Toward Green Road Freight Transportation Trends: Truck Platoon Application

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Abstract—*The place of freight transportation cannot be underestimated or disregarded in the growth of the economy as it's fast rising to a world market. A large part of the inland freight transport is evident in its use on roads. It is dynamic and relative to change as it can be subjected to changes due to the un-ending innovations of man over the coming years, as cognizance needs to the recent trends of initiatives and innovations which have led to the improvement of our technological world. The application of truck platoon in freight transportation has occasioned an introduction of integrated goods freight transportation which has optimized logistics and real-time updates about our vehicular traffic communication, collaborative driving, and autonomous vehicles. In this research work, we gave an insight into the problems in making a reality, a better and adequate movement of goods by the road system to reduce environmental issues and how we can proffer solutions with the aid of technology. We emphatically explained a medium which can increase the effectiveness of this movement scheme by truck platoon transports in order to fulfill the task on a prescribed road network.*

Keyword—Logistics; Truck Platoon; v2v, v2i Technology

1 INTRODUCTION

TRANSPORTATION is one of the key logistic functions that combine separate types of production procedures, from manufacturing to delivering products to consumers. Optimization of transport can largely determine the efficacy of the entire logistic system; the demand for mobile service is fast growing and closely related to the economic growth [1]. The movement scheme assists the general transport of people and goods. However, the mobility aspect is also accountable for the larger percentage of worlds energy & emission due to rise in the technical knowledge & global nation, then transport needs not to be underestimated in the production sector. There is, however, a quest for developing a more sustainable fuel for the transportation sector. A fast-growing improvement in technology has prompted the production of automatic vehicles with less use of fuel, cruise control and joint driving ability. We are in 21st century as a result of major technological advancement in the environment [2]. We are in an era where major advances would be introduced into the market and society over the next couple of decades. For example, vehicular communications [3, 5] enable a large set of new applications, such as collision warning and avoidance [3], automated intersections, and vehicle platooning [4,6]. Vehicular position and velocity data are readily available today [5]. For freight transportation, such data can be combined with advanced vehicle models to make decisions on fuel-optimal routes. Transport systems spanning over large geographic areas with real-time data gathering is been used for increasing efficiency and flexibility in the planning of transport assignments [7], the development of a new freight transport system architecture based on these emerging technologies poses several obstacles. One challenge is simply the overall scale of the system: in the EU there are about 2 million heavy trucks [8]. Recently, the Green transportation and sustainable freight transportation are increasingly important issues in view of rising fuel costs and environmental concerns. Although all forms of transportation contribute to greenhouse gases and congestion, trucking has the largest impact. Truck platoon technologies can be optimized for green road freight transportation to reduce environmental hazard without affecting the maximum output of the trucks.

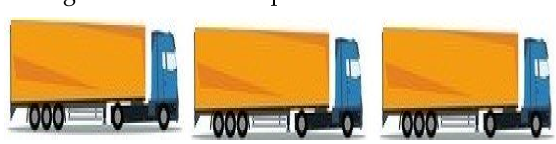

Fig1: trucks platooning

2 ENVIRONMENTAL CONCERNS

The largest source of air pollution in this world is Transportation. Pollution caused by trucks and car are responsible for immediate and long-term effects on the environment, Exhausts from car emit a large percentage of gases and solid matter which are responsible for acid rain, global warming and environmental / human health hazards. Also, Fuel spills and noise generated by Engine causes pollution. Cars, trucks and other forms of transportation are the largest contributor to air pollution in the United States, but car owners can reduce their vehicle's effects on the environment [9]

Fig2: Road fright emissions [10]

