A COMPARISON OF APPROACHES FOR PLATOONING MANAGEMENT

Masterarbeit
von

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List of Abbreviations

ACC	Adaptive Cruise Control
BASt	Bundesanstalt für Straßenwesen (German Federal Highway Research Institute
CACC	Cooperative Adaptive Cruise Control
Caltrans	California Department of Transportation
CC	Cruise Control
CO2	Carbon Dioxide
COMPANION	Cooperative Dynamic Formation of Platoons for Safe and Energy-optimized Goods Transportation
GDP	Gross Domestic Product
HDV	Heavy-Duty-Vehicle
HETAP	Heterogeneous Autonomous Platoon
HEVEP	Heterogeneous Vehicle Type Platoon
HOMAP	Homogenous Autonomous Platoon
HOVEP	Homogenous Vehicle Type Platoon
ITS	Intelligent Transportation Systems
IVC	Inter-Vehicle-Communication
NHTSA	National Highway Traffic Safety Administration
PATH	California Partners of Advanced Transit and Highways
RSU	Road Side Unit
SAE	Society of Automated Engineers

SARTRE	Safe Road Trains for the Environment
V2I	Vehicle-to-Infrastructure Communication
V2V	Vehicle-to-Vehicle Communication
V2X	Vehicle-to-Anything Communication

1 Introduction

The invention of the car more than 100 years ago has been accompanied both by fears of rising traffic congestion and visionary ideas to come to terms with it. The once unimaginable perception of automated driving may offer an elegant solution in the near future. The need for change in the current traffic system, which is mainly based on individual transportation (83% cars, 8% motorbikes and 9% heavy-duty-vehicles (HDV) [Des13]) is urgent, as, for example, the density of traffic in Germany increases every year by 2% [Sta16a] and the number of vehicles and HDV rose by 13% since the millennium [Des13]. This leads to an overuse of highway capacities from which congestions and traffic jams follow. In the long term, the infrastructure for vehicles is expected to be even more expensive than nowadays: the total value of the infrastructure amounts to 773 billion Euro in 2010 and around 20 billion Euro are invested every year (in Germany, [Des13]). As traffic increases, the traffic-caused percentage of CO2 pollution is supposed to rise accordingly: the share of traffic-caused CO2 pollution today is as high as 21% [Eur16a] (in 2010: 200 million tons of CO2 only due to traffic [Des13]). In 2016 the number of deadly car accidents solely in Germany increased to around 4000 [Sta16b] and the number of severely injured persons adds up to 69 000 in 2010 [Des13]. Congestion is not only inconvenient and unsecure but expensive as well. The economic loss resulting from congestions accounts for 1% of the EU's GDP [Eur16b].

1.1 Improvements through Platooning

Taking all these factors into account, the current traffic situation needs to be reformed. There are many concepts which try to solve the current traffic situation like the Cooperative Adaptive Cruise Control. However, the scope of this work is on platooning. Platooning can be shortly explained as follows:

"In the concept of Platooning […] vehicles travel on highways in closely spaced groups." [HC05, p. 405].

The platooning approach concept can help to improve the current traffic situation as shown thereafter. One advantage is that the capacity per lane increases: since vehicles need less spacing between each other, more vehicles can use the same length of highway. Another positive outcome of platooning is the reduction of traffic shockwaves and thereby the prevention of ghost jams. The creation of a ghost jam can be explained as following: A driver steering a vehicle manually might change lanes in a dense traffic situation, because the other lane seems to be faster. After the lane switch the driver behind the lane- changing vehicle needs to adapt its gap. In order to adapt the proper spacing, the vehicle needs to brake. This forces the vehicle behind to brake a little harsher: this process intensifies until one vehicle has to stop to maintain the proper gap. The outcome is a ghost jam [TK13], a traffic jam that arises for no obvious reason (compared to an accident). Since vehicles driving in a platoon would not suddenly change lanes – only if there was enough and secure spacing – platooning helps in dense traffic situation to either resolve the jam or stop the situation worsening. Shladover (2007) states that platooning can increase the capacity of highway lanes by 100-200% compared to normal non-platooning traffic [Shl07]. All in all, this can help to counteract the increase in traffic [TK13].

Furthermore, platooning lessens traffic-caused CO2 pollution: vehicles driving at close gap can significantly reduce their air drag thus reducing their fuel consumption, e.g., a Japanese project achieves 13% fuel savings and 2% CO2 savings [Tsu13].

Another important advantage of platooning is the improvement of safety conditions for the driver. This aspect lies in the technical requirements itself. If the driver or vehicle relied on current standard of manual steering, the danger of collision would be very high for vehicles driving at that close spacing. A driver then can only react to a breaking manoeuvre of the vehicle in the front if the braking lights of the vehicle in front are already flashing. Modern vehicles, in contrast, can even break when the gap between the two cars is reduced (e.g., through laser distance control of the Adaptive Control Cruise (ACC)). Platooning, however, uses *vehicle-to-vehicle* (V2V) communication: the vehicles can communicate via messages to each other, among other possibilities, send emergency notifications or braking signals to the vehicles driving in the platoon. This communication enables the platoon to brake (nearly[1]) simultaneously. Current research indicates that vehicles driving in a platoon seem to be considered safer than manual driven cars with respect to human failure such as slow reaction time or fatigue [Tsu13].

Taking all of these aspects into account, platooning saves money. Since congestion is reduced and in some cases even prevented, highways may be relieved to some extent. Beyond that, some expenditures for infrastructure may be reduced as well as fuel consumption and the number of accidents. Therefore, platooning spares money, increases safety and enables the driver to utilize the time while driving for other things, such as reading the news [Joo12].

1.2 Objective and Approach of the Thesis

Regarding the existing research on platooning, approaches and algorithms on platooning seem to be neither connected nor compared to each other. Instead of developing one single system, researchers have basically focused on new, different approaches and algorithms without using the existing knowledge basis thoroughly. This has led to the current situation in which it is difficult to identify the advantages or disadvantages of a given system. Furthermore, possible learning effects, and synergies may be missed. As a consequence, and in order to overcome the current situation of confusion and disorientation, there is a need to classify platoon approaches and algorithms. Thus two research questions have evolved:

Research question 1: How can platooning approaches be compared and classified?

Research question 2: How can platooning algorithms be compared and classified?

For this reason, the objective of this thesis is to create two classification frameworks: first, a framework for platooning approaches and second, a framework for platooning algorithms. Both are constructed by using a grid. This grid is created stepwise and

[1] The time required to send or receive the message is so short it is presumed that the platoon brakes almost simultaneously.

iteratively by going through every paper while retrieving characteristics. Out of these characteristics relevant categories for the classification have been developed. Both frameworks contain several classification factors, each with at least two possible characteristics. The frameworks do not only show both strengths and weaknesses but also enable researchers to evaluate and compare the approaches/algorithms. This evaluation tries to provide an outlook whether the approaches and algorithms examined are ready for implementation in real cases or if they lack some important considerations.

The first framework deals with the classification of platooning approaches. These approaches can be marked as a top level or macroscopic view on platooning. They explain how the researcher imagines the world comes to life with the conditions and requirements (e.g., specifications for the participating vehicles) for platooning. The second framework focuses on a deeper level: the classification of algorithms. The level of algorithms is a microscopic and very technical view on platooning. Whilst conditions and requirements are assumed to be given or have already achieved status quo, this level constructs implementations when, why, and how vehicles may platoon in a specific world.

1.3 Structure of the Thesis

The remainder of this thesis is structured as follows: Chapter 2 provides definitions and explains the basics of related concepts of platooning approaches. It also includes an overview of the history of platooning approaches. Chapter 3 describes the methodology used to retrieve and review the relevant literature and the construction of the framework. In doing so, the reviewed literature about platoon management will be filtered out for relevant categories. Chapter 4 introduces the framework for platooning approaches and explains in detail the categories and characteristics chosen. Each category contains indications which characteristic was used by the relevant literature. Chapter 5 presents the framework for platooning algorithms following the same structure as used in the chapter before. Chapter 6 provides for a discussion of both frameworks and a critical view on the categories and their evaluation. Chapter 7 concludes the thesis by highlighting limitations of the frameworks, provides an outlook about possible or desirable next steps in researching platoon management, and presents a summary.

2 Foundations of Platooning

This chapter deals with the basics to understand platooning with all its facets. In the beginning Section 2.1, this chapter contains a definition of platooning, platoon coordination, and platoon control. Section 2.2 gives an overview of the history of platooning. Section 2.3 classifies the concept of autonomous driving into different autonomous degrees. Section 2.4 provides an explanation for the control mechanisms regarding longitudinal and lateral movement in automated vehicles. Section 2.5 presents two communication approaches, namely V2V and *vehicle-to-infrastructure* (V2I) communication and demonstrates, how vehicles perform communication with other vehicles or an intelligent infrastructure.

2.1 Definitions

For a thorough understanding of the frameworks presented in Chapter 4 and Chapter 5, the term platooning has to be explained. To do so, two other connected expressions are clarified as well. Platooning as a term is approached from a general, macroscopic view. The other two expressions represent two levels of platooning. While platooning itself is at the same stage as approaches, the other two are at the level of algorithms. The first level, *platoon coordination* is examined from a microscopic view considering technical aspects. The second level, *platoon control* is studied from a microscopic perspective considering the technical details, too. Figure 2.1 provides an overview of the two levels of platooning:

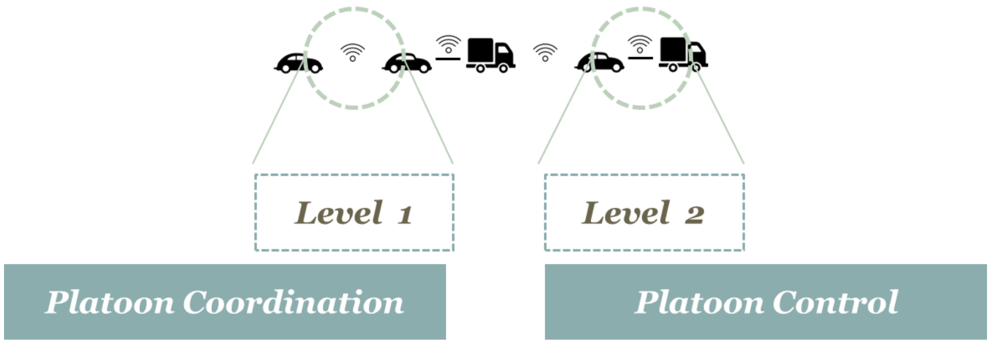

Figure 2.1: The two Levels of Platooning

The academic literature does not provide a consistent definition of the term platooning. However, most definitions are similar to the definition provided by Hall and Chin (2005):

“[In the concept of Platooning] […] vehicles travel on highways in closely spaced groups.” [HC05, p. 405]

and Bergenheim et al. (2012), who define platooning as

“a collection of vehicles that travel together, actively coordinated in formation.” [BPC+12, p.1].

Nevertheless, the demonstrated definitions do not cover all aspects of platooning. Based on the examined literature, three relevant aspects about platooning can be identified: First, platooning is the concept of vehicles driving in small distance to each other while not violating any safety restrictions. Second, the vehicles in the platoon behave exactly in the same way as the lead vehicle does, thereby creating a string of vehicles. Third, all platooning approaches require some degree of automation, albeit not all platooning approaches require the same standard or level of automation. Therefore, the following definition of platooning is provided:

Platooning is a string of fully or partly automated vehicles, which drive in a close spacing behind each other without violating safety restrictions.

The term platooning is important for the development of the framework for platooning approaches since it describes a macroscopic view on platooning. The two levels of platooning, *platoon coordination* and *platoon control,* are essential for the understanding of the framework for platooning algorithms, because the framework works at these two levels.

First, platoon coordination describes inter platoon interaction. This includes platoons or vehicles interacting with another platoon, e.g., joining or leaving a platoon.

Second, platoon control describes the technical view on platooning and refers to the maintenance of a platoon. This, for example, includes maintaining the right spacing or preparing the platoon to take over another vehicle.

For the understanding of the frameworks constructed in Chapter 3, the definitions of platoon, platoon coordination, and platoon control are essential as the definitions and the frameworks are strongly connected. Platooning approaches reflect a high level view on platooning. In other words, it shows how a researcher is constructing the surroundings in which platooning can happen: an imagined world without looking into details. This is, why platooning approaches can be seen to be on the same level as platooning itself. In contrast to the foregoing, details provide a deeper, more technical look into platooning. This deeper level is subsequently described through ideas for algorithms. Thus, algorithms are the mathematical equivalent for platoon coordination and platoon control. These algorithms are implemented into an approach, which means that ideas of platoon coordination and platoon control are matched into a suitable world imagined. The connection of approaches and algorithms to the respective level then represents the analogy of the frameworks: where, on the one hand, the framework for platooning approaches works on a high level view and, on the other hand, the framework for platooning algorithms shows a more detailed view.

2.2 History of Platooning

The history of platooning started in the 1980s in California (USA). In those days the traffic situation deteriorated due to massive congestions on the highways. As a consequence, the highway and public transportation infrastructure had to be improved. The responsible department (California Department of Transportation (Caltrans)) created the “Office for New Technology” and invited 100 specialists to the “Technology Options for Highway Transportation Operations” conference in 1986. In the same year the “California Partners for Advanced Transit and Highways” (PATH) was founded [Shl07]. Since then, several countries initiated similar projects: for example, Japan started in 2008 the “Energy ITS Project”, where three fully automated trucks were following each other with a gap of 10 m at 80km/h [Tsu13]. The European Union founded a project “SARTRE” in cooperation with VOLVO from 2009 until 2012 and since 2013 “COMPANION”, a project in cooperation with SCANIA [RCC10; LLJ15].

These projects are ever since evolving and refined continuously. Some are already suitable for implementation, some for testing only. However, the majority of these projects are still under development and not yet implemented in real use cases.

2.3 Classification of Autonomous Driving

As illustrated in the definition, platooning approaches require some degree of automation in driving. However, not all approaches demand the same degree of automation. The latter consists of two variables: the longitudinal and lateral control [SAE16]. The degree of autonomous driving depends on the stage of development.

The interest in autonomous driving stagnated for a long time but has changed in the last years where recent developments led to enormous improvements [SUni15]. New competitors in the automotive industry, like Google [Gui11], and well-known car manufacturers, like Mercedes-Benz [ZDF+14] conduct intense research and engineering efforts on developing autonomous vehicles. However, the understanding at what point a vehicle becomes fully autonomous, differs between the approaches. Therefore, the "Society of Automated Engineers" (SAE) developed a framework for automated driving containing six different levels of automation [SAE16]. Table 2.1 focuses on the technical standard and does not provide any legal statement. The levels range from no automation to full automation, and each level requires the status of the level before plus an additional factor. The columns provide four categories: execution of steering and acceleration, which describes the control of longitudinal and lateral control; monitoring of driving environment, which indicates whether the input for movement and the surrounding traffic is from the human driver or the system itself; fall-back performance of driving task, which states whether the human or the system reacts, if it is necessary to intervene; systems capability, which provides information of how many driving modes the system is capable of. In level 0 the human driver takes complete action and is fully responsible the whole time. Level 1 adds either longitudinal or lateral control, whereas level 2 requires both. In level 3 it is required that the system gets the necessary input information of the surrounding traffic itself. To achieve level 4, the system needs to react itself (and is responsible), even if the driver does not respond (correctly) to an intervention request.

The highest level 5 is accomplished if the system is able to execute any driving manoeuvre itself. In addition, Table 2.1 compares the standards of the German and American traffic administrations, “Bundesanstalt für Straßenwesen (BASt)” and “National Highway Traffic Safety Administration (NHTSA)”, respectively, to the SAE levels.

Level	*Name of SAE level*	*Execution of steering and acceleration*	*Monitoring of driving environment*	*Fallback performance of driving task*	*System Capability*	*BASt level*	*NHTSA level*
0	No automation	Human driver	Human driver	Human driver	N / A	Driver only	0
1	Driver assistance	Human/ system	Human driver	Human driver	Some driving modes	Assisted	1
2	Partial automation	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
3	Conditional automation	System	**System**	Human driver	Some driving modes	Highly automated	3
4	High automation	System	System	**System**	Some driving modes	Fully automated	3 /4
5	Full automation	System	System	System	**All driving modes**	Fully automated	3 /4

Table 2.1: Overview of the six Levels of Autonomous Driving, based on [SAE16]

2.4 Technology for Autonomous Driving*

All platooning approaches and algorithms rely on at least partly autonomous driven vehicles. Therefore, this section explains the basics for understanding this technology. Autonomous vehicles rely on modern technology which allows them to control longitudinal and lateral movement [SAE16]. Cameras and/or radars are used to maintain gaps or follow lanes, a technique which is already available in some vehicles [ZDF+14]. In the first part, this section explains the longitudinal control mechanisms of a vehicle, whereas in the second part it illustrates the lateral control tools.

