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An Agent-based Simulation Model for Truck Platoon Matching

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Abstract

This paper presents a flexible agent-based simulation (ABS) model to serve as a matchmaking system for trucks such that they can form a platoon. A platoon is a formation of trucks which drive closely behind each other in a (semi)autonomous fashion. We focus on an agent-based system which seeks platoon candidates in the proximity of a truck and tries to find a match based on several properties of the trucks. The ABS does so in a dynamic fashion based on real-time (geo)data. Opposed to centralized systems, the matchmaking is done locally among trucks(agents). Due to the spontaneous nature of this matching type, we denote this type of platoon matching as real-time matching. We illustrate the ABS using a case study at a truck stop near the Port of Rotterdam, The Netherlands. The ABS model serves as a testbed for matching algorithms and to study enabling factors for truck platooning.

Keywords: Agent-based; Micro simulation; Truck platooning; Matchmaking

1. Introduction

The past years have witnessed increased interest in automated driving solutions in the logistics sector. A particular promising solution which has gained attention in both practice and research is truck platooning. Truck platooning enables trucks to drive in an autonomous platoon with short following distances. The trucks are virtually connected (e.g., by lidar) and communicate with each other using Cooperative Adaptive Cruise Control (CACC) to create a platoon, as depicted in Figure 1. The trucks can safely drive close to each other as the typical response time of a human driver is eliminated. The short distances reduce aerodynamic drag and results in fuel and emission savings [1, 7]. Furthermore, the data exchange between the trucks enables advanced systems to support the driver (e.g., automated braking or automated cruise control), increasing traffic safety [8]. Moreover, as trucks drive closer to each other, the road utilization increases [4]. This paper focuses on an Agent-Based Simulation (ABS) model to study the factors influencing the formation of truck platoons at a truck stop near the Port of Rotterdam, The Netherlands.

The remainder of this paper is structured as follows. Section 2 provides a classification of truck platoon planning problems and a brief overview of the literature. In Section 3 we present our ABS model and in Section 4 we present the experimental design and results. We close with conclusions and directions for further research in Section 5.

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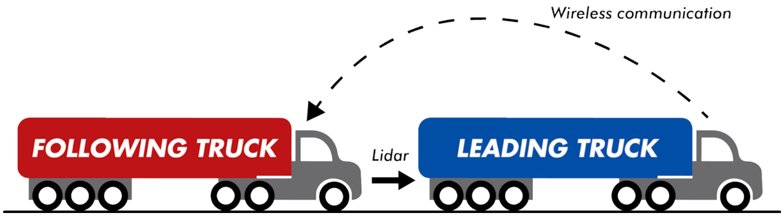


Fig. 1: Illustration of a two-truck platoon.

2. Classification and related literature

To classify our work, we first distinguish between two types of truck platoon matching: (i) offline and (ii) online. The former uses algorithms to find economically viable platoons based on a predefined set of truck schedules. This is for example relevant for a distribution center, where the trips of multiple trucks start from the same area and are known upfront. The latter type does not compute platoons beforehand, but uses real-time data of trucks driving in the neighbourhood to find an economically viable match. In practice, this type of planning has two variants: (i) catch up with a truck, or (ii) wait for a truck. The former adjusts the speed of the trucks until they are close enough to each other to form a platoon. However, adjusting speeds in a mixed traffic situation might be counter-effective due to disruptions in the traffic flow. The latter is applicable to situations where trucks (are willing to) stand still (e.g., during rest periods or at filling stations). A major benefit of this variant is the possibility to form a platoon in a safe manner without disrupting the traffic flow. However, increased waiting times might render potential platoons (economically) infeasible without a proper compensation mechanism. This paper focuses on the latter type of truck platoon matching.

The majority of the literature devoted to truck platooning is focused on technological or safety aspects [6, 8]. However, taking into account the operational side of truck platooning (e.g., finding a truck to platoon with) is the next step to facilitate the integration of truck platooning in the supply chains of logistics service providers. This particular aspect of truck platooning is denoted by the planning or matching of platoons. In this paper we use the term matching to denote (i) the process of finding one or more trucks to form a platoon with and (ii) agreeing upon the conditions of the platoon (e.g., departure time and the division of savings among the platoon members). The literature on this particular topic is relatively scarce, although the importance for practitioners is not to be underestimated. It is not the aim of this paper to provide an exhaustive overview of the literature. The interested reader is referred to a recent literature review [2]. Contrary to related literature, this paper focuses on the evaluation of the factors and constraints influencing the formation of platoons by quantifying the economical impact (e.g., joint savings of the platoon). A comparable, yet more aggregated, simulation study on the fuel saving potential of truck platooning is the most related study to this paper [5]. However, to the best knowledge of the author, this scope on truck platoon matching has not been addressed in the literature before. In this paper we aim to fill this gap by designing a flexible and large-scale ABS model to assess the impact of the factors influencing the emergence of platoons. The model also serves as a testbed for the effectiveness of various matching algorithms and is thus a useful tool for researchers. The context in which we research this system is the Maasvlakte Plaza, a truck stop near the Port of Rotterdam in The Netherlands. The Plaza is an area where truck drivers take their obligatory rest periods and is a highly dense area of trucks.