2.1 The impact of Road Freight Transport on the Environment

According to studies, road freight transport causes 57% of worldwide carbon dioxide (CO2) emissions, while additional levels come from warehousing and handling. In 1995, 22% of CO2 emissions came from the energy use (fossil energy sources) in the transport sector [37]. Road freight grew rapidly during the second half of the twentieth century, because the transport policy in many countries focused predominantly on low-cost, short and prompt ways of delivering goods, especially food, . Vehicles, even if more polluting, were considered as economical and faster modes of transport than trains (Jaroszweski, 2012). Transport, just like the growing demand for electricity, has impacted the total increase in global gas emissions in OECD countries. During the last 30 years, gas emissions have been noticed to rise more or less 1.7% per year. The average consumption of electric power and private cars in Australia, for example, accounts for about 20% of gas emissions, whereas 80% is connected with public and business services or consumer goods supply. Not only is the carbon dioxide emission is a worldwide problem in transportation. In 1996 the National Greenhouse Gas Inventory Committee published the results of non-CO2 emissions in the road sector, where it was clearly shown that medium and heavy trucks used in freight transport also produced great amounts of harmful gases such as: CH4, N2O, NOx and CO (Lenzen, Dey, Hamilton 2008). (Table 1).

Table1: Truck emissions: the constituents of air pollution and their impacts [11].

Constituents of air pollution	Impacts
Particulate matter (PM)	These particles of soot and metals give smog its mucky appearance. Fine particles (less than one-tenth the diameter of a human hair) pose more serious threat to human health, as they can penetrate deep into lungs. PM is a direct (primary) *and* indirect pollution from hydrocarbons, nitrogen oxides, and sulfur dioxides. Diesel exhaust contributes to PM pollution.
Hydrocarbons (HC)	These pollutants react with nitrogen oxides in the presence of sunlight to form ground-level ozone, a primary ingredient in smog. Though beneficial in the upper atmosphere, at the ground-level this gas irritates the respiratory system, causing coughing, choking, and reduced lung capacity.
Nitrogen oxides (NOx)	These pollutants cause lung irritation and weaken the body system defences against respiratory infections such as pneumonia and influenza. Furthermore, they assist in the formation of lower-level ozone and particulate matter.
Carbon monoxide (CO)	This odourless, colourless, and poisonous gas is caused by the combustion of fossil fuels such as gasoline and is emitted primarily from cars and trucks. When inhaled, CO blocks oxygen from the brain, heart, and other vital organs. Fetuses, newborn children, and people with chronic illnesses are especially susceptible to the effects of CO.
Sulfur dioxide (SO_2)	Power plants and motor vehicles create this pollutant by burning sulfur-containing fuels, especially diesel. Sulfur dioxide can react in the atmosphere to form fine particles and poses great health risk to young children and asthmatics.
Hazardous air pollutants (toxics)	These chemical compounds are linked to defects at birth, cancer, and other serious illnesses. The Environmental Protection Agency estimates that the air pollutants emitted from cars and trucks ; which include Benzene, acetaldehyde, and 1,3-butadiene — account for half of all cancers caused by air pollution.
Greenhouse gases	Motor vehicles also emit pollutants, such as carbon dioxide, that contribute to global climate change. In fact, cars and trucks account for over one-fifth of the United States' total global warming pollution; transportation, which includes freight, trains, and air flight, accounts for around thirty percent of all heat-trapping gas emissions.

3 GREEN FREIGHT TRANSPORT

Freight movement is responsible for 16% of all corporate greenhouse gas emissions thereby qualifies it as one of the largest contributors to carbon footprint. The emissions is gotten directly from trucks, trains, ships and planes which carry goods. Companies have the power and financial incentive to minimized their environmental impact from freight. By employing smarter logistics strategies, they can operate more efficiently and affordably [12, 20].