2.4.1 Longitudinal Control

The latest concept of longitudinal control – the *Cooperative Adaptive Cruise Control* (CACC) – has its origins in simple *Cruise Control* (CC) technology. Vehicles with CC get a specific velocity as input and regulate the engine and breaks automatically to maintain the given velocity [AGJ10]. Thus, the CC is able to accelerate or decelerate the engine to reach the desired speed and keep it constantly at that specific level [SAE16]. Important to note is that if the vehicle approaches another vehicle, the CC will not automatically break to avoid an accident or to maintain a safe distance between the vehicles. Hence the human driver needs to anticipate potential hazards and initiate either the breaking procedure or a lane change manoeuvre [AGJ10].

As the next development step, the *Adaptive Cruise Control* (ACC) can be recognized which also is able to regulate the distance between two vehicles. In contrast to the CC, the ACC does not only require software but also a form of sensor technology (e.g., a radar) [LDM+15] in order to function. The automation mechanism of the ACC consists of a two-step process, where first the velocity is maintained according to the manually set velocity by the driver and second the desired gap between the vehicles is constantly controlled [AGJ10]. The development of the gap control mechanism allows the vehicle to detect preceding vehicles with the built-in sensors and enables it to determine whether the gap between the vehicles is sufficiently big. Further, if the gap is too small, the velocity adoption procedure is automatically initiated [AGJ10]. This development has proven to be a key invention towards automated driving.

However, the invention of the ACC is not really sufficient for enabling platooning [PSvN+11]. For platooning, the state-of-the-art ACC has to be further developed for the following reasons: first, platooning requires complex communication tools to form or dissolve platoon formations [PSvN+11]. Second, the platoon needs to be safe at any point of time [vAvDV06]. Since the vehicles in a platoon drive at a very small distance (and, thereby, possibly violating safety requirements), the following vehicle has to be able to react in a short period of time. As humans or even the ACC are not able to react fast enough, for platooning purposes, vehicles need to react (nearly) simultaneously to the changing environment [PSvN+11]. Therefore, the ACC was extended, resulting in the CACC. In addition to the sensors, the CACC relies on V2V communication to share platoon-related information [LDM+15]. The time required to send messages is very small, so that the following vehicle can react earlier compared to sensor-based communication. CACC is easy to be implemented on top of an already existing ACC in a vehicle [PSvN+11]. Most of the platooning approaches integrate a CACC technology.

2.4.2 Lateral Control

Lateral control describes the left and right steering movements. The first attempts of lateral control were undertaken in the 1970s in Japan, where a vehicle with lateral control in addition to the existing longitudinal control was developed [Tsu13]. The system works as follows: two or more machine vision units, attached to the vehicle, scan the lane markings of the highway. To ensure lane keeping, the system uses the incoming information to decide whether the scanned distance from lane marking to vehicle is in an acceptable range [Tsu13]. If the distance between vehicle and lane marking is in the allowed range, the angle of the steering wheel remains unchanged and if the deviation is out of range, the angle will be adjusted to return to the desired range [Tsu13]. Although the optical recognition is still not perfect, lateral control sensors show impressive capabilities. For example, Tsugawa notes that the vehicle can detect lane markings under bridges or when covered with rainwater [Tsu13].

Until now science has made good progress in the autonomous control of vehicles. Still, platooning pushes for further improvement, both in lateral and longitudinal control. As demonstrated in Chapter 4, the vast majority of platooning approaches require longitudinal control for their application; over half of them require lateral control in addition.

2.5 Communication Possibilities

Within platooning, two terms describe the possibilities of communication: *inter-vehicle-communication* (IVC) [SK08, HKK09] and *vehicle-to-anything-communication* (V2X) [Lia14, Tur15]. A major research area in platoon development deals with issues, concepts and standards of communication. V2X communication has two main areas: V2V and V2I communication. The “to” between those expressions does not indicate the direction of communication, which is bi-directional in both cases [GWMY12].

The two communication forms provide the base for platoon management. V2V communication is used for any direct communication between vehicles or platoons. V2V communication is the primary requirement for platooning to function. Using V2V communication, cars, HDV, and busses can exchange information, e.g., the velocity and speed of the vehicles, which enables platoons to drive safely in close distance [Tur15].

V2I communication is used for communication between vehicles/platoons and the infrastructure. V2i provides an additional value for the platoon like traffic prediction. An example for V2I communication are road side units (RSU) [BGF+13], which are communication devices installed along the road at certain intervals. V2I communication is used for the platoon coordination itself, where data such as information about the destination of the vehicles are shared. The infrastructure aggregates data from vehicles and other information sources, processes it, and makes it available to the vehicles in the platoon. However, V2I communication has not become a standard yet. Thus, V2I communication remains very much a theoretical concept, both in terms of physical implementation and technical standard.

3 Methodology

Chapter 3 describes how the papers for building the frameworks are retrieved and how the two frameworks are constructed. The first section explains the method used for the literature review. Thereby, the concept for paper retrieval, the so called *berry picking* method, is explained. The application of this method has yielded in 158 papers, of which, after further examination, 91 have been subsequently selected for classification. The second section describes how the two frameworks are built. The 91 papers selected have been investigated in detail and an iterative process has been used to build a table containing all relevant characteristics. These characteristics were then refined to build categories. The same procedure has been run for the second framework.

3.1 Method for Literature Review

For the literature review, the method *berry picking* is used, as demonstrated by Booth (2008) [Boo08]. Herein, the researcher starts with a general inquiry of the research topic in databases. If the paper found is matching the topic, the search is refined with new keywords – new terms learned from the paper read – retrieved from the paper. The best suitable paper found – the paper that matches the topic best – is defined as the *starting paper*. The next step is called *footnote chasing* respectively *backward chaining* [Boo08]. Here the references from the starting paper are scanned for relevant literature. One limitation of this approach is that it does not constitute an explicit systematic review. Since only one paper is used as a starting point, the researcher might miss specific fields [Boo08, COM15].

To overcome this limitation, several papers have served as a starting point in this thesis. In fact, 27 papers have been used as a multiple starting set. The 27 papers have been selected by the supervisor of this thesis, who happens to be the leader of the team for platoon management at the platoon research project at the University of Mannheim. Thus, the initial set of papers can be assessed as highly relevant. Using the footnote chasing method the researcher follows up the references and footnotes in the starting paper, thereby gaining new and relevant literature.

The described method resulted in a total output of 158 papers. Among these, eight papers have not been able to be retrieved due to restricted access. Out of the remaining 150 papers, 37 papers have been identified as double counts. This results in a total of 113 papers left for reading.

After a first scan of the papers' abstracts, 22 papers have been found not suitable due to several reasons: First, if a paper does not contain the word platooning, it is classified as non-relevant. Second, if a paper shows no connection to platooning algorithms or platooning approaches it is regarded as non-relevant as well. A summary is shown in Figure 3.1.

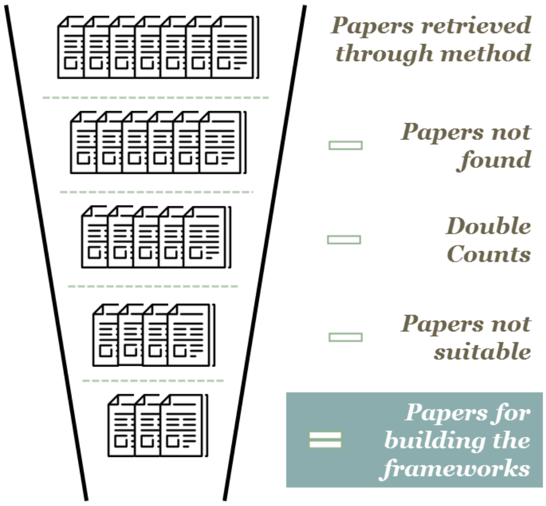

Figure 3.1: Paper Retrieval Process for Building the Frameworks

Therefore, the number of papers finally used for building the framework amount to 91. Around 50% of the papers originate from the journals *IEEE Conference Papers* and *IEEE Transactions on Intelligent Transportation Systems*. The year of publication ranges from 1966 until 2016. However, the vast majority of 94% of the papers have been published since 2000. Moreover, approximately half of the papers have been published since 2010 only.

As mentioned above, 91 papers are used to build the two frameworks. But it is important to notice that this does not indicate that 91 approaches or algorithms have been evaluated.

Some papers, e.g., papers related to the SARTRE project [Joo12, LGV15, RCC10, CGJK12], are describing basically the same approach or a similar development stage of it. Therefore, the number of retrieved papers does not exactly reflect the amount of approaches and algorithms found.

3.2 Construction of the two Frameworks

The methods used for constructing the two frameworks are represented in this section. The framework for platooning approaches has been built first out of the fact that approaches require less knowledge to understand the paper and are easier to understand compared to the more technical prospect of algorithms.

As seen in Figure 3.2.A the method for building the two frameworks is an iterative process of reading papers, retrieving criteria, and, thereby, building a foundation of the frameworks. The process starts first with reading one paper. Since every paper is examined, it is not important which paper is read first.

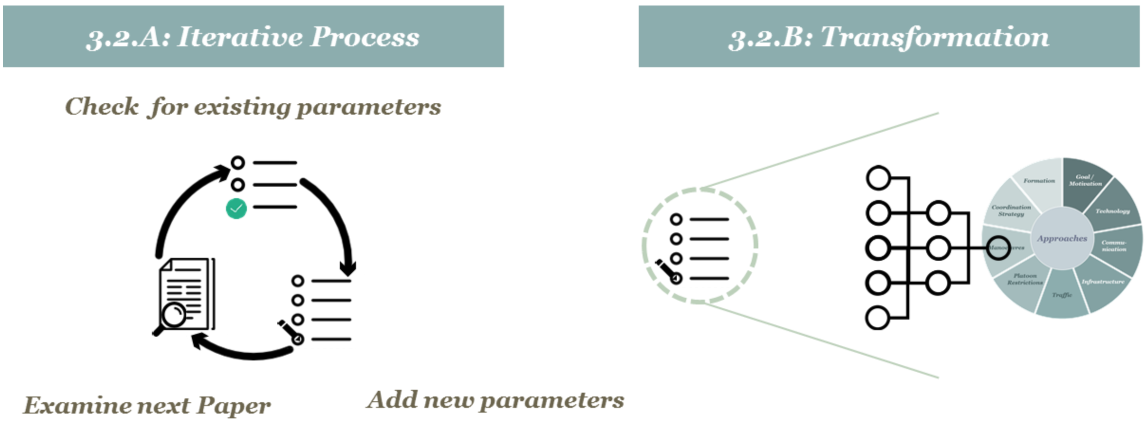

Figure 3.2: Overview for Building the two Frameworks. Figure 3.2.A displays the Iterative Process; Figure 3.2.B shows the Transformation from Characteristic into Umbrella Terms

While reading, a Microsoft Excel table is filled with information from the paper. Thereby, the paper has roughly been described, assessed for relevance in the context of this thesis and systemized into characteristics dependant on the content of the paper. As a result, the first characteristic for the development of the frameworks has evolved. Each time a new characteristic has been found, a column has been named after the characteristic in the Excel table. Whenever paper and characteristic meet, the corresponding cell in the Excel table is ticked. This indicates that the paper names this characteristic as a requirement or idea for its approach or algorithm.

The same approach is repeated for the remaining papers. Additionally, the already identified characteristics are compared to the content of each paper. Thereby, three possible cases exist: if the characteristics are the same, no new column is added. Solely the cell, in which characteristic and new paper meet, is ticked. Second, if the existing characteristic is not mentioned in the examined paper, the corresponding cell is not ticked. Third, if any new characteristics are found, a new column is inserted. Then the cell, in which the new paper and the new characteristic meet, is ticked.

Through this iterative process the related characteristics have been identified and the content of the papers has been deducted to the cells. As a result, two grids consecutively have emerged from the papers, namely one for platooning approaches and one for platooning algorithms. However, it is important to notice that not every paper which can be classified into one grid can be automatically classified into the other grid. These grids are the basis for the two frameworks.

As seen in Figure 3.2.B the basis is used for a three steps process. In step one the characteristics are summarized or transformed. The characteristics are only summarized, if they are similar to each other. Therefore, the meaning of them is analysed and, if similar, they are subsumed. Next, the characteristics are grouped into areas for the following two reasons: first, the grid is easier and more logical to read and second, important information is faster retrieved. The third step is to find an umbrella term suitable for a group of characteristics. These umbrella terms are called categories. The complete set of categories can be found in Appendix 1 and Appendix 2. Researchers can use the table provided as a starting point for obtaining an overview about the categories of existing approaches on platooning in the academic literature.

4 Framework for Platooning Approaches

This chapter describes the categories of the framework for platooning approaches. This framework represents a very high level view on platooning. As described in detail in Chapter 3, through an iterative process of reading papers and forming characteristics a grid has evolved, which serves as the basis for building the framework. These characteristics were then classified into umbrella terms called categories. Therefore, this framework consists of nine categories, each having several characteristics.

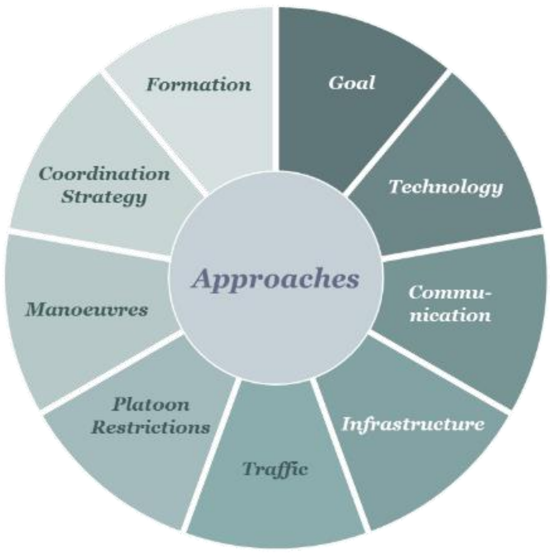

Figure 4.1: The nine Categories of the Framework for Platooning Approaches

As Figure 4.1 shows, the framework for platooning approaches consists of nine categories, each based on the grid described in the methodology part: *Goal, Technology, Communication, Infrastructure, Traffic, Platoon Restrictions, Manoeuvres, Coordination Strategy,* and *Formation.* Each of the following sections explains one category and the characteristics it can possibly adopt. Characteristics can be *mutually exclusive*, which means that they are related in such a way that each excludes the other. The evaluation of the literature allows for data statements for each category and a detailed overview of the data collection for the framework is given in the appendix (see Appendix 1).

4.1 Goal

Figure 4.2: Overview of the Category Goal

The category *Goal* describes the objective for an author or a research team to work on platooning approach. As shown in Figure 4.2, the literature review identified six goals: *driver convenience*, *traffic situation*, *safety issues*, *economic efficiency*, *development*, and *environment*. Important to notice is that not every approach mentions a goal, whereas others target several goals.

First, platooning increases the **driver convenience**. Since the invention of partly – or even fully – automated vehicles, the convenience increases steadily and the ACC is nowadays the main contributing factor to it [AGJ10]. Platooning, in turn, adds even more convenience. If vehicles drive in a platoon the driver possibly is able – always depending on the approach – to perform other activities than driving [CGJK12]. However, there are legal issues restricting this freedom for now [AGJ10, Roe13]. Another limiting factor mentioned in the literature is that platooning might stir problems with the user acceptance [Tsu13]. As many people tend to refuse new technology, this will be an issue to solve. For example, the project Energy ITS is conceived by solely relying on truck drivers, because the developers are convinced that the user acceptance by car drivers will be too low [Tsu13].

Furthermore, the concept of platooning can help to improve the current **traffic situation** [WR02]. As mentioned in the introduction, worldwide traffic increases year per year and with it traffic congestions [Sta16a]. Platooning has the ability to increase the throughput per lane and, consequently, the road capacity [Shl07]. Moreover, dependent on the increase in capacity of the lanes, the average speed rises [vAvDV06]. In some approaches the infrastructure is used to improve the prediction of traffic congestions [LMJ16]. Hence, vehicles can be redirected if necessary – e.g., due to an accident or congestion of highways during peak times. All these factors may better economize the current infrastructure instead of building larger or even multi-storeyed highways [Shl07].

Third, the highways become **safer** for the driver whilst travelling [KB05]. On the one hand, platooning can prevent accidents by enabling communication between vehicles. Due to several reasons described already in the introduction, an important cause is to mitigate the lack of skilled drivers. The threat of unskilled, tired, drunken or impaired people might be minimized under control by platooning [Tsu13, Ban01]. On the other hand, if an accident occurs, emergency responders could be notified faster, because the intelligent infrastructure could automatically call and guide the ambulance [BGF+13].

In addition to the aforementioned points, platooning reduces the **economic efficiency** originating from traffic [Eur16b]. This category finds itself often at the government level. Because of traffic management, the government is able, for example, to better predict traffic or to reduce the investment costs of the infrastructure with electronic toll collection [vNKPN12, HC05]. Better prediction models do not only ease the current situation but also enables the government to better utilize the available data. Through improved planning the infrastructure spending can be allocated better [HC05, AGJ10, Eil15, Joo12].

