce CO₂ emissions [7] [4]. These results arise due to the formation of trucks following each other; the trucks between the first and last trucks in the platoon will have lower air-drag friction compared with the first and the last ones. hence, the trucks in the middle will save fuel consumption and reduced CO₂ emission [11]. Section 2 outlines the background while section 3 offers inputs for platoon algorithms. Section 4 discuss scheduling algorithms and motion policies are discussed in section 5. Vehicle arrival model is given in section 6. Path methods are further elaborated in section 7 followed by a concluding section 8.

II. Background

There is a large volume of literature on how to control the inter-vehicle distance between trucks, and the ideal ways to control trucks motion on highways.

In [2], authors provide a variable spacing policy that can control the inter-vehicle distances between trucks. The policy was proposed is effective to decrease the distance between trucks and to make the spacing near constant. In addition, the policy does not provide heavy communication between

trucks. Once the space between trucks is constant, that can increase the string stability of platoons. Also, it can raise the robustness of the control on trucks specially while driving on long highways [2].

Alan Ali, et al. simulated their policy and their control law on Matlab and TORCS [2]. Their results showed that the inter-vehicle distance decreased to be equal to the desired distance that they need comparing to constant time headway (CTH) policy. The constant time headway policy states that the desired speed of the vehicle should be suitable to the inter-vehicle spacing, with the specified headway being the reciprocal of the constant of proportionality [6]. Moreover, they approved the system is string stable by assuring if the dynamic is changed, the desired distance is changed as well.

Furthermore, the vehicles ability to preserve a fixed distance between them by accelerating or decelerating their speed comes under the range of adaptive cruise systems. In this case, the vehicles can insure safety between them if one of the vehicles in the platoon needs to slow down its speed due to sudden obstacles [13].

In the same context, authors in [12] demonstrated an algorithm that determines the distance between vehicles by coming to a consensus among the vehicles in a platoon. In other words, the algorithm aims to reach to an average distance between the vehicles in a platoon in order to determine the trajectories of trucks and the speed over the specific time and then leads into in the formation of the platoon.

On string stability, there are some experiments on stability insurance such as [16], [15], [17]. Lu, et al. in [17] discussed how string stability could be applied practically for vehicle platooning [17]. The authors state that the practical string stability for vehicles in platoons needs to take some factors into consideration such as time lags in vehicles hardware, pure time delay between take the tasks and process them, or external disturbance such as wind and road.

Regarding string stability, vehicle-to-vehicle communication is one of strong controller options that makes the string of platoon stable. Florin in [8] discussed the structure of a vehicle platoon that is composed of n vehicles; each vehicle is supported with its control agent that is using the vehicle-to-vehicle (V2V) communication through a wireless network. The vehicles in a platoon use their control agents in order to communicate and exchange needed information between each other. He mentioned in [8] that using V2V communication reflects on vehicles performance and will make the whole platoon stability ensuring.

On the other hand, since scheduling is one of our concerns, there are some research that discuss the scheduling idea.

In [3], Bhoopalam, et al. propose the scheduling problem under different conditions. They started with *flexibility* factor, and they state that it is better to make the drivers to select their routes by choosing the shortest paths. However, the authors explain that some drivers may not be prepared to change their given routes. In this case, fixed or flexible routes may affect the scheduling. The second factor they discussed is *restriction*. They argue that sometimes it is good to make the number of trucks in a platoon restricted in order to limit the traffic and to lessen the additional wear and tear on the infrastructure. In addition, they support this idea by pointing out that minimizing the number of trucks in a platoon in a single trip make the division of benefits simpler. In section 3 we will outline input parameters we will consider for our problem followed by scheduling issues.

Other work, such as [9], discussed a communication scheduling method among vehicles in a platoon. However, the goal of the communication scheduling method is to resolve the communication conflicts, with which the string stability and zero steady-state spacing error of the platoon can be guaranteed under the given vehicle controllers [9].

III. The Main Inputs in The Platoon System

Our model depends on three significant components: (a) the road network, (b) size of platoons, and (c) how platoons detect the best path to the destination.