4 CONCEPTUAL DEFINITION OF TRUCK PLATOONING

Truck platooning refers to automatic driving of trucks in small convoys, a short distance apart, resulting in smooth traffic flow, with higher traffic safety, fuel savings and a reduction in CO2 emissions. [12] Truck platooning involves carrying out the automatic control of Truck convoys on highways. A truck in the platoon can be in one of three cases: leader mode, follower mode and free mode; free mode represents the free case where the Truck does not join to any platoon. The leader mode and the free mode are manual control, while the follower control mode is completely automatic. Each transition between these modes is one of the principal platoon supervision operations. These operations are: creating a new platoon, merging two platoons, and the truck input/output procedures are from a platoon. The follower is operated by both control systems (i.e. longitudinal and lateral control systems). A multiple-sensor system is used to provide vehicles velocity, acceleration and localization of vehicle, and also the inter-trucks spacing in the platoon. [19]. The triple measurement device is used for determining the inter-truck spacing signal: multi sensor representing as laser range-finder, a camera which is embedded and an observer, on the basis of the system dynamic equations. This redundancy makes it possible to perform sensors fault detection and identification. Furthermore, it can be exploited to increase the reliability of the follower control mode by introducing a global PS architecture that includes a data fusion level and a decision-making system. The free mode represents the case where the truck does not belong to any platoon.

5 TECHNOLOGIES FOR TRUCK PLATOONING

An overview, from local to global level technologies that enable truck platooning is shown in Figure 2. On local level, technologies within a small range of the vehicle are effective, such as Cruise Control (CC) and Adaptive Cruise Control (ACC). The ACC system is an extension on the CC system and has been illustrated as a means to enable vehicle platooning [26]. Cruise Control is a system which takes over the throttle of the vehicle to maintain a steady speed as set by the driver. The throttle valve controls the power and speed of the engine by limiting the amount of air intakes and is actuated automatically, instead of by pressing a pedal, when the cruise control system is engaged [29]. The Adaptive Cruise Control system is an extension on the CC system, which automatically adjusts the vehicle speed to maintain a safe distance from vehicles ahead. ACC uses either radar or laser sensors to detect the speed of and distance to the vehicle ahead. If the distance to a vehicle or object ahead diminishes, the system will send a signal to the engine or braking system to decelerate the vehicle and the other way around for increasing distance [29].

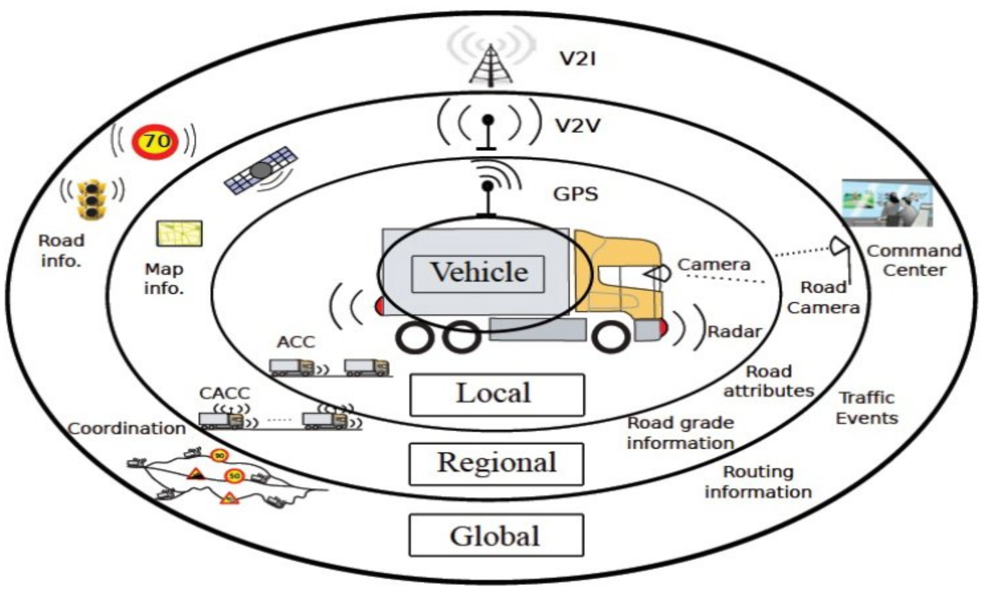

Fig3: Technologies for truck platooning [21].