Fifth, platooning supports the **development** of other areas such as automated driving systems or legal matters [RCC10, Roe13, PGT+15]. The development goal of platooning is divided into scientific and commercial interests. The focus for scientists is to accelerate the development of cooperative systems and to develop the most suitable platooning system [SVJ+14, SJB+15, MLF+06, Tsu13], while the commercialization aspect concentrates besides economic matters on the legislation status of platooning. Vehicle manufacturers want to stay up-to-date with current platooning developments as they want to maintain or even increase their current market position by placing their own platooning concept as the industry standard [RCC10, LLJ15, vNKPN12].

Last but not least, the **environment** can be protected through platooning approaches [LDM+15, SDLC14, RCC10, SB15]. As already mentioned in the introduction platooning reduces fuel spending [SBJ+14, LLJ15, LDM+15, vdHJD15, Joh15, HLCD04], saves energy [HCD05, CGJK12, PSvN+11, MAB+12], and decreases CO2 pollution [LLJ15, vdHJD15, Ala11, MAB+12, LMJ13, MGVP11].

In this context, 61 (67% of the reviewed papers[2]) approaches mention traffic and safety, respectively, and 50 (55%) state the environment as their goal. The least observed goals are economic efficiency 12 and development 17. The goal driver convenience is stated by 26 approaches. An overview of the data collection can be found in Appendix 3.

4.2 Technology

As shown in Figure 4.3 the category *Technology*, incorporates two characteristics: *longitudinal control* and *lateral control* of a vehicle. Following the description in Section 2.4, **longitudinal control** describes automated acceleration [MSH08, Bas07, BDH09, WR02, vAvDV06, BDSH08], breaking and distance keeping, whereas **lateral control** is required [JKRH11, Tsu13, AGM15, BF00] if the approach needs automatic steering, e.g., for taking-over manoeuvres. These two characteristics are not mutually exclusive to each other.

The majority of the approaches use longitudinal control, 88 papers (97%) as a requirement and about 50% of them need lateral control in order to work (39). An overview of the data collection can be found in Appendix 4.

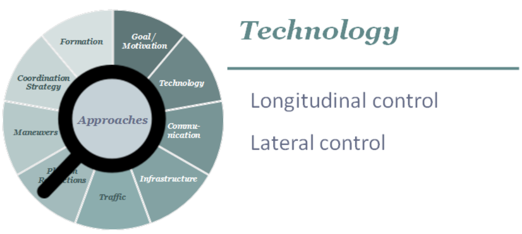

Figure 4.3: Overview of the Category Technology

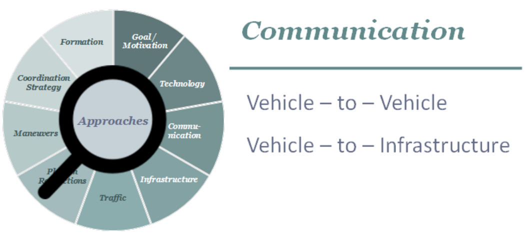

Figure 4.4: Overview of the Category Communication

[2] All percentage numbers that indicate the amount of papers that use a specific characteristic are provided in terms of percentage of the reviewed papers.

4.3 Communication

The category C*ommunication* describes the communication settings and requirements in an approach. As described in section 2.5 communication comprises two main areas, the reason why the category can take two characteristics: V2V and V2I (as seen in Figure 4.4). V2V is the communication between vehicles and platoons, whereas V2I describes any communication between vehicles or platoons and the infrastructure. In most cases the communication is bi-directional [MLF+06]. However, for simplicity reasons, these characteristics should only be seen as indicators whether the approach uses V2V or V2I communication at all. These two characteristics are not mutually exclusive.

An approach requires **V2I** if any kind of infrastructure must communicate with the vehicle [PGB+15, SJB+15, AH97, vdHJD15, HC05]. This, for example, can be achieved through RSUs [BGF+13]. V2I communication is mostly used for route calculation [SB15] and platoon management [BF00].

V2V is the communication between vehicles and platoons [SDLC14, PBG+15, SJB+15, Seg16, PMM15, LHW12]. But V2V communication does not only include communication between platoons and vehicles but also the communication within a platoon. With respect to evaluation purposes of the framework the frequency of messages is a decisive factor [MLF+06]. Too many messages may create a bottleneck, whereas too few messages may contain a safety risk [MLF+06].

Nearly every approach relies on V2V communication (87) and about half (51) of the approaches are based on V2I communication. An overview of the data collection can be found in Appendix 5.

4.4 Infrastructure

The category *Infrastructure* examines the requirements the approach demands regarding the infrastructure. Depending on the approach, it is determined whether the current infrastructure is suitable or changes have to be made. The change is either of technical or of physical nature. Figure 4.5 displays three characteristics that can possibly be achieved: *no adjustments*, *technical adjustments*, and *physical adjustments*. In contrast to the other categories before, the characteristic no adjustments is mutually exclusive. The other two characteristics can be used at the same time.

Physical adjustments are required if, first, the approach states any physical changes as necessary and, second, if the current infrastructure does not meet these specifications. For example, some approaches require dedicated lanes for platooning which is a physical adjustment [AH97, HC05, Shl07, TJP98]. Another interesting point is the dependency between V2I communication and physical adjustments. Some approaches require RSUs for their communication to work [PGT+15, BGF+13, PF09, LWH11, MGVP11]. This demands a physical adjustment.

The characteristic **technical adjustments** describes any infrastructure that needs to be adjusted (upgraded) to provide communication capabilities [LMJ13, MAB+12, JKRH11, NGGdP08, LTSH04, HKK09]. These include both infrastructure communicating with vehicles and infrastructure communicating with other infrastructure. Route calculation, traffic prediction or formations in the far distance are only some examples which require a communicating infrastructure [SBJ+14, LLJ15, LDM+15, LMJ16, JOH15, SSŠ00]. These approaches, however, might require a back-office installation in order for V2I communication to function [BHB10, LTSH04, JKRH11].

The characteristic **no adjustments** contains that the approach does not require any changes to the current infrastructure [SBJ+14, SDLC14, SKC04]. The statement of some authors that their platooning approaches need no adjustment of the current infrastructure must be seen critically. First, it is often misleadingly assumed that, if no physical adjustment is required, no adjustments will be necessary at all. However, if an approach uses V2I communication, it will be a strong indication for technical adjustments, although the author might state the opposite. Second, the approaches originate from different countries. Some authors judge the infrastructure condition of the country in which they conduct research as a given standard. Since each country has a different development status in traffic infrastructure, adjustments might be necessary for some countries.

The characteristics technical adjustments and physical adjustments are used by 49 (54%) and 32 (35%) approaches, respectively. Only 25% of the approaches do not require any adjustment (23). As it shows, the characteristics for technical adjustment and physical adjustments (in terms of RSUs) are highly dependent on the characteristic V2I to be required. Since about half of the approaches rely on V2I communication, they demand technical and physical adjustments. An overview of the data collection is provided in Appendix 6.

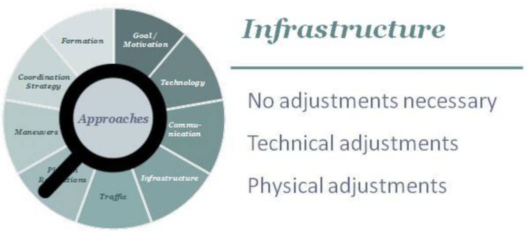

Figure 4.5: Overview of the Category Infrastructure

Figure 4.6: Overview of the Category Traffic

4.5 Traffic

Traffic as a category indicates, whether the approach restricts the surrounding traffic to special vehicles, i.e. whether the platoon able to drive in a normal environment or are there any restrictions regarding the vehicles using the highway. Therefore, traffic contains three characteristics: s*pecial vehicle typ*e, *automation degree*, and *no restrictions*, as presented in Figure 4.6. Like the category infrastructure, the characteristic no restrictions is mutually exclusive, whereas the other two characteristics can be used simultaneously.

Some approaches require the traffic to allow for only one **special vehicle type**: cars, trucks or busses [Swa97, HV00, Shl07]. For example, the PATH project approach allows only an environment with other cars [AH97, Swa97, BMR04, HGHV16]. Other approaches demand a specific **automation degree** of the vehicles surrounding the platoon [Swa97, LTSH04, TJP98]. Again, the PATH project can only comprise fully automated vehicles [BMR04]. If the platoon is allowed to contain different vehicle types at different automated degrees, it will have **no restrictions** regarding the surrounding traffic [LMJ14, Lia14, TBJ15, HC96, SSŠ00, HCCDV13, Tur15].

Most of the papers do not state any restrictions on traffic (72). 5 papers demand special vehicle type requirements and 9 papers a specific automation degree (see Appendix 7).

4.6 Platoon Restrictions

The term *Platoon Restrictions* indicates, what requirements the joining vehicle needs to fulfil. Since not every car is allowed or potentially able to join a platoon, there exist several restrictions. Therefore, the platoon restriction category can take five possible characteristics: *heterogeneous autonomous platoon (HETAP), heterogeneous vehicle type platoon (HEVEP), homogenous autonomous platoon (HOMAP), homogenous vehicle type platoon (HOVEP)*, and *lead vehicle specifications* (as presented in Figure 4.7). As the names indicate, the occurrence of HETAP and HOMAP are mutually exclusive, as well as the occurrence of HEVEP and HOVEP. All other combinations are not mutually exclusive and may potentially occur.

The characteristic **HOMAP** expresses that all vehicles in or joining a platoon have the same degrees of automation (see Section 2.3). Degree of automation in this context means which standard of longitudinal and lateral control the vehicles feature [Roe13, BDSH08, AGM15, TKA11]. In contrast to HOMAP, **HETAP** allows vehicles in the platoon to have a different degree of automation, thus enabling vehicles to join the platoon independently from their automation or potential over-qualification (in case the approach requires a lower standard) [BDSHP11, vNKPN12, SSV+15]. This does not include any special conditions for the lead vehicle, which are illustrated in a separate characteristic.

The **HOVEP** restriction indicates that the platooning approach permits only one specified vehicle type in or joining the platoon: car, truck or bus [Tur15, Lia14, LMJ14, AGJT14, ZNY+14]. The COMPANION project, for example, only allows HDVs to participate in the platoon [PGB+15, SB15, PMM15]. According to the reviewed literature those approaches tolerating only one vehicle type are predominantly HDV-only platooning concepts [LKLJ13, ZNY+14, vNKPN12]. The characteristic **HEVEP,** in contrast, indicates that every type of vehicle is allowed in a platoon [BDSHP11, KD04, AGJ10, AGJT14]. This does not apply to the categories of the lead vehicle. It only indicates the requirements for the rest of the platoon, which is allowed to be heterogeneous.

The characteristic **lead vehicle specification** defines that an approach requires special conditions applying to the lead vehicle. The rest of the platoon is described by the four characteristics HOMAP, HETAP, HOVEP and HEVEP. The SARTRE project is a good example for an approach with special requirements for the lead vehicle [RCC10]. In this project, the lead vehicle has to be an HDV or a bus – it is not allowed to be a car – and has to be driven manually [CGJK12]. However, the rest of the platoon can consist of any vehicle type but must share the same minimum degree of automation. Another information provided by this characteristic is the indication whether the platoon leader assumes any communication tasks. Some approaches require the lead vehicle to adopt the role as a communication representative. This includes communicating with other cars, platoons or the infrastructure, concurrently distributing the information to its platoon members [BGF+13, RCC10]. If any of these cases discussed above is valid, the characteristic for lead vehicle specification is assessed as valid for the observed platoon approach [Joo12, LWH11, BHB10, HCD05].

Although the characteristic HOMAP is more common (39), still some approaches consider HETAP as a more convincing concept (14). The observation for the HOVEP (39) and HEVEP (37) requirement characteristic seem to be evenly distributed. Solely eight papers state lead vehicle specifications. An overview of the data collection can be found in Appendix 8.

Figure 4.7: Overview of the Category Platoon Restrictions

Figure 4.8: Overview of the Category Manoeuvres

4.7 Manoeuvres

The category *Manoeuvres* describes the potential movements a platoon can undertake within an approach. Due to the fact that some authors do not mention the possible manoeuvres explicitly, many observations for this category remain blank, which, however, does not mean that the platoon is not able to engage in any manoeuvre. The term Manoeuvres comprises seven characteristics: *join, maintain, pass, leave, split, emergency,* and *manual override* (see Figure 4.8). These characteristics are neither dependent on each other nor mutually exclusive. If the literature of any of the approaches describes a specific manoeuvre, and, if any of the manoeuvres is described in the approach, it is indicating the related characteristic.

The characteristic **join** refers to the movement of a vehicle joining a platoon [Lia14, LMJ14, HB13]. Typically, a join manoeuvre consists of two parts. In the first part, the vehicles ask for permission to join the platoon, in the second part, permission is granted. If a vehicle is already part of a platoon and wants to keep up with its position, the manoeuvre is called **maintain** [TKT01, HDLBM03, AGJ10]. Very few approaches describe the **pass** manoeuvre, which allows the platoon to overtake another vehicle or platoon [TKT01, Joo12, DCH07]. The manoeuvre **leave** is equal to a car exiting the platoon [MAB+12, Eil15, BHB10]. Although the movement **split** shares similarities with leave, it cannot be considered as the equivalent to it [HLCD04, SDLC14, LTSH04]. Alike leave, the vehicle separates itself from the platoon. However, the vehicle has subsequently the aim to remerge with the platoon again. This is of interest for emergency cases or for unforeseen events. For example, if a non-platoon member intrudes the platoon and forces the platoon to split (not to leave), the latter can re-join as soon as the intruder leaves the gap. The term **emergency** indicates whether the platoon can react to unforeseen and possibly hazardous events, e.g., active emergency braking and hand- over of the control to the human driver [PGB+15, RCC10, HL08]. The approach **manual override** examines whether the platoon is able to react to human driver interventions by the platoon members [CGJK12, BHB10, JKRH11]. For instance, a human platoon driver tries to brake in order to increase the gap. Although this represents an unforeseen non-platoon movement, the vehicle behind is enabled to react and to split from the platoon as the inner spacing of the platoon is too close to maintain with a non-platooning vehicle.

37 (41%) approaches consider the join manoeuvre, around 33 the maintain manoeuvre. Pass, leave, and split are considered by 11, 20 and 17 approaches, respectively. Only few papers consider an emergency (5) or a manual override (4). An overview of the data collection can be found in Appendix 9.

4.8 Coordination Strategy

The term C*oordination Strategy* describes in which way one or several platoons are coordinated. The terms platoon coordination and platoon control both are important to understand this category. Their definitions can be found in Section 2.1. Depending on the strategy, the mechanism of platoon coordination and platoon control is either *decentralized*, *centralized*, or a *hybrid* of both characteristics, as shown in Figure 4.9. Each of the characteristics is mutually exclusive.

The characteristic **decentralized** means that the approach coordinates platoon formation on a local level [Swa97, CGJK12, HL08]. The local level varies from a few kilometres to roughly a 50km radius, however, the range changes from approach to approach. Both, the platoon coordination and platoon control are executed on the local level. This implies that vehicles have to find a suitable platoon by using instruments available to and surrounding them: their own on-board technology, other platoon-guided vehicles, and the communication infrastructure if existing [ELB06, KFAN08, Roe13].

C**entralized** describes approaches coordinating a platoon formation on a global, that is non-local, level. Global means at least a city to city distance, in most cases the author aims to achieve a countrywide level [RCC10]. Both, platoon coordination and control are, therefore, executed on a global level. In these approaches, vehicles are assigned to a platoon without selecting the suitable platoons themselves [HC05, BGF+13, LMJ14]. A back office solves the problem of finding the optimal platoon. For a centralized approach the platoon control (e.g., maintain the correct spacing) needs to be centralized as well, executed by a supervising system.

The characteristic **hybrid** is a mixture of the centralized and decentralized coordination strategy. Thereby, the platoon coordination is executed on a global level, whereas platoon control is performed on a local level [LGV15, LWH11, MSH08]. In addition, approaches using platoon coordination at the centralized level (including all centralized strategies) are capable to use traffic predictions and are able to calculate alternative routes [BDH09]. However, not all hybrid or centralized approaches make use of the foregoing.

The used coordination strategy is highly dependent (and mutually dependent) on communication and infrastructure, for two reasons: First, even a decentralized approach requires V2V communication. Second, a hybrid and/or a centralized coordination requires a communicating infrastructure such as a back office in order to function. Thus, the category coordination strategy is highly dependent on the category infrastructure, since V2I communication always needs at least technical adjustments. Using a hybrid strategy is the most frequently-used option for platoon coordination approaches (37). About 30 papers use decentralized coordination, whereas only 3 approaches consider centralized coordination (see Appendix 10 for the data collection).