First, the road network is all the road segments that platoon needs to use in order to reach the destination starting with a single source and ending with a single destination. Each path in the road network require T time duration to complete it. T time contains the default travel time t plus an additional delay δ that may be encountered. The delay time δ usually includes the reaction time and so on, and it ranges between 0 to 5 units. The idea behind detecting the travel time for each path is to compute the approximate time that platoon needs in order to reach the destination point under normal conditions.

The next input that need to be known is the number of trucks in each platoon. In other words, we can say what is the size of the platoon at the source point that is suitable to journey to the destination point. Most of the resources agree that the best size of platoon should be not a large number. This means the size of platoons could be in range between 3 to 7 trucks. The reason for determining small numbers of trucks in one platoon is to facilitate controlling the trucks and not wasting some time to gather many trucks to put into a platoon. On the same context, due to the time concerns in the model, it is better to let the platoons depart only when the size is acceptable. Restricting the size to a fixed size range does not mean that other platoons cannot join departing platoons

while they are in transit. On the contrary, while the platoons are moving, we highly recommend joining other platoons if they are traveling along the same path.

The last input and the most complex one is how the platoon can detect the best path from the source point to the destination point. In addition, how platoons can compute alternative paths in case they face some obstacles on their main paths. To solve this issue, we need to create algorithms in order to check the optimal paths and alternative paths for the directions. We are going to discuss the algorithms in detail later in this paper.

IV. The Platoon Scheduling System

Scheduling problem is one of the main concerns in any task that is time sensitive. Scheduling platoon transportation offers advantages and disadvantages. Scheduling specifies timing information for each possible occurrence of platoon during a given scheduling length. It can give an expectation time for the delivery in a specific time. In addition, workers in storages will have benefits of the arrangement delivery time so they can schedule their on and off duty times.

Scheduling may give profits in priority ordering. If there is one platoon has been scheduled to be the first, but it has a lower priority than another platoon that is scheduled later, it is easy to swap them as long this swapping will not adversely affect their timetables. Scheduling may cause some drawbacks on transportation system. Some scheduled platoons will not move from the starting point until it is their time to go that is shown in their timetable whatever the previous platoon status was moved already from the starting point or not. Strictly speaking, the waiting time between two platoons should be considered as valuable time; that means, the next platoon may use the waiting time to gain extra benefits. For example, the platoon can use the waiting time as recovery time for the delay time that is going to be encountered during the transportation such as reaction time or traffic time.

V. The Platoon Motion Polices

Motion Control for trucks in platoons requires significant information before and while moving on highways as well in order to control time, movement performance, and supply better safety solutions in transport. Motion control polices in our model could be applied on two main parts: the first part before trucks moving on highways, and the other part is while truck moving on highways.

Scheduling is organizing the platoon departures from the starting point in order to ascertain when the platoon will reach the destination point. Before the platoon leaves the starting

point, it is needed to know how many trucks will be in this platoon, and if there is any chance for the platoon to join another platoon during the trip. The reason for the need to know the possibility of joining another platoon or not is to check for the maximum number of trucks that could join the platoon. There is a maximum platoon size that is determined earlier in the system. Otherwise, trucks could probably wait for other trucks to platoon themselves. Speaking of joining platoons, the driver of the truck leader should decide what if joining another platoon is a good option or not. I mean, the waiting time in the one platoon to gather ten trucks is longer than the platoon that includes three trucks only as obvious. Consequently, we should inspect if the waiting time will conflict with the timetable or not.

Motion control of platooning during travel on highways is more complicated than the initial platoon initiation. The highways may have some sudden obstacles such as accidents or constructions that might hinder platoon motion and hence the arrival time will be affected. In addition, the motion control will be changed if there is a high chance to join other platoons to gain extra benefits such as save more energy. Moreover, breakdown of one of the trucks in a platoon may have effects on the time schedule; whether if all the other trucks will wait with the disabled truck to be fixed which causes latency, or the disabled truck will be abandoned and the platoon will continue to follow the scheduled time, which may cause loss or latency in some goods in the disabled truck.