An extension on the ACC system is Cooperative ACC (CACC), which uses longitudinal auto- mated vehicle control by accounting for road information, such as road grade, and traffic events occurring further ahead in the platoon, such as traffic congestion. This is obtained by wireless communication in short and wide range relative to the vehicle, i.e. by Vehicle to Vehicle (V2V) communication and Vehicle to Infrastructure (V2I) technology, respectively [35] [32]. The interaction between vehicles is enabled through V2V communication and can therefore improve safety. By combining Global Positioning Systems (GPS) and V2V technology, the relative position estimates of neighboring vehicles can be made with high accuracy. Hence, smoother control can be implemented through prediction based upon the gathered information, enabling cooperative driving and realizing automated vehicle platoons [30] . On global level, implementation of routing and road information is enabled through V2I technology. A command center or fleet manager can monitor the vehicles in real-time traffic through V2I, enabling the possibility to react upon road and traffic information and optimize the transport mission and thereby the vehicle's fuel consumption. For example, fuel consumption can be decreased by adjusting the vehicle speed in order to form a platoon. Furthermore, an alternative path can be found through V2I to ensure the arrival deadline of the transport mission when obstructing traffic situations are encountered [33] [18]. Technologies such as V2V and V2I are part of Intelligent Transport Systems and services (ITS), where ITS denotes the integration of Information and Communication Technology (ICT) with transport infrastructure, vehicles and users [21]. Figure 3 represents an illustration of ITS, where ITS includes all types of communication in and between vehicles (V2V communication) along with communication between vehicles and infrastructure (V2I communication). With the aid of these communication devices, a cooperative system is formed for supporting and replacing human functions in various driving processes in order to enhance operational performance, mobility, environmental benefits, and safety. [21].

6 EFFECTIVE TRUCK PLATOONING

Platooning is found to contribute towards energy saving in the following aspects:

First is the reduction of aerodynamic drag while the second is the provision of larger room due to increased road capacity to surrounding traffic. The first is microscopic contribution, while the latter is macroscopic contribution. Microscopic contribution involves conducting the simulation of computational fluid dynamic with the aims of investigating the aerodynamic drag reduction [12]. The CD-value of the front truck and the last truck decreases above 20 %, and that of the middle truck decreases by about 50 %. This implies that when 3 trucks are driving with a small gap then the aerodynamic drag decreases, and this contributes to energy saving. Therefore, when trucks are driving at high speed, the aerodynamic drag is larger than the rolling resistance; there would be decrease in the fuel consumption of the platoon by about 15 %.

6.1 Platoon truck Energy Consumption

According to the Energy ITS project; since 1990, while the energy consumption trend in the industry sector has been almost constant, those in the civil sector and transportation sector have increased. In the transportation sector it has increased by 7 % in 2010 as compared to that of 1990. In 2010, the energy consumption by automobiles accounts for 89 % for passenger transportation and for 90 % for freight transportation, while the transportation volume (passengers-km or ton-km) by automobiles accounts for 65 % for passengers and 61 % for freight transportation. The fuel consumption was measured during the experiments on a test track under the conditions that the velocity was constant and 80 km/h, the gap was 10m and 4.7m, and the trucks were empty-loaded. Figure 1 shows the results. The measurements indicate 13% energy saving at 10m gap and 18 % saving at 4.7m gap. When the trucks are ordinarily loaded and drive at 80 km/h, the fuel saving will be 8 % when 10 m gap of 10 m, and 15 % when 4 m gap. [22]

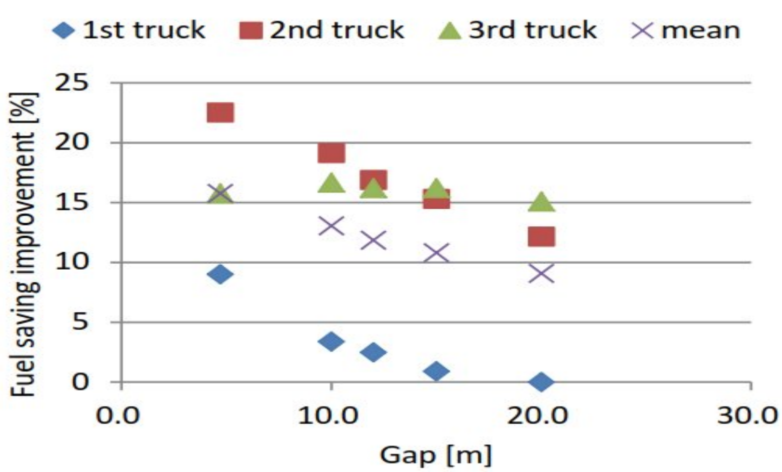

Fig 4: Relationship between the fuel saving improvement and the gap in the platoon [22].