3. Agent-based matching

We deploy the agent-based matchmaking system in the area described above. In our approach we represent every truck as an agent, with its own attributes (e.g., departure time, route, destination and urgency). The truck agents try to find a suitable platoon partner based on a certain matchmaking algorithm. The algorithm is executed when the agents arrive at the Plaza. We use two algorithms: (i) First-Viable Match (FVM) and (ii) Best-Match (BM). The former accepts the first match which is economically viable. Due to the simple nature of this algorithm it is highly useful for real-time decision making. The latter loops over all truck agents present at the Plaza and matches with the agent with whom the highest earnings can be achieved. The economic viability of the match depends on the costs of waiting for another truck beyond your obligatory rest period at the Plaza. The savings consist of (i) fuel savings due to reduced aerodynamic drag and (ii) wage savings if no (or fewer) drivers are required. To avoid that one member of the platoon has a disproportional amount of costs or savings (e.g., the leading truck has less benefit from the reduced fuel consumption), we deploy an equal-share allocation rule. That is, the earnings (i.e., savings minus costs) of the entire platoon are divided equally over the platoon members, regardless of their position in the platoon. The description of the truck agent type is shown in Table 1.

Table 1: Truck agent descriptor.

	Description
Name	Truck Agent
Description	Represent a physical truck and corresponding attributes and preferences
Cardinality	One per truck
Lifetime	While in system
Initialization	Set truck attributes, open DB connections
Demise	Close open DB connections, gather statistics
Functionalities	Match making
Uses data	Plaza DB, Destination DB, Overlap DB, Truck agent attributes
Produces data	Plaza DB, Truck Agent attributes
Goals	Find match with other Truck Agents to create a platoon
Percepts responded to	New arriving truck at Plaza, Departure single truck, Departure platoon
Actions	Find platoon candidate(s), create platoon, add truck to platoon, stop, go
Protocol and interactions	Read and write to transport management system, enable CACC

4. Simulation modelling

To visualize and test the effectiveness of the algorithms, as well as to study the impact of the factors influencing the matching of truck platoons, we deploy ABS. We use discrete-event simulation (DES) to model our system as ABS is a variant of DES [3]. We implement our model in Plant Simulation from Siemens (see Figure 2). We model the layout of the Plaza using tracks and the truck agents as Movable Units (MUs). The MUS are characterized by the attributes as discussed in Section 3. For brevity we focus on the match making process in situations where the arriving truck does not invoke waiting time on a potential match. That is, a match is not feasible when the agent already waiting on the Plaza needs to alter its scheduled departure time. Figure 3 describes this process for both algorithms and for all factors included in the model. When a match has been found, the truck agents create a platoon. In this study we restrict ourselves to platoons of a maximum size of three, as longer platoons may negatively influence the flow of traffic. In our approach, the platoon creation process does not mean that the trucks immediately leave in a platoon. They first have to spend (the remainder of) their obligatory rest period on the Plaza and only leave as platoon at platoon departure time agreed upon. Note that no truck may leave the Plaza before its own rest period has finished.

4.1. Experimental design

The main objective of the simulation study is to assess the impact of the factors influencing the matching making of platoons at the Plaza. We distinguish between two types of factors: (i) the matching algorithm used and (ii) agent characteristics. The latter captures the properties of the truck agent and the former distinguishes between the two types of algorithms, as discussed in Section 3. In our experiments we use 24-hour runs with rush-hour intensity, based on traffic data obtained from the Dutch National Data Warehouse. The truck agents' attributes are initialized when a truck enters the system. The destination and route (length) of the trucks are determined based on the top 15 (European) corridors with origin Rotterdam. This focus is chosen as platooning is especially beneficial on larger distances. This results in five corridors in the Netherlands and ten foreign corridors. The truck agents are assigned a corridor based on their relative frequency. A distance matrix is used to determine the overlap in routes (only required for different corridors). The expected number of kilometers that can be platooned between two or more trucks is estimated by the expected overlap, from which we subtract a value drawn from a Gamma-distribution. In particular we found that when using shape parameter $\alpha = 2$ and rate parameter $\beta = 5\%$ of the overlap, it realistically models the number

Fig. 2: Screen capture of the implemented simulation model.

