LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
School of Engineering Science
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MODELS OF ECONOMICS BEHIND DATA-BASED SERVICES IN VEHICLE FLEETS

MASTER’S THESIS

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D.Sc. (Tech) Ari Happonen
# ABSTRACT

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Together with modern data-based technologies invention and development the world of transport businesses changes. Modern cars are becoming more and more sophisticated in regard to their equipment with wireless communication technologies, data trackers, geolocation systems, etc. Quite clear, that in case of private use of a single vehicle these devices are just providing assistance to a driver, whereas in case of a fleet business they can generate a plenty of opportunities for cost reduction based on better services, optimization or operations and management, elimination of unexpected expenses, risks, etc. Data collection and analysis in vehicle fleets is a key component and the main mean of the future fleet business operations.

The main research method includes two directions. The first one is searching for already existing economical models in vehicle fleets from different literature sources available, including scientific databases and specialized Internet pages. The second direction is elaboration of own possible cost reduction ways in vehicle fleets and supporting their feasibility via literature.

The main results of the investigation made include identification of the main directions of vehicle fleet businesses improvement. They are concentrated around three main possibilities for fleet businesses: automation of services and internal activities, dynamics in operations, planning and management and involvement of non-typical actors to fleet business value development.
ACKNOWLEDGEMENTS

This Master’s Thesis has generated a lot of outcomes, knowledge and even new competences for me as the topic was quite unfamiliar before, but still very interesting and valuable. I was happy to get familiarized with such an extensive field of the world’s business and learn something new from day to day. Considering tight schedule for writing the work, it has required quite strong effort from me to deliver it on time, and, hopefully, I have coped with this task. I would like to thank everyone who has taken direct or secondary part in writing, guidance and preparation to this work.

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<tr>
<td>ACC</td>
<td>Adaptive Cruise Control</td>
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<td>ASE</td>
<td>Active Safety Equipment</td>
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<td>B2B</td>
<td>Business-to-Business</td>
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<tr>
<td>B2C</td>
<td>Business-to-Consumer</td>
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<tr>
<td>CA</td>
<td>Crash Aggressiveness</td>
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<td>CO₂</td>
<td>Carbon Dioxide</td>
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<td>CORS</td>
<td>Continuous Operational Reference Station</td>
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<td>CW</td>
<td>Crash Worthiness</td>
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<td>ECG</td>
<td>Electrocardiogram</td>
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<td>EDA</td>
<td>Electro-Dermal Activity</td>
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<td>EV</td>
<td>Electric Vehicle</td>
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<td>FCA</td>
<td>Forward Collision Avoidance</td>
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<td>FME</td>
<td>Fractions of Mileage Exposure</td>
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<tr>
<td>GIS</td>
<td>Geographic Information System</td>
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<tr>
<td>GPRS</td>
<td>General Packet Radio Service</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<td>LDW</td>
<td>Lane Departure Warning</td>
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<tr>
<td>MIP</td>
<td>Mixed Integer Programming</td>
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<tr>
<td>NOₓ</td>
<td>Nitrogen Oxides</td>
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<td>OBD</td>
<td>On-Board Diagnostics</td>
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<tr>
<td>PF</td>
<td>Particulate Filter</td>
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<td>PSE</td>
<td>Passive Safety Equipment</td>
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<tr>
<td>RSC</td>
<td>Roll Stability Control</td>
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<td>RTDR</td>
<td>Road Traffic Death Rate</td>
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<tr>
<td>SMS</td>
<td>Short Message Service</td>
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<tr>
<td>tkm</td>
<td>Thousand Kilometers</td>
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<td>UBI</td>
<td>Usage-Based Insurance</td>
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<td>V2G</td>
<td>Vehicle-to-Grid</td>
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1 INTRODUCTION

From the end of the previous century businesses based on vehicle fleets have become officially established and started to make profits from provision of value to customers. During several decades later on, vehicle fleet owners have proved their efficiency and profitability of providing cars to population and businesses, and number of people who prefer taking a car rather that acquiring it is increasing (NADA report, 2015). New business models are appearing and by now there are several ways of their organization: it could be car renting with daily payments, car leasing for long term vehicle usage with possibility of its acquisition and the newest model is car sharing for short trips with hourly or minute-by-minute payment basis. This is current situation, but with modern speed of high-tech progress fundamental changes in vehicle fleet businesses could be expected.