6.2 Platoon truck Emission

The CO_2 emission trend in Japan and in general, the increasing rate of the CO_2 emission from the transportation sector is larger than that from whole Japan. Like the energy consumption trend, due to unfavorable economy, the increasing rates have been decreasing recently, and in summary the increments rate of the sector is 8.6 %. In 2008 compared to that in 1990, and that of Japan is 6.2 %. The CO2 emission from the transportation sector (228 M ton in 2008) accounts for 19 % of the total emission from Japan (1,214 M ton in 2008), and 90 % of CO2 of the transportation sector is released from automobiles. Thus, automobiles are major causes of the global warming, and since the energy of current automobiles that use an internal combustion engine is petroleum that emits CO2 after burning, the counter-measure of the global warming for automobiles(current) is energy saving.

7.2 TRUCK PLATOONING PROJECTS IN THE WORLDWIDE

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7.3 State of the Art

In the last few decades, several platooning projects have started to explore different aspects of platooning. These projects defined platooning objects, platoon properties, and platoon operations as per their own notion.

1. **SARTRE** – In a European platooning project SARTRE, a vehicle is defined as following vehicle, lead vehicle, other vehicle, potential following vehicle, potential lead vehicle, potential platoon vehicle, or platoon vehicle. Different platoon operations such as create platoon, join platoon, maintain platoon, leave platoon, and dissolve platoon are defined as platoon use cases (Bergenhem et al., 2010; Robinson et al., 2010).
2. **PATH** – The US based truck platooning project PATH only referred to two types of platoon objects as ; lead vehicle and preceding vehicle and platoon properties such as inter-vehicle spacing, inter-platoon spacing, platooning vehicle types, number of vehicles in platoon, platoon length, vehicle acceleration or deceleration, communication time lag and delay, and highway operating speed (Carbaugh et al., 1998; Michael et al., 1998; Rajamani et al., 2000). Operations like lane keeping, lane change, join, and split are tested in this project.
3. **SCANIA** – The Swedish truck maker SCANIA has started two platooning projects: Distributed Control of a Heavy Duty Vehicle Platoon, and iQFleet (Bergenhem et al., 2012b). Here, Deng (2016) modeled a platoon class as a group of heavy duty vehicles with platooning capability and having three mandatory properties: platoonID, speed and a list of platoon members. Deng classified the driving behavior of a platoon into basic and advance operations. Basic operations include acceleration, deceleration and desired inter-vehicle distance adjustment. In contrast, speed planning and platoon aggregation and disaggregation are considered advance operations.
4. **Others** – In the Japanese platooning project Energy ITS, Tsugawa et al. (2011) defined the control system for path following and lane keeping operations. CHAUFFEUR3 demonstrated different maneuvers – coupling, termed as 'flthe joint', decoupling, termed as 'inverted fljoin joint', and platooning driving such as lane changing, accelerating and braking. Vehicles used in a platooning project COMPANION are not necessarily bound to the same source and destination: platoons can be formed on the flu by merging vehicles and other platoons, traveling jointly for parts of the route. To encourage development, integration and deployment of cooperative driving, the Grand Cooperative Driving Challenge were organized in 2011 and 2016. In terms of platoon operations, the challenge mainly tested collaborative vehicle movement as a platoon based on predetermined technology and interoperable communication standards and tested a join operation and allowed the change of role of participating vehicles (Lidström et al., 2011; Bergenhem et al., 2012b).Other than the above mentioned platooning projects, Amoozadeh et al. (2015) presented a platoon management protocol and simulated three basic platoon maneuvers: merge, split, and lane change. They also explained three platooning scenarios: leaving of the leader, leaving of a follower, and entry at the end. The platoon management protocol considered first different variables that any platoon enabled vehicle should have, namely vehicle ID, platoon ID, platoon depth, platoon size and platoon members. Though different research projects and research articles discussed some of the platoon maneuvers and platoon properties, none of them defined those operations formally. More prominently, the different projects defined platooning objects and platoon operations in incompatible ways. For example, the join operation in SARTRE is the same as the aggregation operation in SCANIA's projects, and the coupling operation in CHAUFFEUR. Not only do terminology differ, but also the object and operation concepts. SARTRE used eight different platooning objects to address different platoon operations whereas most of the other projects used three objects: platoon leader, platoon follower, and platoon, and sometimes additionally free vehicle. SCANIA's projects defined the platoon creation and the platoon join separately, whereas other projects did not address platoon creation or considered create as an implicit operation of join. Moreover, typically no justification and explanation have been provided on the operation categorizations. Therefore, the requirement of standardization of platooning objects and operation is necessary. [17]