of kilometers that can be platooned given the length of the corridor. An experiment is defined by considering the following factors: (i) the algorithm used (FVM or BM), (ii) multi-brand platooning (on or off), (iii) the share of urgent trucks (20% or 40%), (iv) the hourly wage savings (0%, 8% or 90%) and (v) whether exact-matching is used (on or off). When the latter is switched on, only matches are considered where all trucks have the same corridor. Otherwise, the distance matrix is used to estimate the overlap of two or more different corridors after which we subtract the value drawn from the Gamma-distribution to obtain the expected number of kilometers that can be platooned. When a truck agent is classified as urgent, the maximum waiting time to form a platoon is capped at five minutes. The hourly wage savings depend on whether the drivers of the following vehicles in a platoon (i) are still required and not compensated for (i.e., 0%), (ii) are required, but are compensated via road taxes or relaxed DOT rules (estimated at 8%) or (iii) are not required anymore (estimated at 90% savings). This results in a total of 48 experiments. Moreover, the top five manufacturers of trucks and their relative frequency in the Port of Rotterdam were used as input for the multi-brand factor. The remainder of the model parameters are shown in Table 2.

Table 2: Model parameters.

Parameter	**Value**	**Unit**
Hourly wage of truck driver	45	euro
Truck fuel efficiency	0.28	ℓ / km
Fuel price	1.08	euro / ℓ
Rest period	$U \sim (15, 45)$	minutes
Fuel savings (leading truck)	4	percent
Fuel savings (following truck)	16	percent
Fuel savings (last truck)	10	percent

4.2. *Simulation results*

For brevity we focus on the most insightful results of the simulation study. Figure 4a shows the impact of the two different matching algorithms on the percentage of trucks that leave the Plaza in a platoon based on 36 runs of 24 hours. On average the algorithms are comparable in performance (33% against 30%), where BM has the ability to obtain higher ratios in more favorable scenarios (e.g., high wage savings). However, from Figure 4b it can be seen that BM outperforms FVM on the kilometers driven by the platoon. This result is explained by the fact that platooning over larger distances is more preferred due to increased fuel savings. Contrary to FVM, BM loops over all potential matches and thus has the ability to capture this preference.