Technological development in vehicle management direction provides plenty of opportunities to fleet owners to reduce their operational costs and one of them is to apply services based on data analysis in fleet owners’ business models. In our case, both carsharing and car leasing models are considered in the work providing their own specific ways of cost reduction. But basically, most modern cars are equipped with board computers, GPS (Global Positioning System), cameras etc. which can track fuel consumption, geolocation and other data.

The main potential challenge nowadays is that it is not so easy to track data constantly and in real time; additionally, data reading standards could differ from one car manufacturer to another and among car generations. Anyway, from year to year methods and technologies of data gathering become more advanced and in the nearest future fleet drivers will provide this data by their everyday operations which can later be collected, analyzed and converted to cost-reduction methods for a fleet business.
1.1 BACKGROUND AND HISTORY

Car leasing as a business appeared in 1918 and only by 1940 it was developed up to fleet scales (Kutch, 1986). Since those times, fleet owners heavily competed with banks and insurance companies which encouraged people to take loans and acquire vehicles rather than to lease them. Anyway, together with the world’s development car leasing has proved its efficiency and provided appropriate alternative to vehicle acquisition (NADA report, 2015).

Alternatively, thirty years after in 1948 in Switzerland appeared the first community for car sharing (Shaheen et al, 1998). It was made for people who couldn’t afford to buy a car, but were willing to use and pay for it for short trips only. Later, more Carsharing initiatives appeared around Europe, but they were not successful. However, since 1980 carsharing activities have undergone rapid development and till now continue to spread around the globe.

Therefore, there are at least two models for fleet business companies to operate in. In particular, this work generally considers modern B2B (Business-to-Business) models of vehicle leasing and partly deals with B2C (Business-to-Consumer) leasing and carsharing sectors. Nowadays, these B2B fleet owners mainly with quite big number of vehicles collaborating with firms and companies which prefer to lease cars, lorries, buses, etc. rather that maintaining their own vehicle fleet. For monthly payment companies get certain amount of cars with obligations of their maintenance, insurance acquisition, fault fixing etc. on lessor company.

Every business aims to save its resources, especially financial ones, for their more efficient use. So do fleet owners and in front of them there are plenty of opportunities for this. As vehicle fleet businesses are often dealing high-tech devices which could potentially serve to this need, they could rely on the direction
of data analysis cost reduction, which together with modern innovation technologies will make it even more effective in the nearest future.

1.2 OBJECTIVES

Not so long time ago, vehicle on-board devices provided quite simple operations for fuel consumption control, trip mileage records, average speed and so on. By now, together with the wireless communication techniques development (like Wi-Fi, telematics and GPS) the invention of sophisticated multi-task devices has become an issue of several years. And, the most important, implementation of such kind of knowledge and based on it gadgets is almost infinite like needs of potential vehicle owners and users.

Therefore, the main aim of the work is to provide literature-based investigation of the most recent trends, directions and technologies which already exist or will be developed in the nearest future for fleet management in a whole and for its cost reduction in particular. The process of investigation can be described by three research questions:

**RQ1:** What economical models in vehicle fleets have already been developed and described by scholars?

**RQ2:** What new opportunities for vehicle fleets could be generated basing on the most recent literature sources?

**RQ3:** What new trends and directions of data-driven vehicle fleet business could be expected to appear now and in the nearest future?

The research questions are tightly connected to each other as every new technological development generates plenty of new opportunities for vehicle manufacturers, fleet businesses and vehicle users of all kinds. Additionally to that,
not only tangible devices are developed for fleet management and cost reduction, but also IT programs, mathematical models and organizational operations.

The work was concentrated around private vehicle fleets of passenger cars and heavy trucks for business operations. In some cases fleets of governmental busses, ambulance, etc. were mentioned in the work to use them as examples of a certain technology implementation, but it was done mainly for assessment of applicability of this technology to private fleets. The investigation wasn’t attached to any certain place in the world, but was diversified to provide more valid information about the latest technological achievements from all over the world.