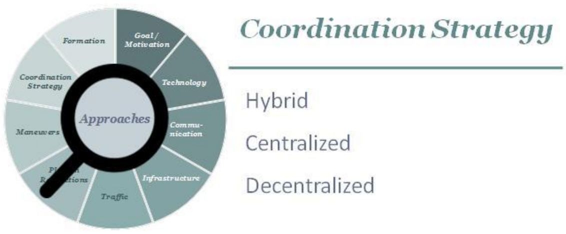

Figure 4.9: Overview of the Category Coordination Strategy

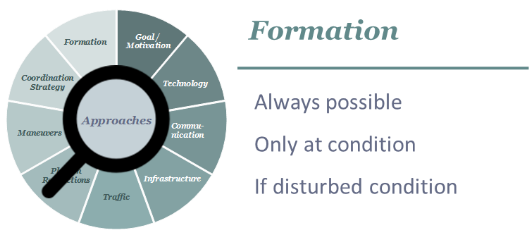

Figure 4.10: Overview of the Category Formation

4.9 Formation

The category *Formation* indicates, at which point of time a platoon is allowed to be formed. Formation does not indicate by which particular criteria, e.g., by destination, a platoon is formed. Instead, it examines whether an approach restricts platoon formation to specific locations and time. Figure 4.10 shows the category assuming three possible characteristics: *only at condition, if disturbed condition,* and *always possible*. Always possible is mutually exclusive with the other conditions, whereas the other two conditions can be required at the same time. Two expressions are helpful to understand: first-time-formation and second-time-formation. First-time-formation signifies that the vehicles form a platoon for the first time. Second-time-formation indicates that the vehicles have formatted a platoon before, have been forced to split and now aim to remerge again.

The **only at condition** embodies whether an approach limits the action of the first-time-formation to a condition precedent. Thereby, o*nly at* gives evidence that the formation is only possible if the vehicles are to be found at a specific location. The characteristic for this category is only used, if an approach states or logically indicates such limitations [LTSH04, HC05, PGB+15]. A popular example is the COMPANION approach, where trucks are allowed to form a platoon at highway intersections only [LLJ15].

The **if disturbed condition** only has relevance for second-time-formation. It answers the question, whether a platoon is able to re-join anywhere, possibly after being forced to split. This characteristic is considered only if the approach does either not allow a second-time-formation or restricts it to a specific condition except a location; see *only at* condition described before. Hall and Chin for example explain an approach, where vehicles form platoons only at highway ramps (*only at* condition fulfilled) [HC05]. If a platoon is forced to split, there is no possibility of re-joining (*if disturbed* condition fulfilled) whereas COMPANION allows merging at a specific place only (*only at* condition fulfilled), but vehicles can re-merge as soon as re-joining is possible (*if disturbed* condition not fulfilled) [LLJ15].

The condition **always possible** is valid, if any kind of formation is not restricted at all. This indicates that first-time- and second-time-formation is possible at any time at any location [KD04, AGJ10, AGJT14, ZNY+14, vNKPN12, Tur15].

75% of the approaches do not express any restriction, therefore, the characteristic always possible is used by 68 papers. Eight approaches express an only at condition, whereas only one paper shows an if disturbed condition (please refer to Appendix 11 for the data collection)

5 Framework for Platooning Algorithms

This chapter describes the categories of the framework for platooning algorithms. As presented in Section 2.1, this framework provides a more detailed and more technical view on platooning.

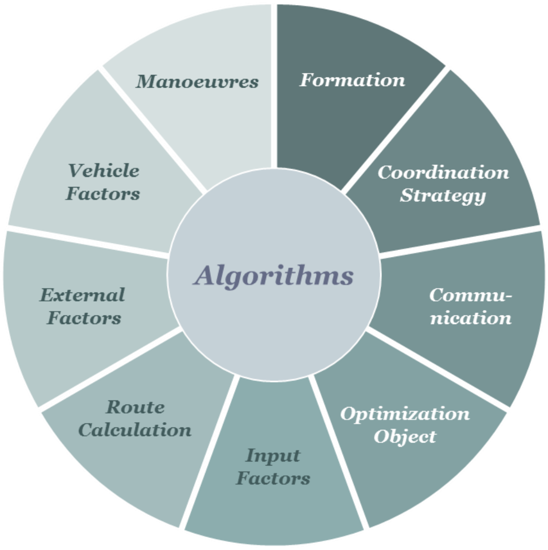

Figure 5.1: The nine Categories of the Framework for Platooning Algorithms

As Figure 5.1 shows, the framework for platooning algorithms consists of nine categories, which are created based on the methodology described in Chapter 3. These nine categories are *formation, coordination strategy, communication, optimization object, input factors, route calculation, external factors, vehicle factors,* and *manoeuvres*. Similar to the previous chapter, in the following each section of this chapter explains one category and the characteristics it can possibly assume. Again, these characteristics are either (mutually) exclusive or not. The evaluation of the relevant papers allows for data statements for each category. An overview of the data evaluation is provided in the appendix (see Appendix 2).

This framework also has categories that serve as connectors between the two frameworks. Although an algorithm might be explicitly applied to one approach, it may – under the right environment – also be suitable for another approach. Therefore, the three critical restriction categories (formation, coordination strategy, and communication) are defined as connectors between the two frameworks.

5.1 Formation

As explained in Chapter 4, the category *Formation* describes how the platoon is formed. As Figure 5.2 shows, the category formation has three characteristics, namely *approach formation restriction, unilateral formation,* and *bilateral formation*. However, in this framework the category works on two levels. On the first level, it serves as a connector between the framework for platooning algorithms and the framework for platooning approaches. To indicate possible restrictions, the characteristic *approach formation restriction* is used. On the second level, two characteristics are added to demonstrate a more detailed perspective of the formation category.

As indicated above, the characteristic **approach formation restriction** describes whether any formation restrictions are stated by an approach (see Section 4.9) [[LTSH04, HC05, PGB+15, LLJ15]. If that is the case, this characteristic shows that the approach carries restrictions regarding formation. Possible restrictions are important information, as they narrow down the scope the algorithm can act within. This, in turn, is essential to find suitable matches between algorithms and approaches.

The characteristic **unilateral formation** indicates that only one vehicle takes action to build a platoon. This means that some algorithms form platoons by only one vehicle creating (or joining) the platoon, e.g., through accelerating to meet other vehicles at the next intersection [NGGP08, LMJ13]. In contrast to that, the characteristic **bilateral formation** means that at least two vehicles take action for building a platoon [LTSH04, Joo12, HB13].

Only few papers consider formation on the level of algorithms at all. 9 papers express an approach formation restriction (10%). 7 papers form platoons through unilateral formation, and 10 papers arrange platoons through bilateral formation (11%). An overview of the data collection for the category formation at the level of algorithms is presented in Appendix 12.

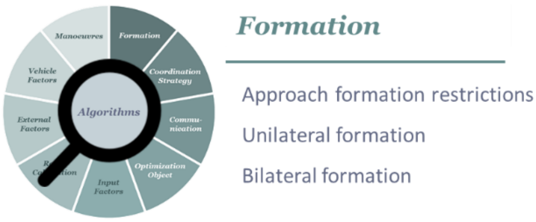

Figure 5.2: Overview of the Category Formation

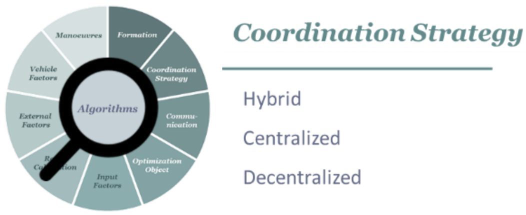

Figure 5.3: Overview of the Category Coordination Strategy

5.2 Coordination Strategy

Similar to the formation category, *Coordination Strategy* constitutes a connection factor between the approaches framework and the algorithm framework, as it represents an essential variable for the scope within the algorithms are able to work. The idea behind is that an algorithm can serve either for platoon coordination or for platoon control, thus affecting both levels of the coordination strategy. Therefore, this connection provides a better understanding whether algorithm and approach are suitable for each other. The coordination strategy category has exactly the same characteristics with the same meaning as in the framework for platooning approaches (see Figure 5.3 for an overview). The most used characteristic at the level of algorithms is the hybrid coordination strategy (37). The majority of hybrid coordination strategies use the *team agent architecture* [HCD05, Ala11], where several layers take over or assign different roles to a vehicle called agent. The characteristic decentralized is considered 29 times and centralized 3 times (see Appendix 13 for the data collection).

5.3 Communication

Identical to the other two categories before, *Communication* works as a connector between two frameworks. As explained in Chapter 4, the category can potentially assume two characteristics: V2V and V2I communication (see Figure 5.4). This category is chosen as a connector, because the other two connection factors, formation and coordination strategy, are dependent on the category communication. Another reason is that several categories in the framework for platooning algorithms depend on the communication category. Therefore, it is necessary to check for communication requirements to find out whether an algorithm is suitable for a specific approach. For example, if an approach provides for V2V but not for V2I communication, an algorithm is only suitable if it requires no information based on V2I communication. 87 algorithms require V2V, 51 algorithms require V2I communication (refer to Appendix 14 for the data collection).

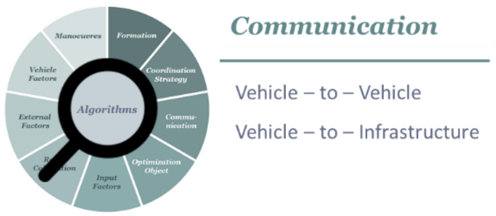

Figure 5.4: Overview of the Category Communication

Figure 5.5: Overview of the Category Optimization Object

5.4 Optimization Object

The category *Optimization Object* describes by means of which variable the algorithm maximizes or minimizes the outcome. Depending on the type of algorithm, the category optimization object can take five characteristics, which are *fuel efficiency, destination, capacity of roadway, safety,* and *fastest route*. An overview can be found in Figure 5.5. These variables are mutually exclusive, which means an algorithm cannot hold several optimization objects. However, some are used as implicit constraints.

The optimization object **fuel efficiency** describes algorithms that minimize the vehicles' fuel consumption [Joh15, SB15]. Due to reduced air drag (as explained in Chapter 1) platoons are able to reduce their fuel consumptions and, thereby, save fuel. Algorithms that aim for fuel efficiency calculate, therefore, whether it is fuel-efficient to build or to catch up with a platoon [LMJ16, Ala11]. If the amount of fuel used to build the platoon is smaller than the positive effect on fuel consumption gained through platooning, the algorithm initiates the join manoeuvre. Nevertheless, in many cases this characteristic may be impeded by (too long) detours [vdHJD15, AGJ10]. Although in some cases the algorithm would initiate platooning for reasons of fuel efficiency, the constraint does not allow platooning as the detour either has to be kept shorter than possible or equal to zero.

The characteristic **destination** illustrates algorithms that build platoons depending on the destinations [LKLJ13]. Arranging by destination does not necessarily implicit that vehicles are grouped only if they have the same destination [HC05]. It can also refer to the gathering of vehicles with a similar path to their specific destination [Joo12].

The characteristic **capacity of roadway** describes algorithms that optimize the traffic flow of vehicles through platooning [LDM+15, LLJ15, HLCD04, HCD05]. For example, some algorithms adapt the speed limits to the current traffic conditions (dynamic speed limits) [BDSH08, BDH09]. In dense traffic the speed limit is reduced to prevent shockwaves, which are all too often responsible for traffic jams (as explained in Chapter 1) [TK13].

Safety as a characteristic refers to algorithms that maximize the safety of a vehicle or platoon [MLF+06, Seg16, HV00]. There are several ways to increase the safety. One way is to maintain the gaps between the vehicles sufficiently small, so that no non- platooning vehicle can intrude the platoon [RCC10, RHC+01]. Another way is to reshape the platoon, e.g., driving in parallel instead as a string. Thus, instead of splitting the platoon, it is maintained in a different form as long as the dangerous situation prevails. Once the latter is dissolved, the platoon is rearranged and the vehicles drive as a string again [GWMY12].

Fastest route as an optimization object contains algorithms, which minimize the time travelled between the starting point and the destination. Thereby a vehicle only joins platoons, if no time delay occurs [vdHJD15, MAB+12].

The most common characteristic is capacity of roadway (47). Around 25% of the literature use safety (22) and fuel efficiency (21) as their optimization object. Fastest route and destination are used by 10 and 7 papers, respectively. Please note that the data collection also adds the implicit constraints to the numbers described (see Appendix 15).

5.5 Input Factors

The category *Input Factors* describes which variables are required for the algorithm to calculate a suitable platoon. In other words, the algorithm calculates which vehicle belongs to which platoon based on the given input factors. Since not every algorithm requires the same input factors, this category has six characteristics it can take: *velocity*, *acceleration*, *destination*, *vehicle type*, *current position*, and *desired constraint* (see Figure 5.7). Neither characteristic is exclusive nor mutually dependent. Note, that, if the algorithm does not explicitly list required input factors, although input factors are obviously required, the implied characteristic is inserted.

Velocity [SBJ+14, LLJ15, SB15, Shl07] is required as an input factor if an algorithm needs information about the current speed of a vehicle, which likes to join the platoon. Similar to that, **acceleration** [Seg16, CGJK12, LDM+15] as a characteristic delineates algorithms which require the information about the acceleration power of the vehicle. The characteristic **destination** indicates whether an algorithm needs the vehicle to provide information about its final destination of the journey [Bre16, PGB+15, HC05]. Since some approaches are restricting the vehicle joining to a specific type, algorithms might require the information of the characteristic **vehicle type** depending on whether the algorithm needs to be suitable for a specific approach [LLJ15, PGB+15, SB15, PMM15]. Some algorithms require to get to know the **current position** of the vehicle in order to initiate the desired manoeuvre. [KD04, AGJ10, AGJT14, ZNY+14]. The characteristic **desired constraint** incorporates algorithms, which allow grouping after different optimization objects such as shortest route or most fuel-efficient route [AGM15, HGLC03, Bas07]. The driver can select which constraint is preferred as an input factor, e.g., the desired velocity being defined as the speed at which the driver desires to travel. This input factor is particularly useful for, but not limited to countries without speed limits like Germany. In this case the scope is wider to decide which velocity is preferred, e.g., 100 km/h or 140 km/h [BDSH08].

Depending on the requirements of the algorithm and the approach, different input factors are required. Obviously, the category input factors is highly dependent on the category optimization objects. The majority of algorithms require the characteristic current position as a basic input factor (56), followed by velocity (44) and vehicle type (39). One third considers acceleration (28) and destination (24) as input variables, whereas only 11 papers offer the characteristic desired constraint. An overview of the data collection for the category input factors can be found in Appendix 16.

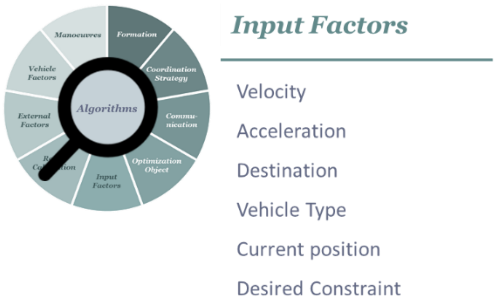

Figure 5.7: Overview of the Category Input Factors

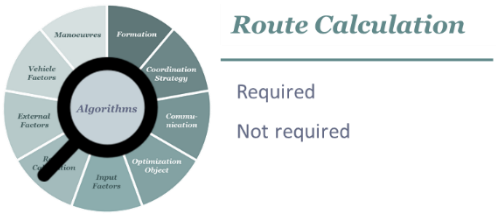

Figure 5.6: Overview of the Category Route Calculation

5.6 Route Calculation

Route Calculation as a category indicates whether an algorithm needs to determine the route for successful platooning. Figure 5.6 shows this category taking one of two characteristics: *required* or *not required*.

These two characteristics are mutually exclusive. **Required** characterizes approaches which calculate the route for the vehicles that plan to join a platoon [ELB06, KFAN08, LKLJ13, LMJ14, Lia14]. This can imply that the algorithm requires a route calculation only in the beginning which is not related to other functions like rerouting or traffic prediction. If necessary, the characteristic required is valid, otherwise the characteristic **not required** is accurate [SSV+15, TJP98, TKA11, Tsu13]. The category route calculation is highly dependent on the communication characteristic V2I. 21 algorithms use the characteristic **required**, and over 75% of them use V2I communication. For the rest of the papers (70) a route calculation is not required (please refer to Appendix 17 for the data collection).

5.7 External Factors

The category *External Factors* contains information whether an algorithm considers data about (non-constant) conditions surrounding the vehicle. Data such as road conditions can be a crucial factor for platooning. Therefore, this category has three characteristics it can take: *road conditions, weather conditions,* and *not considered*, as Figure 5.9 shows. The characteristic *not considered* is mutually exclusive to the others, which are neither exclusive nor dependent on each other.

The characteristic **road conditions** implies that algorithms require or possess information about road categories like steepness of the highway which can be an important factor for HDV platooning [LMJ16, Ala11, Tur15, Lia14]. Road conditions also can imply the comprehension of traffic signs such as speed limits or distance plates and traffic warning signals like dynamic display panels [Tsu13]. If an algorithm considers these factors, the characteristic road conditions is used. The characteristic **weather conditions** describes, whether the algorithm comprises the current weather situation in its calculation [MAB+12, AGJ10, BDSHP11]. N**ot considered** as a characteristic notifies that no examination of this factor has happened [LGV15, LWH11, MSS+14].

14 papers comprise the characteristic road conditions and 6 take weather conditions into account. Still, the majority of 76 papers do not consider external factors (see Appendix 18 for the data collection).