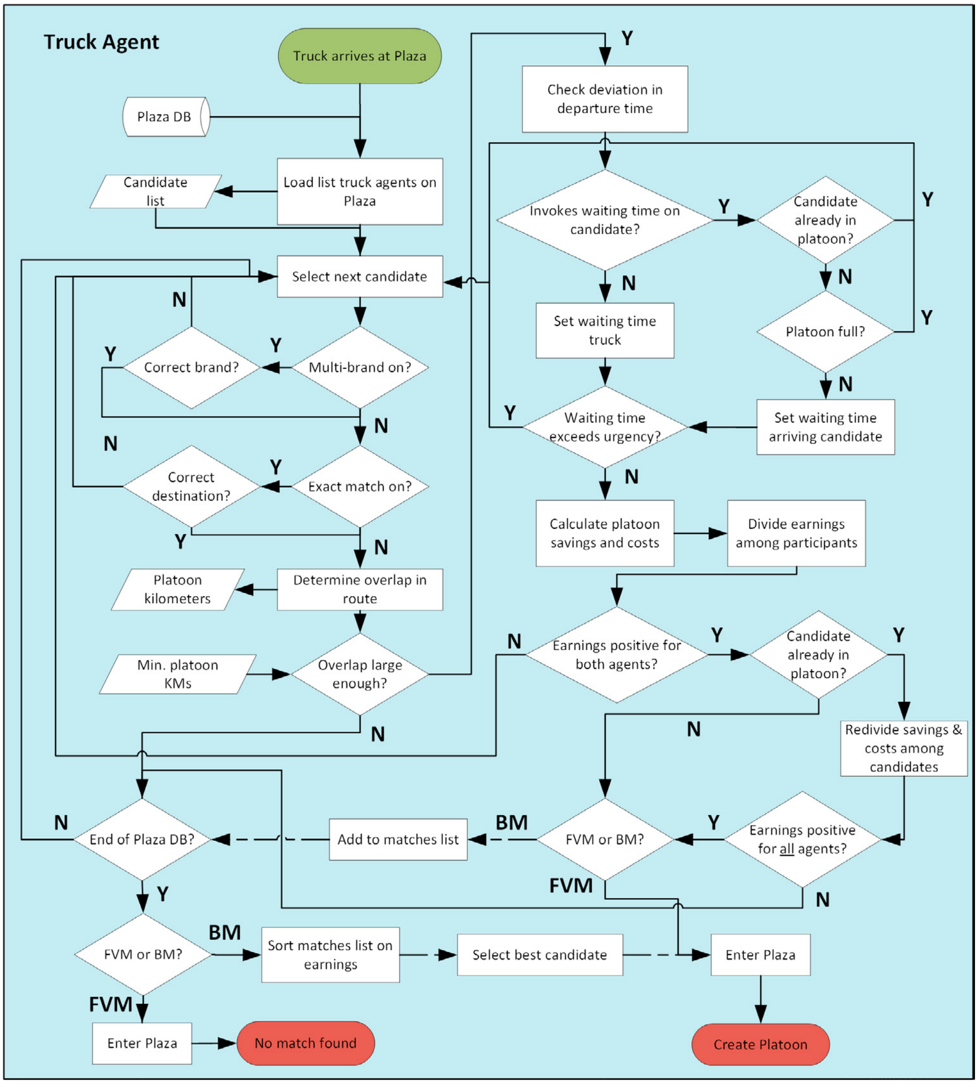


Fig. 3: Overview of the match making process.

Table 3a shows the impact of the hourly wage savings. When there are no wage savings (i.e., truck drivers required in the following vehicles with no compensation) the earnings per kilometer are relatively low. However, when drivers in the following vehicles are compensated (i.e., 8% savings), the earnings increase almost threefold. When no drivers are required for the following vehicles (i.e., 90% savings) the earnings further increase by a factor eight. We also found a large increase in platoons with three trucks, as the hourly wages of two truck drivers are saved and thus the platoon becomes relatively profitable, even though more waiting time might be required to match a larger platoon.

Table 3b shows the impact of multi-brand platooning on the number of platoons. When platooning is allowed between the five truck manufacturers considered (i.e., the CACC-technology is standardized), the number of platoons increases by a factor two where the earnings per kilometer remain the same.

Interestingly, doubling the share of urgent trucks (from 20% to 40%), was found to have no significant impact on the metrics considered. The urgency factor was modeled to capture the possibility of arriving late at the destination due to waiting for a platoon (e.g., a penalty due to exceeding a time window). As non-urgent trucks are willing to wait for urgent trucks, platoons can still be formed without invoking waiting time on the urgent trucks. Furthermore, when exact matching was turned on, a slightly higher number of platoons were formed (31% against 27%). This finding is in line with the conjecture that platooning is only worthwhile for relatively long distances.

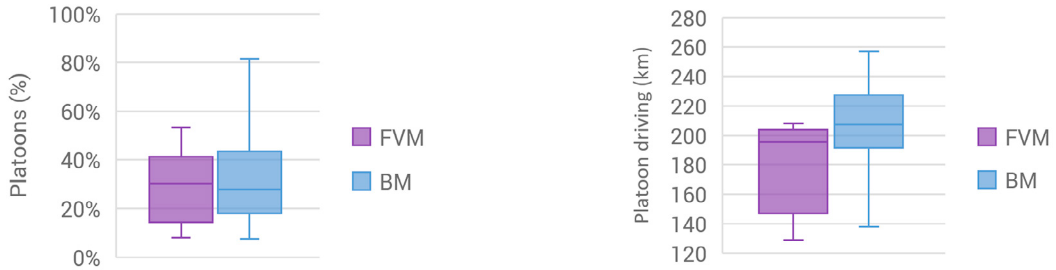
Table 3: Impact of (a) hourly wage savings and (b) multi-brand platooning on platooning metrics.

Wage savings (%)	Trucks platoons (%)	Earnings per km (€)
0	20.2	0.01
8	26.2	0.03
90	36.4	0.23

(a) Percentage of trucks in platoon

Multi-brand	Trucks in platoon (%)	Earnings per km (€)
On	36.7	0.01
Off	18.6	0.01

(b) Platoon kilometers



(a) Percentage of trucks in platoon

(b) Platoon kilometers

Fig. 4: Difference between matching algorithms on (a) percentage of platoons formed and (b) platoon kilometers.

5. Conclusion and future research

This paper presented a flexible agent-based simulation (ABS) model, where a single-agent type system provides promising results for truck platooning. The Maasvlakte Plaza in the Netherlands was chosen as a matchmaking area. We performed preliminary experiments where we found that on average 33% of the trucks were able to form a platoon with an average platooning distance of 200 kilometers, corresponding to average savings of €0.08 per kilometer. The largest influencing factor was found to be the hourly wages of the drivers. When no drivers are required for the following trucks, up to 37% of the trucks can platoon and the savings increase to €0.23 per kilometer. Moreover, the ability to platoon with different truck manufacturers approximately doubles the number of platoons and thus the standardization of CACC among truck manufacturers seems a valuable proposition. Varying the percentage of urgent trucks (i.e., not willing to wait) and whether an exact match was required, were found not to significantly influence the number of platoons formed. Directions for future research include (i) increase the dynamic nature of the agents, where agents may change matches over time based on individual preferences, (ii) assessment of the robustness of the results to the model parameters and (iii) the assessment of the impact of different sizes and intensities of platoons on the traffic flow.

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