VI. Vehicle Arrival Model

At the station, the vehicles will arrive randomly. In the range between t_1 to t_2 , there are probable appearance for several vehicles at the station to the extent that it complements the platoon size. The probability arrival of vehicles could be calculated in (1):

$$\int_{t_1}^{t_2} vehicle_{appearing} = prob. of reaching the platoon size. \quad (1)$$

At t time, when t is the current time in the system, the arrival time and the departure time for vehicle i is t_{ir} and t_{id} respectively. Whereas t_{ir} should be less than or equal to t_{id} , and t_{i+1r} greater than or equal t_{ir} .

$$0 \leq t_{ir} \leq t_{id}$$

$$t_{ir} \leq t_{i+1r}$$

VII. Path Methods

Path selection algorithms discussed in this section starting with finding any path.

A. Finding a path:

We solve the finding a path problem by using an adaptation of Dijkstra algorithm. The reason behind using Dijkstra's algorithm [16] is that it solves the single-source shortest path problem like our path selection situation. Dijkstra's algorithm depends on positive, weighted, directed paths. Algorithm 1 uses weight that are travel time duration for the road segment. The vertices here in this situation are the truck platoon stations, which trucks are allowed to visit for supplies and fuel. Consequently, algorithm 1 will be applied between the source and the destination to find the shortest path and the time that needs to go over the shortest path.

Algorithm 1 Finding a Path

Inputs: $G(V,E)$, w , s

Output: the shortest path, weight

```
1:  $weight[s] \leftarrow 0$ 
2: for each  $v \in V$ 
3:    $weight[v] \leftarrow \infty$ 
4:  $Visited \leftarrow \emptyset$ 
5:  $Unvisited \leftarrow V$ 
6: while  $Unvisited \neq \emptyset$  do
7:    $u \leftarrow \min\_weight(Unvisited, weight)$ 
8:    $Visited \leftarrow Visited \cup \{u\}$ 
9:   Remove  $u$  from  $Unvisited$ 
10:  for all  $v$  that neighbor of  $u$  do
11:    if  $weight[v] > weight[u] + weight(u, v)$ 
12:       $weight[v] = weight[u] + weight(u, v)$ 
13: Return weight
```

Each platoon is going to have two paths that can be used to reach its destination point; the first path is we call the primary path, and the second one is termed the alternative path. The platoon can use the alternative path in case the primary path is unavailable or we can say that the path is off. In order to check the path status, we will use the global position system (GPS) navigation because the path status is usually changeable depending on the traffic, construction, or

may be the weather. For that reason, we intend to use the GPS because it is a satellite-based navigation system made up of at least 24 satellites, and it works in all conditions. Algorithm 2 will allow the vehicle to check the availability of the first path.

Algorithm 2 Path Checking Status

Inputs: $pth1$, $pth2$

Output: the shortest path

```
1:  $p1$  checks  $pth1$ 
2: if  $\nexists$  obs in  $pth1$ :
3:   return  $pth1$ 
4: else
5:   return  $pth2$ ;
6: end
```

B. Joining a platoon:

A platoon can join another platoon in two cases. In the first case while the platoon is at the start point before departure. The second case is when the platoon is driving on the road.

In the first case, the first platoon ($p1$) that is going to a destination ($des1$) will check its two paths to see which one has another platoon ($p2$) that is using the same path at that time heading to the same destination ($des2$), that means $des1 = des2$.

As it is shown in algorithm 3. If there is a $p2$ on the alternative path ($pth2$) is going to the $des2=des1$, then $p1$ will send a message to $p2$ asking for joining it. The message includes the number of trucks in $p1$, the destination (des), and the time the $p1$ needs to reach $p2$. The goal of sending the number of trucks is to let $p2$ checks how many total trucks will be whereas $p1$ joining $p2$. Once $p2$ has received the message, $p2$ will check the number of total trucks (i.e., the number of trucks in $p1$ adding to the number of trucks in $p2$); if the total number of trucks is more than the threshold (i.e., the threshold value should be given by the system), then $p2$ will send the rejection back to $p1$. The threshold number is usually in the range between 5 to 10. In addition, $p2$ will check the waiting time that it needs, if the waiting time is more than δ (i.e., the δ value should be given by the system), then $p2$ will send the refusal back to $p1$. Otherwise, $p2$ will send the acceptance back to $p1$

Algorithm 3 joining a platoon (case 1)