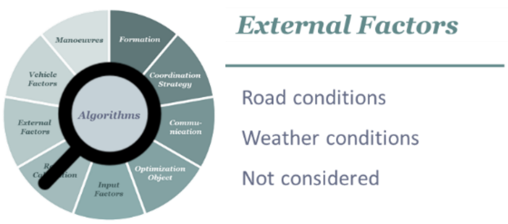

Figure 5.9: Overview of the Category External Factors

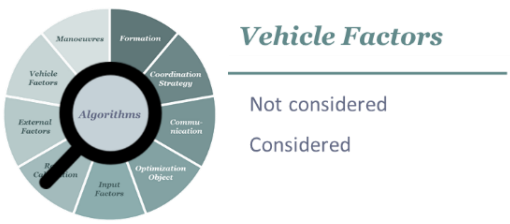

Figure 5.8: Overview of the Category Vehicle Factors

5.8 Vehicle Factors

The category *Vehicle Factors* deals with algorithms considering the specifications of a given vehicle, excluding the vehicle type. Since in reality not even vehicles within the same vehicle type are fully identical, it is a very demanding but crucial factor to examine. However, for simplicity, the category has two characteristics: *considered* and *not considered*, as Figure 5.8 illustrates. These two characteristics are mutually exclusive.

If an algorithm considers or even requires specific information about physical conditions of the vehicle the characteristic **considered** is valid [vdHJD15, LTSH04, MAB+12, LWH11]. Interesting factors like age, condition or setting of the vehicle have an immense impact on platooning in reality. For example, if an algorithm activates the vehicle's brakes, the braking distance might severely differ from the simulated characteristic, if a vehicle is affected in its braking function by its mechanical condition [Ala11]. Another exemplification refers to the load, e.g., whether an HDV is loaded or unloaded, as the mass and the stowage of the HDV have an impact on the acceleration and braking abilities [SSV15, MSH08, LDM+15]. The characteristic **not considered** indicates that the algorithm does not consider any vehicle specifications, notwithstanding the vehicle type [HC05, HLCD04, HCD05]. As mentioned before, this category is a very challenging factor to study and implement. Therefore, most algorithms do not adopt vehicle factors (81). Still, 10 algorithms discuss vehicle factors (see Appendix 19 for the data collection).

Figure 5.10: Overview of the Category Manoeuvres

5.9 Manoeuvres

As already explained in the approaches framework, the category *Manoeuvres* describes the possible actions of the platoon. The category manoeuvres in the algorithm framework has identical characteristics as in the approaches framework (see Figure 5.10). Only some algorithms directly describe or specify manoeuvres, however, this does not mean that the algorithm is restricted to a number of manoeuvres. This category is useful as a signal if an algorithm describes manoeuvres: join (36), maintain (18), pass (33), leave (19), split (12), emergency (4), and manual overrides (4). An overview of the data collection can be found in Appendix 20.

6 Discussion

This chapter is divided into two sections. First, Section 6.1 provides for a discussion of the frameworks, and second, Section 6.2 discusses the findings of the evaluation of the categories.

6.1 Discussion of the Frameworks

The worldwide traffic intensifies daily and platooning represents one concept to reduce the resulting problems. Although apparently there were vast improvements with regard to the concept of platooning, so far only few papers [BPC+12] examined the context of the classification of platooning approaches and algorithms. Therefore, this thesis is based on and researches two questions:

Research question 1: How can platooning approaches be compared and classified?

Research question 2: How can platooning algorithms be compared and classified?

158 papers were retrieved out of which two separate grids evolved. These two grids were used in the following to construct two frameworks: The framework for platooning approaches and the framework for platooning algorithms.

To answer the first research question the framework for platooning approaches has been constructed. The framework consists of nine categories, which potentially can assume two or more characteristics. These nine categories are *Goal*, *Technology*, *Communication*, *Infrastructure*, *Traffic*, *Platoon Restrictions*, *Manoeuvres*, *Coordination Strategy*, and *Formation* (as seen in Figure 4.1). This framework does not only classify the approaches but also facilitates comparing them, because every approach is examined through objective categories. Only few approaches comprise the complete set of all nine categories, whereas the majority does only partly consider the categories (e.g., the manoeuvres cate gory is not as often considered as the communication category). This might be interpreted as an indication that researchers were not aware of the full scope of approach categories which need to be analysed in order to create a competitive approach. Most of the approaches are missing details which hinder the approaches to be implemented in a real environment, e.g., approaches for HDVs that disregard the importance of vehicle factors [JKRH11, BF00, Eil15, LGV15]. Therefore, the framework can be used to better identify the shortcomings of a platooning approach. In addition, the framework shows that platooning approaches might state diverse requirements when implemented in reality. The framework also allows to determine whether a factor (for example RSU for a communicating infrastructure) is only found in a certain environment (e.g., country specific) or given all-round [BGF+13]. As some approaches might assume factors which cannot be found everywhere, the framework will be able to help developing an approach which is working in all environments.

The second research question – how platooning algorithms can be classified – is answered by the framework for algorithms. Alike the framework for approaches it consists of nine categories: *Formation*, *Coordination Strategy*, *Communication*, *Optimization Object*, *Input Factors*, *Route Calculation*, *External Factors*, *Vehicle Factors*, and *Manoeuvres* (see Figure 5.1). Again, this framework does not only has a classification but also an evaluation purpose. The categories of the framework demonstrate that the ideas for suitable algorithms are complex and diverse. That is remarkable, since only few papers contain detailed information about algorithms. This diversity within the algorithms indicates that so far no standard for requirements and categories of platooning algorithms has been established. Further, some characteristics show only "one-or-zero" indications (e.g., required and not required for the category route calculation). From that observation it can be derived that the majority of algorithms is still at an early development stage. Another interpretation of the findings is that many researchers do not clearly state which approach is suitable for which algorithm (e.g., through explicitly stating or listing the requirements for an approach). This leads to confusion and additional work to find matching pairs of algorithms and approaches.

6.2 Discussion of the Categories

In this section several categories of the two frameworks will be discussed with regard to their stage of development in research. Since the two frameworks are intertwined through several factors (Formation, Coordination Strategy, Communication and Manoeuvres) those factors will not be discussed twice.

The discussion of the categories of the framework for platooning approaches reveals interesting observations. The category Goal appears to be used especially for the traffic characteristic. Solving the current traffic problem seems to be the priority as nearly 70% of approaches state traffic as their motivation behind the research [SBJ+14]. The emergence of the goal environment seems to be connected to the increased awareness regarding environmental pollution: since 2005 the goal of the papers shifted towards environment. As the CACC seems to be the foundation of platooning [PSvN+11], it is not surprising that the majority requires longitudinal control and V2V. The latter explains the huge research interest to build a reliable standard for IVC technology [MAB+12, SJB+15, MLF+06, MBC+04]. Over a half of the approaches require V2I and with it technical adjustments. This could indicate that the implementation might take a while, because communicating infrastructure is still a concept of the future, which needs to be implemented first. Another interesting question is whether an approach is restricted regarding the category Traffic. If so, the implementation might be even more costly and difficult, because the platoon traffic has to be separated from the normal traffic [Shl07]. It appears that the majority considers this fact, as nearly four out of five approaches do not state any restrictions. Furthermore, in the category Platoon Restrictions over 40% of approaches use the HOVEP characteristic, where the majority is homogenous towards HDV platooning (over 70%). The interest into HDV platooning is explained through the automotive industry to keep up with new developments and freight transportation companies, which want to reduce the amount of fuel thus reducing the overall cost [LMJ16, AGJ10, RCC10]. Fuel consumption is still one of the biggest cost for fleet owners and is no expected to change in the future [TM14]. Another possible explanation for the interest is that the driver could use the time to work on administrative tasks. This, for example, might help saving time for loading and unloading an HDV. Another point of interest is that the join and maintain in the category Manoeuvres are the most common characteristics of the category manoeuvres. This is not surprising as these two manoeuvres seem to be the easiest to implement. Moreover, the characteristic hybrid seems to be the superior Coordination Strategy as it provides a trade-off between complexity, required input, and usage of information. Since a centralized coordination requires high computational power and the decentralized coordination only provides information in the local area instead of having foresight information, the majority of approaches prefers the hybrid strategy [LLJ15]. Most approaches using the hybrid coordination strategy apply a *team agent architecture*, where several layers take over or assign different roles to a vehicle called agent [HCD05, Ala11]. In addition, the category Formation reveals several insights: the always possible characteristic appears to work better than the two characteristics only at condition and if disturbed condition. Since platoons may be forced to split quite frequently, it appears useful if a platoon can remerge again. Therefore, the two condition characteristics might be less suitable for implementation in reality. The majority of papers provide the impression of anticipating this case.

The categories of the framework for platooning algorithms are utilized less frequently than those in the other framework. As mentioned before, this appears to be due to the early development stage of the algorithms. The category Formation on the deeper level of algorithms is considered by only 14 papers. This reveals that even the join manoeuvre is in its infancy regarding how to two vehicles merge. In addition, the category Optimization Object shows that the characteristic destination is, surprisingly, the least frequently used. This may be due to the reason that algorithms have evolved only recently and with it the focus on more advanced optimization objectives like fuel efficiency and capacity of roadway. The interest in the latter can be explained by the growing concerns regarding traffic and environmental pollution [LLJ15, vdHJD15, Ala11]. Moreover, the characteristic desired constraint, belonging to the category Input Factors, attracts only 11 papers. This shows that the algorithms are still struggling with the basic concepts, therefore having no capacity to offer more advanced ideas like desired constraints. Important to note is that the majority of algorithms did not clearly state the required input factors, thus indicating the incompleteness of some algorithms. Furthermore, the category Route Calculation needs to be evaluated critically. Although route calculation provides advantages towards the stability of the platoon and (in some cases) anticipates current traffic [LLJ15], the computational power required to calculate the route, e.g., the most fuel efficient one, seems to be very high [LMJ16]. A platooning system with thousands of participants may finally become unrealisable. Another two categories are embodied by External and Vehicle Factors. As mentioned before, these two represent an important step towards the implementation of platooning in reality. They should be seen as crucial conditions to realize platooning, as both road conditions and weather conditions, as well as technical factors of a vehicle have a huge impact on the vehicles themselves. Therefore, for a platooning algorithm to work in reality, these factors represent an important hurdle to take.

7 Conclusion

This chapter consists of three sections. Section 7.1 discusses the limitations of the methodology. Section 7.2 provides a future outlook for the field of platooning before Section 7.3 finally concludes the thesis with a summary.

7.1 Limitations

This section deals with the limitations of the methodology for retrieving the papers and building the frameworks, as well as limitations for the frameworks themselves.

One limitation of the methodology for retrieving papers used in this thesis is that relevant literate might be missed. This is due to several reasons. First, only one method was used instead of combining several. Adding another research method, like forward chaining, mitigates the risk of leaving interesting literature out of sight [Boo08]. Second, the backward chaining method uses only one paper for starting the literature search. Although the starting paper is researched well, the possibility to find all relevant areas of a topic in one paper is low [Boo08]. Therefore, in this thesis 27 papers were used as a starting point to diversify the risk. However, these 27 papers have not been examined thoroughly before starting the backward chaining method. In addition, also 27 papers can leave out an area of interest. Therefore, a small possibility of missing relevant literature remains.

One limitation can be found in the fact that the frameworks and categories rely on subjective evaluation. Therefore, it might be useful to challenge the proposed grid and frameworks in further research. Although the frameworks in this thesis rely on a thoroughly and consistently conducted review process, it might be useful to validate the two frameworks through expert interviews.

The frameworks have several limitations: First, both reflect a status quo. This means that the two frameworks are only partly capable to keep up with new developments. If, for example, a new lateral movement is invented, the framework still holds with the very general characteristic “lateral movement”. But then, if a new platooning approach wants to include electric cars, thus incurring the new constraint “lower possible travelling distance”, the framework will not be able to integrate the new characteristic. Therefore, a first limitation is the missing ability of the framework to keep track with new developments. The second constraint is the limited evaluation possibility of the frameworks. Albeit the two frameworks provide a detailed look into the completeness of an approach or algorithm, they might not be able to identify the specific part missing for the approach or algorithm to work in reality. Another limitation is the possibility of missing relevant characters or characteristics, although the literature retrieved is diverse and examined thoroughly. This could lead to incomplete frameworks, which in turn would only provide limited insight into the approaches and algorithms.

7.2 Recommendations for Future Research

The frameworks have revealed several opportunities recommended for further research. First, future research could concentrate on the discussed limitations. This includes considering other research methods for retrieving papers, e.g., taking other starting papers or using the method forward chaining [Boo08]. In addition, to overcome the problem of subjective evaluation, further research could be conducted on the validation of the proposed characteristics in the grid. Furthermore, future research could focus on further development of the frameworks, so that they can be adjusted for changes in the technology to reflect the state of the art. Another aspect which can be interesting for research is mapping the characteristics for an approach or algorithm with respect to its implementation in reality. Besides this research to overcome the limitations, the recommendations are split into two parts: the problems identified by the papers and the research gaps found in the papers whilst constructing the frameworks.

7.2.1 Identified Problems of Platooning by the Papers

Four identified problems are explained here that can be regarded as future research topics requiring further action. First, communication – despite being well researched up to now– needs further investigation as it constitutes on of the most crucial factor for platooning. Depending on the approach, the messages sent, for example, can create a bottleneck, which in turn can cover up life-saving information thereby endangering the safety of the platoon and the traffic [HLCD04]. Segata et al. (2014) have examined the topic of IVC thoroughly, stating the need of further research [SBJ+14].

Another important field of future research can be identified in the high level of security required to make vehicular communication fail-safe. If the platooning approach relies on V2I communication for implementation, the consequences of a dysfunction or a cyberattack will be perilous. Raya et al. (2006) describe the safety of communication as a topic requiring further research [RPH06].

In addition, the authors Van Nunen et al. (2012) write on the problem of stagnation regarding the implementation of platooning [vNKPN12]. While the government is waiting for the industry to develop further automatic vehicles, the automotive industry only cautiously advances the research with regard to this topic. Since the timeframe for implementation of platooning remains uncertain, the industry is not inclined to invest into that subject and requires the government to take the next step, e.g., through building a suitable infrastructure. But, alike the industry, the government does not want any misspending as well. The mutual indecision of both parties creates a vicious circle impeding the further development of platooning. A field for further valuable research could be the exploration of incentives for both governments and companies to motivate more participants to join in platooning development [vNKPN12].

7.2.2 Research Gaps revealed by the Frameworks

Several research gaps are disclosed through the frameworks: These could be the next research steps in the topic of platooning.

The first research gap is identified in the fact that there is no proposal for cost calculations for the utilization of V2I communication. Since V2I communication requires a high investment both in infrastructure and computing power, future research should examine approaches for cost estimation and possible financing solutions for V2I communication implementation. Research in this topic might advance the implementation of platooning.

The second research gap identified is that one characteristic dealing with the optimization objective has been neglected so far, namely the grouping of vehicles depending on different speed levels. As the name indicates, the algorithm solely allocates a vehicle to a platoon if their speed level – given as input from the driver – concur. In particular, this is interesting for countries, with high or no speed limits on some parts of the road infrastructure (e.g., Germany). Regarding the optimization objective and possible constraints another important goal is to build a system that incorporates the use of electric vehicles. Since electric cars need to be charged more frequently than gas-fuelled vehicles, it may put an additional constraint on platooning. It also reveals the need for an approach or algorithm that considers fuelling. All calculations not taking into account the recharging/refuelling will become somehow invalid, if a vehicle is forced to leave the platoon for that reason before arriving at the destination off-ramp. This leads to the conclusion that literature has not researched enough optimization objects and possible constraints yet. A solution could be to map all driving modes or driver's behaviour as well as the limitations of vehicles (e.g., braking functions or the size of the tank).

A third possible research gap can be imagined more as a recommendation. The grade of restrictions for traffic is an interesting topic. Whereas longitudinal control becomes almost the norm, lateral control is still more difficult to achieve and, therefore, more expensive for potential buyers. Since half of the approaches require lateral control, only a fraction of the population will be able to pay for participating in platooning. The majority of the population, however, should then be enabled to use highways without the restriction to use platooning. The other reason is that motorcycles or other earthbound vehicle designs might never be automated (due to their structural constraints or the reason they are bought for) no matter how fast the development of automatic cars, trucks, and busses will proceed. This implies that there is always a fraction of traffic not capable to platoon. Interestingly, the relevant literature does not consider this dependency. Therefore, it might be interesting to research the impact of the category traffic on traffic participants.

Moreover, another field of research should be the evaluation of the advantages due to the air drag. Bonnet and Fritz (2000) note that the lead vehicle in a platoon saves significantly less fuel compared to the following vehicles [BF00]. However, the vehicles should not change position in order to distribute the fuel savings evenly among the platoon, because every change in the position of the vehicle leads to more fuel consumption and less utilization of the air drag effect. This situation even worsens with more traffic, as the platoon needs more time to rebuild again. A solution for this problem could be an incentive system, where the lead vehicle is paid a settlement (e.g., in credits or money). Such an incentive system is not considered by literature yet. However, it is a very important topic to examine, because it may be difficult to find a lead vehicle, if no form of incentive is provided.