8. TRENDS OF TRUCK PLATOONING

Truck platooning has a number of impacts on transport system and environmental system.

8.1 Transport System

These impacts include; increased road capacity

8.1.1 Increase of Road Capacity

The major aim of vehicle platooning is to increase road capacity. In order to achieve this, it is important to operate vehicles closer together than its possible with manual driving. Unfortunately, a vehicle platoon system has never been deployed on a large scale. Most of the capacity studies are hence based on simulations.

One of the studies conducted by Vander (Werf, et al., 2015) focused on the capacity impacts of an increasing market penetration of ACC and CACC vehicles, relative to manual driving [15]. They performed a microscopic simulation of a 16-kilometer one-lane highway with on- and off-ramps every 1.6-kilometer. Initially, an analysis of simulation scenarios was conducted with vehicle type compositions of 100% manual driving, 100% ACC vehicles (time gap of 1.4 seconds) and 100% CACC vehicles (time gap of 0.5 seconds). These simulations resulted in a nominal capacity of respectively 2100, 2150 and 4250 vehicles per lane per hour. Later, they analyzed a scenario with a more realistic mix of vehicles. As it turns out, both

ACC and CACC improve the highway capacity in all cases. [16]. However, the impact of ACC is relatively small: a capacity increase of at most 7% was achieved compared to manual driving. It is argued that ACC achieves this benefit by smoothening the traffic flow instead of closing the operating gaps. In fact, the 1.4 seconds time gap turned out to be modest compared to an average time gap of 1.1 seconds under manual control. The analysis shows besides that CACC has the potential to significantly increase the capacity, especially for high market penetrations. This effect is explained by the need of a CACC system to have a preceding vehicle, which is also equipped with a CACC system. After all, a preceding vehicle needs to transmit information for following vehicles to operate. If a preceding vehicle is not equipped, the system behaves like ACC and acts solely on radar information. Similar results in terms of road capacity increase have been shown in AHS studies. One of them is a numerical analysis by Michael, et al., [13]. Their main conclusion is that AHS can increase the road capacity but the increase is dependent, among others, on:

a. the degree of inter-vehicle cooperation
b. average platoon length,
c. the intra-platoon spacing.

Unfortunately, most studies about the impacts of platooning systems on the road capacity are based on simulation or analytical analysis. Better would be to measure the impacts of a particular platooning system in a large-scale test-bed. However, this is capital intensive and requires a good motivation in order to do so.

8.2 Environmental Issues.

8.2.1 Reduction of Environmental Impacts

The transportation system is a large contributor to the emission of green- house gasses. Indeed, transportation can have accounted for approximately 30% of the total CO2 emission in the USA over 2008 [29]. Since environmental issues are a hot topic, the transportation industry is also looking for solutions to reduce fuel consumption and hence reduce environmental impacts.