Inputs: p1, p2, pth1, pth2, dis1, dis2

Output: acceptance or refusal

```
1: p1 checks pth1 && pth2
2: if pth2 || pth1 has p2:
3:   if dis2 = dis1,
4:     p1 sends a msg
5:     p2 checks if (# of trucks
6:       > thrshold) || (time >  $\delta$ )
7:     p2 refuses
8:   else
9:     p2 accepts
10: end
10: end
```

In the second case, let us suppose there are two platoons on the road, and both have the same destination. However, they are in different locations as it is shown in figure 2. It is worth mentioning that in the platoon system, each truck is supported with a platoon GPS; which is able to determine the locations of all platoons in the surrounding area. Here in this case, platoon 2 (p2) can see platoon 1 (p1) in the area by using the platoon GPS, so p2 will send a message to p1 asking for joining.

After p1 receiving the message from p2, p1 needs to check three things; calculating the number of total trucks (should be less than threshold), if it is the same destination, and also the necessary waiting time for p2 to be arrived (should be less than δ). Depending on these results, p1 will decide whether if p2 is going to join or not. Algorithm 4 shows how the procedure works.

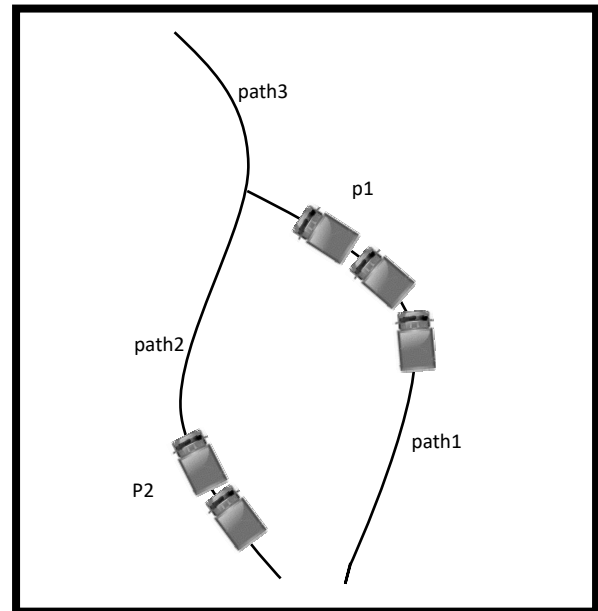


Figure 2: Joining a platoon (case 2)

Another key point that we can use regarding a platoon that needs to decide whether waiting for another platoon or not as mentioned in [1]. Authors identified an algorithm that states a tradeoff between energy consuming and time delay, it is called energy-delay tradeoff. Authors clarified that despite of platoons with many vehicles are obviously better in terms of energy consumption, but at the same time the vehicles need to wait long periods of time for each other, which increases delay. So, in this case, authors worked on to analyze the fundamental energy-delay tradeoff.

After all, the last and significant part is to test these algorithms on a simulation system to check their functionality. In this paper, we formulated the ideas of finding a path and joining a platoon, and the next step will be to apply them on the simulation systems using a platform like MATLAB.

Algorithm 4 joining a platoon (case 2)

Inputs: $p1, p2, pth1, pth2, dis1, dis2$

Output: acceptance or refusal

```
1: If  $\exists pth3 = (pth1 \cap pth2)$ 
2:   p2 sends a msg to p1
3:   switch (msg):
4:     {case1: # of trucks  $\gg$  threshold
5:       yes  $\rightarrow$  continue;
6:       no  $\rightarrow$  p1 refuses;
7:     case2: dis1 == dis2
8:       yes  $\rightarrow$  continue;
9:       no  $\rightarrow$  p1 refuses;
10:    case3: time  $\ll$   $\delta$ 
11:      yes  $\rightarrow$  continue;
12:      no  $\rightarrow$  refuses;}
13:   p1 returns acceptance;
14: end
```

VIII. Conclusions

To capitulate, the platoon system improves the transportation system. It could be better in cost because trucks can save some energy driving following each other. In addition, it could be better in saving time due to transporting more goods in shorter time. This paper has highlighted finding efficient travel path for platoons. This paper has also discussed the benefits of platoon merging.

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