7.3 Summary

Three major conclusions can be drawn from this thesis: first, both frameworks provide valuable insights into the development status of platooning approaches and algorithms even though some have a high level of development whereas others lack such development like vehicle factors. The insights of this thesis want to help to overcome most of the limitations of approaches and algorithms and to further develop platooning itself. Second, as multifaceted as the frameworks are, as diverse are the approaches and algorithms. Although this might be a sign of low interdependence, it also may demonstrate the multiplicity of possibilities. Consequently, the next step should be to improve the most promising proposals and to concentrate on further developing their cooperation abilities. Third, the frameworks reveal research gaps which request further analysis of characteristics missing and of a realistic and well-adapted implementation of the platooning in the real traffic environment.

Researches can use this thesis as a basis to develop new forms of platooning approaches and algorithms. Based on the results of the thesis already existing approaches and algorithms can now be further developed and completed. Thus this thesis is an important step to bring platooning alive.

Platooning might not be ready yet, however, the two frameworks revealed both, the potential of platooning to solve societal traffic problems and the urgency to provide all necessary resources into the research of this topic.

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Appendix

Category	Characteristic	Absolute number	% of papers used
Goal	Driver Convenience	26	29%
	Traffic	61	67%
	Safety	61	67%
	Economic Efficiency	12	13%
	Development	17	19%
	Environment	50	55%
Technology	Longitudinal Control	88	97%
	Lateral Control	39	43%
Communication	V2V	87	96%
	V2I	51	56%
Infrastructure	No adjustments	23	25%
	Technical adjustments	49	54%
	Physical adjustments	32	35%
Traffic	Special vehicle type	5	5%
	Automation degree	9	10%
	No restrictions	72	79%
Platoon Restrictions	HETAP	14	15%
	HEVEP	37	41%
	HOMAP	39	43%
	HOVEP	39	43%
	Lead vehicle specifications	8	9%
Manoeuvres	Join	37	41%
	Maintain	33	36%
	Pass	11	12%
	Leave	20	22%
	Split	17	19%
	Emergency	5	5%
	Manual overrides	4	4%
Coordination Strategy	Centralized	3	3%
	Decentralized	30	33%
	Hybrid	37	41%
Formation	Only at condition	8	9%
	If disturbed condition	1	1%
	Always possible	68	75%

Appendix 1: Overview of the Data Evaluation for the Framework for Platooning Approaches

Category	Characteristic	Absolute number	% of papers used
Formation	Approach formation restrictions	9	10%
	Unilateral Formation	7	8%
	Bilateral Formation	10	11%
Coordination Strategy	Centralized	3	3%
	Decentralized	29	32%
	Hybrid	37	41%
Communication	V2V	87	96%
	V2I	51	56%
Optimization Object	Fuel Efficiency	21	23%
	Destination	7	8%
	Capacity of roadway	47	52%
	Safety	22	24%
	Fastest route	10	11%
Input Factors	Velocity	44	48%
	Acceleration	28	31%
	Destination	24	26%
	Vehicle type	39	43%
	Current position	56	62%
	Desired constraint	11	12%
Route Calculation	Required	21	23%
	Not required	70	77%
External Factors	Road conditions	14	15%
	Weather conditions	6	7%
	Not considered	76	84%
Vehicle Factors	Not considered	81	89%
	Considered	10	11%
Manoeuvres	Join	36	40%
	Maintain	18	20%
	Pass	33	36%
	Leave	19	21%
	Split	12	13%
	Emergency	4	4%
	Manual overrides	4	4%

Appendix 2: Overview of the Data Evaluation for the Framework for Platooning Algorithms

Name of Paper	1	2	3	4	5	6
[SBJ+14]		X	X		X	X
[LK13]		X	X			
[LLJ15]						X
[LDM+15]		X				X
[Bre16]		X	X			X
[SDLC14]		X	X			X
[PGB+15]		X	X			X
[SJB+15]					X	
[AH97]		X				
[vdHJD15]						X
[HC05]		X	X	X		
[HLCD04]	X	X	X			X
[HCD05]		X	X			X
[LMJ16]		X	X			X
[Joh15]	X	X	X			X
[MLF+06]			X		X	
[Ala11]		X	X			X
[RCC10]	X	X	X		X	X
[MBC+04]					X	
[SB15]						X
[Swa97]			X			
[Seg16]					X	
[PMM15]		X	X			X
[LHW12]			X			
[AGJ10]	X	X	X	X		X
[CGJK12]	X	X	X			X
[HV00]	X	X	X			X
[SUKT00]					X	
[SHL07]	X	X	X	X		
[RHC+01]			X			
[BHB10]	X	X	X			
[GWMY12]	X	X	X	X		X
[PSvN+11]		X	X			X
[HL08]	X		X			
[NGGdP08]		X	X			
[LTSH04]		X	X			
[HKK09]		X	X			
[DCH07]	X	X				X
[BMR04]						X
[MAB+12]	X	X	X		X	X
[JKRH11]	X	X	X	X		X
[Tsu13]	X	X	X	X	X	X
[LMJ13]		X				X
[ELB06]						X
[KFAN08]						X
[MSH08]	X	X	X	X		X

Name of Paper	1	2	3	4	5	6
[Bas07]		X		X		
[BDH09]		X				
[Roe13]					X	X
[WR02]		X	X			
[vAvDV06]		X				
[BDSH08]		X				
[MGVP11]		X				X
[AGM15]	X	X	X			X
[BF00]		X		X		X
[BGF+13]			X		X	
[Eil15]	X	X	X	X	X	X
[Joo12]		X	X	X		X
[LGV15]	X	X	X			X
[LWH11]		X	X			X
[MSS+14]		X	X			
[PF09]		X				
[PGT+15]	X	X	X		X	X
[RMM+02]					X	
[SSV+15]			X		X	
[TJP98]		X	X			
[TKA11]						X
[BDSHP11]		X				
[TKT01]		X	X		X	X
[HB13]			X			
[LKLJ13]		X		X		
[HGLC03]	X	X	X			X
[TKM00]	X	X	X			X
[Ban01]	X	X	X			X
[HCD04]	X	X	X			X
[HGHV16]		X				
[HdLBM03]			X			
[KD04]			X			
[AGJ10]						X
[AGJT14]			X			
[ZNY+14]	X		X			
[vNKPN12]		X	X		X	X
[SKC04]		X				
[KB05]	X	X	X			
[LMJ14]						X
[Lia14]		X	X			X
[TBJ15]			X			X
[HC96]	X		X			
[SSŠ00]			X			
[HCCdV13]		X	X			
[Tur15]		X	X			X

Appendix 3: Data Collection for the Category Goal for the Framework for Platooning Approaches

Legend: 1 = Driver Convenience, 2 = Traffic, 3 = Safety, 4 = Economic Efficiency, 5 = Development, 6 = Environment

Name of Paper	1	2
[SBJ+14]	X	
[LK13]	X	X
[LLJ15]	X	X
[LDM+15]	X	
[Bre16]	X	X
[SDLC14]	X	X
[PGB+15]	X	
[SJB+15]	X	
[AH97]	X	
[vdHJD15]	X	X
[HC05]	X	
[HLCD04]	X	X
[HCD05]	X	X
[LMJ16]	X	
[Joh15]	X	
[MLF+06]	X	
[Ala11]	X	X
[RCC10]	X	
[MBC+04]	X	
[SB15]	X	
[Swa97]	X	
[Seg16]	X	
[PMM15]	X	
[LHW12]	X	X
[AGJ10]	X	
[CGJK12]	X	X
[HV00]	X	X
[SUKT00]	X	
[SHL07]	X	
[RHC+01]	X	X
[BHB10]	X	X
[GWMY12]	X	X
[PSvN+11]	X	
[HL08]	X	X
[NGGdP08]	X	X
[LTSH04]	X	X
[HKK09]	X	X
[DCH07]	X	X
[BMR04]	X	
[MAB+12]	X	
[JKRH11]	X	X
[Tsu13]	X	X
[LMJ13]	X	
[ELB06]		
[KFAN08]		
[MSH08]	X	

Name of Paper	1	2
[Bas07]	X	X
[BDH09]	X	X
[Roe13]	X	
[WR02]	X	
[vAvDV06]	X	
[BDSH08]	X	X
[MGVP11]	X	
[AGM15]	X	X
[BF00]	X	X
[BGF+13]	X	
[Eil15]	X	
[Joo12]	X	X
[LGV15]	X	
[LWH11]	X	
[MSS+14]	X	
[PF09]	X	
[PGT+15]	X	X
[RMM+02]	X	
[SSV+15]	X	X
[TJP98]	X	X
[TKA11]	X	X
[BDSHP11]	X	
[TKT01]	X	X
[HB13]	X	
[LKLJ13]	X	
[HGLC03]	X	X
[TKM00]	X	X
[Ban01]	X	X
[HCD04]	X	X
[HGHV16]	X	X
[HdLBM03]	X	
[KD04]	X	
[AGJ10]	X	
[AGJT14]	X	
[ZNY+14]	X	
[vNKPN12]	X	
[SKC04]		
[KB05]	X	X
[LMJ14]	X	
[Lia14]	X	
[TBJ15]	X	
[HC96]	X	
[SSŠ00]	X	
[HCCdV13]	X	
[Tur15]	X	X

Appendix 4: Data Collection for the Category Technology for the Framework for Platooning Approaches

Legend: 1 = Longitudinal Control, 2 = Lateral Control

Name of Paper	1	2
[SBJ+14]	X	
[LK13]	X	X
[LLJ15]	X	X
[LDM+15]	X	
[Bre16]	X	X
[SDLC14]	X	X
[PGB+15]	X	X
[SJB+15]	X	X
[AH97]	X	
[vdHJD15]	X	X
[HC05]	X	X
[HLCD04]	X	
[HCD05]	X	
[LMJ16]	X	X
[Joh15]	X	X
[MLF+06]	X	X
[Ala11]	X	X
[RCC10]	X	X
[MBC+04]	X	X
[SB15]	X	X
[Swa97]	X	X
[Seg16]	X	X
[PMM15]	X	X
[LHW12]	X	
[AGJ10]	X	X
[CGJK12]	X	
[HV00]	X	X
[SUKT00]	X	
[SHL07]	X	X
[RHC+01]	X	
[BHB10]	X	X
[GWMY12]	X	
[PSvN+11]	X	
[HL08]	X	
[NGGdP08]	X	X
[LTSH04]	X	X
[HKK09]	X	X
[DCH07]	X	
[BMR04]	X	
[MAB+12]	X	X
[JKRH11]	X	X
[Tsu13]	X	
[LMJ13]	X	X
[ELB06]		
[KFAN08]		
[MSH08]	X	

Name of Paper	1	2
[Bas07]	X	X
[BDH09]	X	X
[Roe13]	X	
[WR02]		
[vAvDV06]	X	
[BDSH08]	X	X
[MGVP11]	X	X
[AGM15]	X	
[BF00]	X	
[BGF+13]	X	X
[Eil15]	X	X
[Joo12]	X	X
[LGV15]	X	X
[LWH11]	X	X
[MSS+14]	X	X
[PF09]	X	X
[PGT+15]	X	X
[RMM+02]	X	
[SSV+15]	X	
[TJP98]	X	
[TKA11]	X	
[BDSHP11]	X	X
[TKT01]	X	
[HB13]	X	
[LKLJ13]	X	X
[HGLC03]	X	
[TKM00]	X	
[Ban01]	X	
[HCD04]	X	
[HGHV16]	X	
[HdLBM03]	X	
[KD04]	X	
[AGJ10]	X	
[AGJT14]	X	X
[ZNY+14]	X	X
[vNKPN12]	X	X
[SKC04]		
[KB05]	X	X
[LMJ14]	X	X
[Lia14]	X	X
[TBJ15]	X	
[HC96]	X	
[SSŠ00]	X	X
[HCCdV13]	X	X
[Tur15]	X	X

Appendix 5: Data Collection for the Category Communication for the Framework for Platooning Approaches

Legend: 1 = V2V Communication 2 = V2I communication

Name of Paper	1	2	3
[SBJ+14]	X		
[LK13]		X	
[LLJ15]		X	X
[LDM+15]			
[Bre16]		X	X
[SDLC14]	X		
[PGB+15]		X	
[SJB+15]		X	X
[AH97]			X
[vdHJD15]		X	X
[HC05]		X	X
[HLCD04]			
[HCD05]	X		
[LMJ16]		X	X
[Joh15]		X	
[MLF+06]		X	
[Ala11]		X	X
[RCC10]		X	
[MBC+04]		X	
[SB15]	X		
[Swa97]		X	
[Seg16]		X	
[PMM15]		X	
[LHW12]			
[AGJ10]		X	X
[CGJK12]	X		
[HV00]		X	X
[SUKT00]	X		
[SHL07]		X	X
[RHC+01]			
[BHB10]		X	
[GWMY12]	X		
[PSvN+11]			
[HL08]	X		
[NGGdP08]		X	X
[LTSH04]		X	X
[HKK09]		X	
[DCH07]	X		
[BMR04]	X		
[MAB+12]		X	
[JKRH11]		X	
[Tsu13]			X
[LMJ13]		X	X
[ELB06]	X		
[KFAN08]	X		
[MSH08]	X		

Name of Paper	1	2	3
[Bas07]		X	X
[BDH09]		X	X
[Roe13]	X		
[WR02]			
[vAvDV06]			
[BDSH08]		X	X
[MGVP11]		X	X
[AGM15]			
[BF00]			
[BGF+13]		X	X
[Eil15]		X	X
[Joo12]		X	X
[LGV15]		X	X
[LWH11]		X	X
[MSS+14]		X	
[PF09]		X	X
[PGT+15]		X	X
[RMM+02]			
[SSV+15]	X		
[TJP98]			X
[TKA11]			
[BDSHP11]		X	X
[TKT01]	X		
[HB13]	X		
[LKLJ13]		X	
[HGLC03]			
[TKM00]			
[Ban01]			
[HCD04]			
[HGHV16]	X		
[HdLBM03]	X		
[KD04]	X		
[AGJ10]	X		
[AGJT14]		X	
[ZNY+14]		X	
[vNKPN12]		X	X
[SKC04]	X		
[KB05]		X	
[LMJ14]		X	X
[Lia14]		X	X
[TBJ15]			
[HC96]	X		
[SSŠ00]		X	
[HCCdV13]		X	
[Tur15]		X	X

Appendix 6: Data Collection for the Category Infrastructure for the Framework for Platooning Approaches

Legend: 1 = No adjustments necessary, 2 = Technical adjustments, 3 = Physical adjustments

Name of Paper	1	2	3
[SBJ+14]			X
[LK13]			X
[LLJ15]			X
[LDM+15]			X
[Bre16]			X
[SDLC14]			X
[PGB+15]			X
[SJB+15]			
[AH97]			X
[vdHJD15]			X
[HC05]			X
[HLCD04]			X
[HCD05]		X	X
[LMJ16]			X
[Joh15]			X
[MLF+06]			X
[Ala11]			X
[RCC10]			X
[MBC+04]			X
[SB15]			X
[Swa97]	X	X	
[Seg16]			X
[PMM15]			X
[LHW12]			
[AGJ10]			X
[CGJK12]			X
[HV00]	X	X	
[SUKT00]			
[SHL07]	X	X	
[RHC+01]			X
[BHB10]			X
[GWMY12]			X
[PSvN+11]			X
[HL08]			X
[NGGdP08]			X
[LTSH04]		X	
[HKK09]			X
[DCH07]			X
[BMR04]	X	X	
[MAB+12]			
[JKRH11]			X
[Tsu13]			X
[LMJ13]			X
[ELB06]			
[KFAN08]			
[MSH08]			X

Name of Paper	1	2	3
[Bas07]			X
[BDH09]			X
[Roe13]			X
[WR02]			
[vAvDV06]			
[BDSH08]			X
[MGVP11]			X
[AGM15]			
[BF00]			X
[BGF+13]			X
[Eil15]			X
[Joo12]			X
[LGV15]			X
[LWH11]			X
[MSS+14]			X
[PF09]			X
[PGT+15]			X
[RMM+02]			X
[SSV+15]			X
[TJP98]	X	X	
[TKA11]			X
[BDSHP11]			X
[TKT01]		X	
[HB13]			
[LKLJ13]			
[HGLC03]			X
[TKM00]			X
[Ban01]			X
[HCD04]			X
[HGHV16]			X
[HdLBM03]			X
[KD04]			X
[AGJ10]			X
[AGJT14]			X
[ZNY+14]			X
[vNKPN12]		X	
[SKC04]			X
[KB05]			X
[LMJ14]			X
[Lia14]			X
[TBJ15]			X
[HC96]			X
[SSŠ00]			X
[HCCdV13]			X
[Tur15]			X

Appendix 7: Data Collection for the Category Traffic for the Framework for Platooning Approaches