Truck Platooning can be one of the solutions to environmental issues like global warming. Closely operating vehicles in a platoon reduce the average air resistance and hence the fuel consumption. This result was obtained in wind tunnel tests and field exper- iments [32, 18]. The results of the field experiments show that fuel savings in vehicle platoons are strongly correlated to the position of the vehicle in the platoon and operating distance. A vehicle operating with a vehicle in front and back, can save fuel up to 10% (operating distance of 3 to 6 meters). The last and the leading vehicle of a platoon experience savings of respectively 7% and 3-4%. Hence, all vehicles in a platoon benefit.

9. THE FUTURE OF TRUCK PLATOONING

There are some important infrastructure barriers that must be overcome to make truck platoon a realistic and effective concept for the nearest future. Present research studies focus more on lighter trucks instead of heavy trucks. By using heavy vehicles to study platoon, it provides more useful information about the effectiveness of truck platooning on green road freight transportation. Fuel consumption from a vehicle engine occurs as the vehicle travels on the green road with the output of the fuel contributing to Aerodynamic losses, Auxiliary loads and inertial grade. Truck platooning has a number of benefits. These benefits range from an increased road capacity and improved safety to a reduction of the environmental impacts and improved driving comfort. Understanding these benefits and the impact of Vehicle Platooning is very important; they serve as the justification of the development of vehicle platoon systems. The automated truck platoon developed in the project consists mainly of N heavier (25 ton) trucks, and currently drives at 80 km/h with the gap of 10 m on a test truck and along an expressway before public use. [35]. The functions of the platoon are lane keeping, speed control, collision avoidance, and gap keeping. Among these functions, the gap keeping function contributes to energy saving, and the last one contributes towards increasing the safety and reducing the workload of drivers. The configuration of a truck for the automated platoon. The feature of the platoon system is high reliability with redundancy in the sensing systems, the vehicle control ECU (electronic control unit), the communication system, and the actuators. The control period for the trucks is 0.5-1.5s.

In (2020), an automated platoon of 3 trucks with automated lateral control will be introduced under mixed traffic. The gap will be 10 m at an early stage and will be shortened to 4 m afterwards. In the platoon CACC (Cooperative ACC) will be performed with the V2V communications to make traffic flow smooth. A driver will be in each truck. The energy saving goal is 8 to 15 % reduction by aerodynamic reduction and 5 % reduction by smooth traffic flow.

In (2030), a fully automated platoon of 3 or 4 trucks will be operated along a dedicated lane on an expressway, and a driver will be only on the lead truck. The energy saving goal is 18 % reduction by aerodynamic drag and 10 % reduction by eco driving. The length of a platoon is bounded, because a long platoon can disturb other traffic along an expressway, and the longest platoon is a 4-truck platoon in this project. [33].

CONCLUSION

This paper has reviewed platoon trucks technology, by conceptualizing potential trends in automated technology which brings environmentally positive effects, reduces pollution and noise, as well as unusual accidents are minimized. Therefore, in a bid to developing a new innovation for transport system; the freight transportation and logistics enables better use of transport infrastructure and contributes to reducing environmental issues (hazards), congestion and distances travelled by truck. The application of the technologies is of high reliability and aiming at the near future introduction. Fuel consumption measurement on a test track and along an expressway shows that the fuel can be saved by about 13 % when the gap was 10 m. The evaluation simulation shows that the effectiveness of the platooning with the gap of 10 m when the 40 % penetration in heavy trucks is 2.1 % reduction of

CO_2 along an expressway. Research is developing new and innovative solutions to enhance the environmental sustainability and efficiency of the logistics chain. Significant gains have been achieved by optimizing freight transport infrastructure, by efficiently combining transport modes, and by identifying potential performance, improvement for logistics truck CO_2 emission. However, It would also focus on the effectiveness of low-carbon policy and economy; companies, governments and financial institutions tends to develop technologically, that is they will encourage companies which implement new technological solutions in the model of truck platooning.

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