Legend: 1 = Special vehicle type, 2 = Automation degree, 3 = No restrictions

Name of Paper	1	2	3	4	5
[SBJ+14]		X	X		
[LK13]					
[LLJ15]			X	X	
[LDM+15]			X	X	
[Bre16]	X	X			
[SDLC14]					
[PGB+15]			X	X	
[SJB+15]	X	X			X
[AH97]			X	X	
[vdHJD15]			X	X	
[HC05]				X	
[HLCD04]		X	X		
[HCD05]		X	X		X
[LMJ16]			X	X	
[Joh15]			X	X	
[MLF+06]					
[Ala11]			X	X	
[RCC10]	X	X			X
[MBC+04]					
[SB15]			X	X	
[Swa97]			X	X	
[Seg16]	X	X			
[PMM15]			X	X	
[LHW12]					
[AGJ10]			X	X	
[CGJK12]		X	X		X
[HV00]			X	X	
[SUKT00]					
[SHL07]			X	X	
[RHC+01]					
[BHB10]		X	X		X
[GWMY12]			X	X	
[PSvN+11]					
[HL08]			X	X	
[NGGdP08]		X	X		
[LTSH04]		X	X		
[HKK09]		X			
[DCH07]	X				
[BMR04]					
[MAB+12]			X		
[JKRH11]			X	X	
[Tsu13]	X			X	
[LMJ13]				X	
[ELB06]					
[KFAN08]					
[MSH08]				X	

Name of Paper	1	2	3	4	5
[Bas07]		X			
[BDH09]		X			
[Roe13]					
[WR02]		X			
[vAvDV06]					
[BDSH08]		X	X		
[MGVP11]		X	X		
[AGM15]			X	X	
[BF00]	X			X	X
[BGF+13]	X	X			
[Eil15]			X	X	
[Joo12]	X	X			X
[LGV15]			X	X	
[LWH11]			X	X	X
[MSS+14]	X	X			
[PF09]	X	X			
[PGT+15]			X	X	
[RMM+02]					
[SSV+15]	X	X			
[TJP98]			X	X	
[TKA11]			X	X	
[BDSHP11]	X	X			
[TKT01]			X	X	
[HB13]		X			
[LKLJ13]				X	
[HGLC03]		X	X		
[TKM00]		X	X		
[Ban01]		X	X		
[HCD04]		X	X		
[HGHV16]				X	
[HdLBM03]		X			
[KD04]		X			
[AGJ10]		X			
[AGJT14]		X		X	
[ZNY+14]				X	
[vNKPN12]	X	X			
[SKC04]		X			
[KB05]		X			
[LMJ14]				X	
[Lia14]				X	
[TBJ15]				X	
[HC96]				X	
[SSŠ00]		X			
[HCCdV13]		X			
[Tur15]				X	

Appendix 8: Data Collection for the Category Platoon Restrictions for the Framework for Platooning Approaches

Legend: 1 = HETAP, 2 =HEVEP, 3 = HOMAP, 4 = HOVEP,5 = Lead vehicle specifications

Name of Paper	1	2	3	4	5	6	7
[SBJ+14]	X						
[LK13]	X			X	X		
[LLJ15]							
[LDM+15]							
[Bre16]	X		X	X	X		
[SDLC14]	X	X	X	X	X		
[PGB+15]	X		X	X	X	X	
[SJB+15]			X				
[AH97]	X	X			X		
[vdHJD15]	X		X	X			
[HC05]	X	X					
[HLCD04]	X	X		X			
[HCD05]	X	X					
[LMJ16]	X		X	X			
[Joh15]	X	X	X	X			
[MLF+06]			X				
[Ala11]	X		X				
[RCC10]	X		X	X		X	
[MBC+04]							
[SB15]							
[Swa97]			X				
[Seg16]							
[PMM15]							
[LHW12]							
[AGJ10]			X				
[CGJK12]	X		X				X
[HV00]	X						
[SUKT00]							
[SHL07]	X		X				
[RHC+01]			X				
[BHB10]	X			X			X
[GWMY12]			X!				
[PSvN+11]			X				
[HL08]					X	X	
[NGGdP08]					X		
[LTSH04]	X	X					
[HKK09]	X						
[DCH07]					X		
[BMR04]			X				
[MAB+12]	X		X	X			
[JKRH11]	X			X	X		X
[Tsu13]							
[LMJ13]							
[ELB06]							
[KFAN08]							
[MSH08]							

Name of Paper	1	2	3	4	5	6	7
[Bas07]							
[BDH09]			X				
[Roe13]							
[WR02]							
[vAvDV06]							
[BDSH08]			X				
[MGVP11]							
[AGM15]			X				
[BF00]							
[BGF+13]							
[Eil15]	X	X	X	X			
[Joo12]	X	X	X	X	X		
[LGV15]	X		X				
[LWH11]			X				
[MSS+14]							
[PF09]							
[PGT+15]	X	X				X	
[RMM+02]			X				
[SSV+15]			X				
[TJP98]							
[TKA11]							
[BDSHP11]							
[TKT01]	X	X	X	X	X		
[HB13]	X						
[LKLJ13]							
[HGLC03]	X	X		X			
[TKM00]	X	X		X			
[Ban01]	X	X		X			
[HCD04]	X	X		X			
[HGHV16]							
[HdLBM03]			X				
[KD04]			X				
[AGJ10]			X				
[AGJT14]							
[ZNY+14]			X			X	
[vNKPN12]							
[SKC04]	X						
[KB05]	X	X					
[LMJ14]	X						
[Lia14]	X						
[TBJ15]							
[HC96]	X	X		X			
[SSŠ00]							
[HCCdV13]							X
[Tur15]							

Appendix 9: Data Collection for the Category Manoeuvres for the Framework for Platooning Approaches

Legend: 1 = Join, 2 = Split, 3 = Maintain, 4 = Leave, 5 = Pass, 6 = Emergency, 7 = Manuel Overrides

Name of Paper	1	2	3
[SBJ+14]		X	
[LK13]			X
[LLJ15]			X
[LDM+15]			X
[Bre16]			X
[SDLC14]		X	
[PGB+15]			X
[SJB+15]			X
[AH97]			X
[vdHJD15]			
[HC05]	X		
[HLCD04]			X
[HCD05]			X
[LMJ16]			X
[Joh15]			X
[MLF+06]			X
[Ala11]			X
[RCC10]		X	
[MBC+04]			X
[SB15]		X	
[Swa97]		X	
[Seg16]			X
[PMM15]			X
[LHW12]			
[AGJ10]			X
[CGJK12]		X	
[HV00]			X
[SUKT00]			
[SHL07]			X
[RHC+01]		X	
[BHB10]		X	
[GWMY12]			
[PSvN+11]		X	
[HL08]		X	
[NGGdP08]			X
[LTSH04]			
[HKK09]			X
[DCH07]			X
[BMR04]			
[MAB+12]			
[JKRH11]			
[Tsu13]		X	
[LMJ13]			
[ELB06]		X	
[KFAN08]		X	
[MSH08]			X

Name of Paper	1	2	3
[Bas07]			
[BDH09]			X
[Roe13]		X	
[WR02]		X	
[vAvDV06]		X	
[BDSH08]			
[MGVP11]			X
[AGM15]			
[BF00]		X	
[BGF+13]	X		
[Eil15]			X
[Joo12]			X
[LGV15]			X
[LWH11]			X
[MSS+14]		X	
[PF09]		X	
[PGT+15]			X
[RMM+02]			
[SSV+15]			
[TJP98]		X	
[TKA11]		X	
[BDSHP11]			
[TKT01]			
[HB13]		X	
[LKLJ13]			
[HGLC03]			X
[TKM00]			X
[Ban01]			X
[HCD04]			X
[HGHV16]			
[HdLBM03]		X	
[KD04]		X	
[AGJ10]		X	
[AGJT14]			X
[ZNY+14]			X
[vNKPN12]			
[SKC04]			
[KB05]		X	
[LMJ14]	X		
[Lia14]		X	
[TBJ15]		X	
[HC96]			
[SSŠ00]		X	
[HCCdV13]		X	
[Tur15]			X

Appendix 10: Data Collection for the Category Coordination Strategy for the Framework for Platooning Approaches

Legend: 1 = Centralized, 2 = Decentralized, 3 = Hybrid

Name of Paper	1	2	3
[SBJ$^+$14]	X		
[LK13]	X		
[LLJ15]	X		
[LDM$^+$15]	X		
[Bre16]	X		
[SDLC14]	X		
[PGB$^+$15]		X	
[SJB$^+$15]	X		
[AH97]	X		X
[vdHJD15]	X		
[HC05]		X	
[HLCD04]	X		
[HCD05]	X		
[LMJ16]		X	
[Joh15]	X		
[MLF$^+$06]	X		
[Ala11]	X		
[RCC10]	X		
[MBC$^+$04]			
[SB15]	X		
[Swa97]	X		
[Seg16]	X		
[PMM15]		X	
[LHW12]			
[AGJ10]	X		
[CGJK12]	X		
[HV00]	X		
[SUKT00]			
[SHL07]			
[RHC$^+$01]	X		
[BHB10]	X		
[GWMY12]	X		
[PSvN$^+$11]			
[HL08]			
[NGGdP08]	X		
[LTSH04]		X	
[HKK09]	X		
[DCH07]	X		
[BMR04]	X		
[MAB$^+$12]	X		
[JKRH11]	X		
[Tsu13]	X		
[LMJ13]	X		
[ELB06]			
[KFAN08]			
[MSH08]		X	

Name of Paper	1	2	3
[Bas07]	X		
[BDH09]	X		
[Roe13]	X		
[WR02]			
[vAvDV06]			
[BDSH08]	X		
[MGVP11]	X		
[AGM15]	X		
[BF00]	X		
[BGF$^+$13]	X		
[Eil15]	X		
[Joo12]	X		
[LGV15]	X		
[LWH11]			
[MSS$^+$14]	X		
[PF09]			
[PGT$^+$15]		X	
[RMM$^+$02]			
[SSV$^+$15]	X		
[TJP98]	X		
[TKA11]	X		
[BDSHP11]	X		
[TKT01]	X		
[HB13]	X		
[LKLJ13]			
[HGLC03]	X		
[TKM00]	X		
[Ban01]	X		
[HCD04]	X		
[HGHV16]	X		
[HdLBM03]	X		
[KD04]	X		
[AGJ10]	X		
[AGJT14]	X		
[ZNY$^+$14]	X		
[vNKPN12]	X		
[SKC04]			
[KB05]	X		
[LMJ14]	X		
[Lia14]	X	X	
[TBJ15]	X		
[HC96]	X		
[SSŠ00]	X		
[HCCdV13]			
[Tur15]	X		

Appendix 11: Data Collection for the Category Formation for the Framework for Platooning Approaches

Legend: 1 = Always possible, 2 = Only at condition, 3 = If disturbed condition

Name of Paper	1	2	3
[SBJ+14]			X
[LK13]			
[LLJ15]			
[LDM+15]		X	X
[Bre16]			
[SDLC14]			
[PGB+15]	X		X
[SJB+15]			
[AH97]	X		
[vdHJD15]			
[HC05]	X	X	
[HLCD04]			
[HCD05]			
[LMJ16]	X		X
[Joh15]			
[MLF+06]			
[Ala11]			
[RCC10]			
[MBC+04]			
[SB15]			
[Swa97]			
[Seg16]			
[PMM15]	X		X
[LHW12]			
[AGJ10]			
[CGJK12]			
[HV00]			
[SUKT00]			
[SHL07]			
[RHC+01]			
[BHB10]			
[GWMY12]			
[PSvN+11]			
[HL08]			
[NGGdP08]		X	
[LTSH04]	X		X
[HKK09]			
[DCH07]			
[BMR04]			
[MAB+12]			
[JKRH11]			
[Tsu13]			
[LMJ13]		X	
[ELB06]			
[KFAN08]			
[MSH08]	X		

Name of Paper	1	2	3
[Bas07]			
[BDH09]			
[Roe13]			
[WR02]			
[vAvDV06]			
[BDSH08]			
[MGVP11]			
[AGM15]			
[BF00]			
[BGF+13]			
[Eil15]			
[Joo12]			X
[LGV15]			
[LWH11]			
[MSS+14]			
[PF09]			
[PGT+15]	X		
[RMM+02]			
[SSV+15]			
[TJP98]			
[TKA11]			
[BDSHP11]			
[TKT01]			
[HB13]		X	X
[LKLJ13]			
[HGLC03]			
[TKM00]			
[Ban01]			
[HCD04]			
[HGHV16]			
[HdLBM03]			
[KD04]			
[AGJ10]			X
[AGJT14]			
[ZNY+14]			
[vNKPN12]			
[SKC04]			
[KB05]			
[LMJ14]		X	X
[Lia14]	X	X	
[TBJ15]			
[HC96]			
[SSŠ00]			
[HCCdV13]			
[Tur15]			

Appendix 12: Data Collection for the Category Formation for the Framework for Platooning Algorithms

Legend: 1 = Approach formation restrictions, 2 = Unilateral formation, 3 = Bilateral formation

Name of Paper	1	2	3
[SBJ+14]		X	
[LK13]			X
[LLJ15]			X
[LDM+15]			X
[Bre16]			X
[SDLC14]		X	
[PGB+15]			X
[SJB+15]			X
[AH97]			X
[vdHJD15]			
[HC05]	X		
[HLCD04]			X
[HCD05]			X
[LMJ16]			X
[Joh15]			X
[MLF+06]			X
[Ala11]			X
[RCC10]		X	
[MBC+04]			X
[SB15]		X	
[Swa97]		X	
[Seg16]			X
[PMM15]			X
[LHW12]			
[AGJ10]			X
[CGJK12]		X	
[HV00]			X
[SUKT00]			
[SHL07]			X
[RHC+01]		X	
[BHB10]		X	
[GWMY12]			
[PSvN+11]			
[HL08]		X	
[NGGdP08]			X
[LTSH04]			
[HKK09]			X
[DCH07]			X
[BMR04]			
[MAB+12]			
[JKRH11]			
[Tsu13]		X	
[LMJ13]			
[ELB06]		X	
[KFAN08]		X	
[MSH08]			X

Name of Paper	1	2	3
[Bas07]			
[BDH09]			X
[Roe13]		X	
[WR02]		X	
[vAvDV06]		X	
[BDSH08]			
[MGVP11]			X
[AGM15]			
[BF00]		X	
[BGF+13]	X		
[Eil15]			X
[Joo12]			X
[LGV15]			X
[LWH11]			X
[MSS+14]		X	
[PF09]		X	
[PGT+15]			X
[RMM+02]			
[SSV+15]			
[TJP98]		X	
[TKA11]		X	
[BDSHP11]			
[TKT01]			
[HB13]		X	
[LKLJ13]			
[HGLC03]			X
[TKM00]			X
[Ban01]			X
[HCD04]			X
[HGHV16]			
[HdLBM03]		X	
[KD04]		X	
[AGJ10]		X	
[AGJT14]			X
[ZNY+14]			X
[vNKPN12]			
[SKC04]			
[KB05]		X	
[LMJ14]	X		
[Lia14]		X	
[TBJ15]		X	
[HC96]			
[SSŠ00]		X	
[HCCdV13]		X	
[Tur15]			X

Appendix 13: Data Collection for the Category Coordination Strategy for the Framework for Platooning Algorithms

Legend: 1 = Centralized, 2 = Decentralized, 3 = Hybrid

Name of Paper	1	2
[SBJ+14]	X	
[LK13]	X	X
[LLJ15]	X	X
[LDM+15]	X	
[Bre16]	X	X
[SDLC14]	X	X
[PGB+15]	X	X
[SJB+15]	X	X
[AH97]	X	
[vdHJD15]	X	X
[HC05]	X	X
[HLCD04]	X	
[HCD05]	X	
[LMJ16]	X	X
[Joh15]	X	X
[MLF+06]	X	X
[Ala11]	X	X
[RCC10]	X	X
[MBC+04]	X	X
[SB15]	X	X
[Swa97]	X	X
[Seg16]	X	X
[PMM15]	X	X
[LHW12]	X	
[AGJ10]	X	X
[CGJK12]	X	
[HV00]	X	X
[SUKT00]	X	
[SHL07]	X	X
[RHC+01]	X	
[BHB10]	X	X
[GWMY12]	X	
[PSvN+11]	X	
[HL08]	X	
[NGGdP08]	X	X
[LTSH04]	X	X
[HKK09]	X	X
[DCH07]	X	
[BMR04]	X	
[MAB+12]	X	X
[JKRH11]	X	X
[Tsu13]	X	
[LMJ13]	X	X
[ELB06]		
[KFAN08]		
[MSH08]	X	

Name of Paper	1	2
[Bas07]	X	X
[BDH09]	X	X
[Roe13]	X	
[WR02]		
[vAvDV06]	X	
[BDSH08]	X	X
[MGVP11]	X	X
[AGM15]	X	
[BF00]	X	
[BGF+13]	X	X
[Eil15]	X	X
[Joo12]	X	X
[LGV15]	X	X
[LWH11]	X	X
[MSS+14]	X	X
[PF09]	X	X
[PGT+15]	X	X
[RMM+02]	X	
[SSV+15]	X	
[TJP98]	X	
[TKA11]	X	
[BDSHP11]	X	X
[TKT01]	X	
[HB13]	X	
[LKLJ13]	X	X
[HGLC03]	X	
[TKM00]	X	
[Ban01]	X	
[HCD04]	X	
[HGHV16]	X	
[HdLBM03]	X	
[KD04]	X	
[AGJ10]	X	
[AGJT14]	X	X
[ZNY+14]	X	X
[vNKPN12]	X	X
[SKC04]		
[KB05]	X	X
[LMJ14]	X	X
[Lia14]	X	X
[TBJ15]	X	
[HC96]	X	
[SSŠ00]	X	X
[HCCdV13]	X	X
[Tur15]	X	X

Appendix 14: Data Collection for the Category Communication for the Framework for Platooning Algorithms

Legend: 1 = V2V communication, 2 = V2I communication

Name of Paper	1	2	3	4	5
[SBJ$^+$14]			X		
[LK13]			X		
[LLJ15]			X		
[LDM$^+$15]			X		
[Bre16]			X		
[SDLC14]			X		
[PGB$^+$15]			X		
[SJB$^+$15]			X		
[AH97]			X		
[vdHJD15]	X				X
[HC05]		X			
[HLCD04]			X		X
[HCD05]			X		X
[LMJ16]	X	X	X		X
[Joh15]	X				
[MLF$^+$06]			X	X	
[Ala11]	X				
[RCC10]				X	
[MBC$^+$04]			X		
[SB15]	X				
[Swa97]			X		
[Seg16]			X	X	
[PMM15]			X		
[LHW12]					
[AGJ10]	X				
[CGJK12]			X		
[HV00]			X	X	
[SUKT00]					
[SHL07]			X		
[RHC$^+$01]				X	
[BHB10]					
[GWMY12]				X	
[PSvN$^+$11]			X		
[HL08]			X	X	
[NGGdP08]					
[LTSH04]			X	X	
[HKK09]				X	
[DCH07]			X		
[BMR04]	X		X		
[MAB$^+$12]					X
[JKRH11]			X		
[Tsu13]	X				
[LMJ13]	X				
[ELB06]	X				
[KFAN08]	X				
[MSH08]		X	X		

Name of Paper	1	2	3	4	5
[Bas07]					
[BDH09]		X	X		
[Roe13]	X				
[WR02]			X		
[vAvDV06]			X		
[BDSH08]			X		X
[MGVP11]					
[AGM15]			X	X	
[BF00]	X			X	
[BGF$^+$13]			X	X	
[Eil15]	X		X		
[Joo12]		X			
[LGV15]	X				
[LWH11]			X		
[MSS$^+$14]			X		
[PF09]			X		
[PGT$^+$15]			X		
[RMM$^+$02]			X		
[SSV$^+$15]			X	X	
[TJP98]			X		
[TKA11]	X				
[BDSHP11]			X		
[TKT01]					
[HB13]				X	
[LKLJ13]		X			
[HGLC03]			X		X
[TKM00]			X		X
[Ban01]			X		X
[HCD04]			X		X
[HGHV16]			X		
[HdLBM03]				X	
[KD04]				X	
[AGJ10]	X				
[AGJT14]				X	
[ZNY$^+$14]				X	
[vNKPN12]					
[SKC04]					
[KB05]				X	
[LMJ14]	X				
[Lia14]	X				
[TBJ15]	X				
[HC96]				X	
[SSŠ00]				X	
[HCCdV13]				X	
[Tur15]	X				

Appendix 15: Data Collection for the Category Optimization Object for the Framework for Platooning Algorithms

Legend: 1 = Fuel efficiency, 2 = Destination, 3 = Capacity of roadway, 4 = Safety, 5 = Fastest route

Name of Paper	**1**	**2**	**3**	**4**	**5**	**6**
[SBJ+14]	X				X	
[LK13]						
[LLJ15]	X			X	X	
[LDM+15]	X	X		X	X	
[Bre16]			X		X	X
[SDLC14]						
[PGB+15]			X	X		
[SJB+15]	X	X			X	
[AH97]	X			X		
[vdHJD15]				X		
[HC05]			X	X	X	
[HLCD04]					X	X
[HCD05]					X	
[LMJ16]				X		
[Joh15]	X		X	X	X	
[MLF+06]	X		X		X	
[Ala11]			X	X	X	X
[RCC10]	X		X		X	
[MBC+04]						
[SB15]	X			X	X	
[Swa97]	X			X		
[Seg16]	X	X			X	
[PMM15]			X	X		
[LHW12]						
[AGJ10]				X	X	X
[CGJK12]	X	X			X	
[HV00]	X			X	X	
[SUKT00]						
[SHL07]	X			X	X	
[RHC+01]					X	
[BHB10]						
[GWMY12]				X		
[PSvN+11]						
[HL08]				X	X	
[NGGdP08]	X				X	
[LTSH04]	X				X	
[HKK09]	X				X	
[DCH07]	X	X			X	
[BMR04]	X					
[MAB+12]	X	X	X		X	
[JKRH11]	X			X		
[Tsu13]	X	X		X	X	
[LMJ13]				X	X	
[ELB06]	X	X	X		X	
[KFAN08]	X	X	X		X	
[MSH08]			X	X	X	

Name of Paper	**1**	**2**	**3**	**4**	**5**	**6**
[Bas07]						
[BDH09]			X		X	X
[Roe13]						
[WR02]	X	X	X		X	
[vAvDV06]	X	X			X	
[BDSH08]			X			X
[MGVP11]						
[AGM15]				X		X
[BF00]	X	X		X	X	
[BGF+13]						
[Eil15]	X	X	X	X	X	
[Joo12]	X	X	X		X	
[LGV15]	X	X	X	X	X	
[LWH11]	X			X	X	
[MSS+14]	X				X	
[PF09]						
[PGT+15]	X	X	X	X	X	
[RMM+02]	X				X	
[SSV+15]					X	
[TJP98]				X		
[TKA11]				X		
[BDSHP11]						
[TKT01]				X		
[HB13]						
[LKLJ13]			X	X		
[HGLC03]		X			X	X
[TKM00]		X			X	X
[Ban01]		X			X	X
[HCD04]		X			X	X
[HGHV16]				X		
[HdLBM03]						
[KD04]	X	X			X	
[AGJ10]	X	X			X	
[AGJT14]	X	X	X	X	X	
[ZNY+14]	X	X		X	X	
[vNKPN12]						
[SKC04]						
[KB05]	X	X			X	
[LMJ14]	X	X	X	X	X	
[Lia14]	X		X	X	X	
[TBJ15]	X	X		X	X	
[HC96]				X		
[SSŠ00]	X	X	X		X	
[HCCdV13]						
[Tur15]	X			X	X	

Appendix 16: Data Collection for the Category Input Factors for the Framework for Platooning Algorithms

Legend: 1 = Velocity, 2 = Acceleration, 3 = Destination, 4 = Vehicle type, 5 = Current position, 6 = Desired constrain

Name of Paper	1	2
[SBJ+14]	X	
[LK13]		X
[LLJ15]	X	
[LDM+15]		X
[CoIS16]		X
[SDLC14]		X
[PGB+15]	X	
[SJB+15]		X
[AH97]		X
[vdHJD15]		X
[HC05]	X	
[HLCD04]		X
[HCD05]		X
[LMJ16]		X
[Joh15]	X	
[MLF+06]		X
[Ala11]		X
[RCC10]	X	
[MBC+04]		X
[SB15]	X	
[Swa97]		X
[Seg16]		X
[PMM15]	X	
[LHW12]		X
[AGJ10]	X	
[CGJK12]	X	
[HV00]		X
[SUKT00]		X
[SHL07]		X
[RHC+01]		X
[BHB10]		X
[GWMY12]		X
[PSvN+11]		X
[HL08]		X
[NGGdP08]		X
[LTSH04]		X
[HKK09]		X
[DCH07]		X
[BMR04]		X
[MAB+12]		X
[JKRH11]		X
[Tsu13]		X
[LMJ13]		X
[ELB06]	X	
[KFAN08]	X	
[MSH08]		X

Name of Paper	1	2
[BAS07]		X
[BDH09]		X
[Roe13]		X
[WR02]		X
[vAvDV06]		X
[BDSH08]		X
[MGVP11]		X
[AGM15]		X
[BF00]		X
[BGF+13]		X
[Eil15]	X	
[Joo12]	X	
[LGV15]	X	
[LWH11]		X
[MSS+14]		X
[PF09]		X
[PGT+15]	X	
[RMM+02]		X
[SSV+15]		X
[TJP98]		X
[TKA11]		X
[BDSHP11]		X
[TKT01]		X
[HB13]		X
[LKLJ13]	X	
[HGLC03]		X
[TKM00]		X
[Ban01]		X
[HCD04]		X
[HGHV16]		X
[HdLBM03]		X
[KD04]		X
[AGJ10]		X
[AGJT14]		X
[ZNY+14]		X
[vNKPN12]		X
[SKC04]		X
[KB05]		X
[LMJ14]	X	
[Lia14]	X	
[TBJ15]	X	
[HC96]		X
[SSŠ00]		X
[HCCdV13]		X
[Tur15]	X	

Appendix 17:Data Collection for the Category Route Calculation for the Framework for Platooning Algorithms

Legend: 1 = Required, 2 = Not required

Name of Paper	1	2	3
[SBJ+14]	X		
[LK13]	X		
[LLJ15]			X
[LDM+15]	X		
[Bre16]	X		
[SDLC14]	X		
[PGB+15]	X		
[SJB+15]	X		
[AH97]	X		
[vdHJD15]			X
[HC05]	X		
[HLCD04]	X		
[HCD05]	X		
[LMJ16]			X
[Joh15]	X		
[MLF+06]	X		
[Ala11]			X
[RCC10]	X		
[MBC+04]	X		
[SB15]	X		
[Swa97]	X		
[Seg16]	X		
[PMM15]	X		
[LHW12]	X		
[AGJ10]		X	X
[CGJK12]	X		
[HV00]	X		
[SUKT00]	X		
[SHL07]	X		
[RHC+01]	X		
[BHB10]	X		
[GWMY12]			X
[PSvN+11]	X		
[HL08]	X		
[NGGdP08]	X		
[LTSH04]	X		
[HKK09]	X		
[DCH07]	X		
[BMR04]	X		
[MAB+12]		X	X
[JKRH11]	X		
[Tsu13]			X
[LMJ13]	X		
[ELB06]	X		
[KFAN08]	X		
[MSH08]			X

Name of Paper	1	2	3
[Bas07]	X		
[BDH09]	X		
[Roe13]	X		
[WR02]	X		
[vAvDV06]	X		
[BDSH08]	X		
[MGVP11]	X		
[AGM15]	X		
[BF00]	X		
[BGF+13]	X		
[Eil15]			X
[Joo12]	X		
[LGV15]	X		
[LWH11]	X		
[MSS+14]	X		
[PF09]	X		
[PGT+15]			X
[RMM+02]	X		
[SSV+15]			X
[TJP98]	X		
[TKA11]	X		
[BDSHP11]		X	
[TKT01]	X		
[HB13]	X		
[LKLJ13]	X		
[HGLC03]	X		
[TKM00]	X		
[Ban01]	X		
[HCD04]	X		
[HGHV16]	X		
[HdLBM03]	X		
[KD04]	X		
[AGJ10]	X		
[AGJT14]	X		
[ZNY+14]	X		
[vNKPN12]	X		
[SKC04]	X		
[KB05]	X		
[LMJ14]	X		
[Lia14]		X	X
[TBJ15]		X	X
[HC96]	X		
[SSŠ00]	X		
[HCCdV13]	X		
[Tur15]		X	

Appendix 18: Data Collection for the Category External Factors for the Framework for Platooning Algorithms

Legend: 1 = Not considered, 2 = Weather conditions, 3 = Road conditions

Name of Paper	1	2
[SBJ+14]	X	
[LK13]	X	
[LLJ15]	X	
[LDM+15]		X
[Bre16]	X	
[SDLC14]	X	
[PGB+15]	X	
[SJB+15]	X	
[AH97]	X	
[vdHJD15]		X
[HC05]	X	
[HLCD04]	X	
[HCD05]	X	
[LMJ16]		X
[Joh15]	X	
[MLF+06]	X	
[Ala11]		X
[RCC10]	X	
[MBC+04]	X	
[SB15]	X	
[Swa97]	X	
[Seg16]	X	
[PMM15]	X	
[LHW12]	X	
[AGJ10]	X	
[CGJK12]	X	
[HV00]	X	
[SUKT00]	X	
[SHL07]	X	
[RHC+01]	X	
[BHB10]	X	
[GWMY12]	X	
[PSvN+11]	X	
[HL08]	X	
[NGGdP08]	X	
[LTSH04]		X
[HKK09]	X	
[DCH07]	X	
[BMR04]	X	
[MAB+12]		X
[JKRH11]	X	
[Tsu13]	X	
[LMJ13]	X	
[ELB06]	X	
[KFAN08]	X	
[MSH08]		X

Name of Paper	1	2
[Bas07]	X	
[BDH09]	X	
[Roe13]	X	
[WR02]	X	
[vAvDV06]	X	
[BDSH08]	X	
[MGVP11]	X	
[AGM15]	X	
[BF00]	X	
[BGF+13]	X	
[Eil15]	X	
[Joo12]	X	
[LGV15]	X	
[LWH11]		X
[MSS+14]	X	
[PF09]	X	
[PGT+15]		X
[RMM+02]	X	
[SSV+15]		X
[TJP98]	X	
[TKA11]	X	
[BDSHP11]	X	
[TKT01]	X	
[HB13]	X	
[LKLJ13]	X	
[HGLC03]	X	
[TKM00]	X	
[Ban01]	X	
[HCD04]	X	
[HGHV16]	X	
[HdLBM03]	X	
[KD04]	X	
[AGJ10]	X	
[AGJT14]	X	
[ZNY+14]	X	
[vNKPN12]	X	
[SKC04]	X	
[KB05]	X	
[LMJ14]	X	
[Lia14]	X	
[TBJ15]	X	
[HC96]	X	
[SSŠ00]	X	
[HCCdV13]	X	
[Tur15]	X	

Appendix 19: Data Collection for the Category Vehicle Factors for the Framework for Platooning Algorithms

Legend: 1 = Not considered, 2 = Considered

Name of Paper	1	2	3	4	5	6	7
[SBJ^{+}14]			X				
[LK13]	X			X	X		
[LLJ15]							
[LDM^{+}15]							
[Bre16]	X		X	X	X		
[SDLC14]	X	X	X	X	X		
[PGB^{+}15]	X		X	X	X	X	
[SJB^{+}15]			X				
[AH97]	X	X			X		
[vdHJD15]	X		X	X			
[HC05]	X	X					
[HLCD04]	X	X		X			
[HCD05]	X	X					
[LMJ16]	X		X	X			
[Joh15]	X	X	X	X			
[MLF^{+}06]			X				
[Ala11]	X		X				
[RCC10]	X		X	X		X	
[MBC^{+}04]							
[SB15]							
[Swa97]			X				
[Seg16]							
[PMM15]							
[LHW12]							
[AGJ10]			X				
[CGJK12]	X		X				X
[HV00]	X						
[SUKT00]							
[SHL07]	X		X				
[RHC^{+}01]			X				
[BHB10]	X			X			X
[GWMY12]			X				
[PSvN^{+}11]							
[HL08]					X	X	
[NGGdP08]					X		
[LTSH04]	X	X					
[HKK09]	X						
[DCH07]					X		
[BMR04]			X				
[MAB^{+}12]	X	X	X				
[JKRH11]	X			X	X		X
[Tsu13]							
[LMJ13]							
[ELB06]							
[KFAN08]							
[MSH08]							

Name of Paper	1	2	3	4	5	6	7
[Bas07]							
[BDH09]			X				
[Roe13]							
[WR02]							
[vAvDV06]							
[BDSH08]			X				
[MGVP11]							
[AGM15]			X				
[BF00]							
[BGF^{+}13]							
[Eil15]	X	X	X	X			
[Joo12]	X	X	X	X	X		
[LGV15]	X		X				
[LWH11]			X				
[MSS^{+}14]							
[PF09]							
[PGT^{+}15]	X	X			X		
[RMM^{+}02]			X				
[SSV^{+}15]			X				
[TJP98]							
[TKA11]							
[BDSHP11]							
[TKT01]	X	X	X	X	X		
[HB13]	X						
[LKLJ13]							
[HGLC03]	X	X		X			
[TKM00]	X	X		X			
[Ban01]	X	X		X			
[HCD04]	X	X		X			
[HGHV16]							
[HdLBM03]			X				
[KD04]			X				
[AGJ10]			X				
[AGJT14]							
[ZNY^{+}14]			X			X	
[vNKPN12]							
[SKC04]	X						
[KB05]	X	X					
[LMJ14]	X						
[Lia14]	X						
[TBJ15]							
[HC96]	X	X		X			
[SSŠ00]							
[HCCdV13]							X
[Tur15]							

Appendix 20: Data Collection for the Category Manoeuvres for the Framework for Platooning Algorithms

Legend: 1 = Join, 2 = Split, 3 = Maintain, 4 = Leave, 5 = Pass, 6 = Emergency, 7 = Manual Override