1.3 METHODOLOGY

The investigation is provided by two opposite processes. The first one is searching for economical value adding models for vehicle fleet already developed by scholars, car manufacturers, fleet managers, etc. and describing them in the work by structuring information and sometimes applying it for specific cases or, conversely, taking single case of implementation in a fleet and speculating on possible wider utilization. The second process supposes generation of potential fleet economic models by identification of customers’ needs and benefits for fleet companies and searching for means of bringing them to life.

In both cases, plenty of literature sources are available, starting from Internet pages of specialized automobile companies and ending with scientific databases. Among databases, Science Direct was the most commonly used, providing open access scientific articles with lots of information about the state of art. Some of the articles could also be found via Internet together with specialized sites, also containing economical models, modern techniques and other data-driven means of fleet cost reduction. What comes to images, almost all figures in the work were taken from
original articles with permission of their authors given by e-mail; other figures were either self-created or based on text of the articles with relevant links to their authors.

1.4 STRUCTURE

The report consists of four chapters with several sub-chapters in each to provide comprehensive investigation of the state of art. In the *Introduction* chapter basic information about vehicle fleet businesses and their history is given as well as overview of research methods, investigation process and data sources. The third chapter presents *Literature research* and possible *Economic models* for vehicle fleets, structuring information about current and future directions of vehicle fleet businesses development. In the chapter with *Discussions and conclusion* the main results of the work made presented, explaining how and why vehicle fleets can be improved in the future. In the *Summary* the main points of the work are summarized, giving clear understanding of the future of vehicle fleets.
2 LITERATURE RESEARCH AND ECONOMIC MODELS GENERATION

As was mentioned before, the research strategy includes two directions of investigation: searching for already described by scholars models of economics for vehicle fleets or just generating them based on global trends of value provision. It was found, that the main directions of vehicle fleet management are the following: safety, drivers’ education, cost reduction, maintenance operations and security. The chapter in detail describes all approaches, technologies and directions of possible vehicle fleet business operations and management.

2.1 SAFETY IN VEHICLE FLEET SCALE: DATA-DRIVEN APPROACHES

Any private vehicle fleet owner should aim to provide safe services to customers. No doubt that the newest cars have already the most advanced safety equipment, but there are no limits for improvement as car accidents still exist. Moreover, most of conventional automobiles have during-accident assistance such as safety belts and airbags, called passive safety equipment (PSE) (Kumar, 2017). This means that by using them properly chance of injuries or death during car accident decreases, but such kind of equipment doesn’t prevent accident itself and there is only reliance on driver’s reaction remains. Therefore, more attention during new technologies development should be paid to active safety equipment (ASE), which monitors driver’s and automobile’s state as well as road situation to prevent car crash rather than to manage it to decrease damage.

Aiming to provide more advanced car safety assistance, modern digital technologies are undergoing rapid development and vehicle fleets are not an exception to be affected. Nowadays, there are plenty of data-driven safety systems under investigation and testing. The main problem is that they are not so widely spread (usually only on quite expensive cars), but it could be expected that every single car
will be equipped with active safety systems, which in the future will become more affordable financially and recognized by auto manufacturers.

The main basic technologies for ASE are sensors and cameras, which can be installed on a car to get quite large amount of data to be analyzed. Modern driver’s assistance systems are mostly dealing with the following directions: driver’s state monitoring, lane-keeping, collision prevention, etc.

### 2.1.1 Active safety systems

Active driver’s assistance can be operated by direct affecting on driver’s sensory organs. It usually involves light signals and sound noises to attract driver’s attention to pre-fault situation. These alerts are provided by analysis of data from digital on-board cameras and special computing systems, which can be used for headway monitoring, lane departure warning (LDW), forward collision avoidance (FCA) and pedestrian collision warnings (Thompson et al, 2018). These systems have proved their efficiency and changed driver’s behavior, increasing safety, but only when they were actively providing alerts. Quite important was the fact that around quarter of forward collision alerts were false alarms and maybe this fact provided quite bad experience for testing drivers. Therefore, these systems were believed by its testers to be useful for safety, but drivers didn’t trust them as they could really prevent an accident.

Another study (Eichelberger & McCartt, 2016) used systems of adaptive cruise control (ACC), forward collision avoidance (some models with auto braking) and lane departure warning installed on Toyota high-class cars. These systems besides using cameras also used radars for distance measuring and speed control. After testing period the drivers were asked about their experience, and 90% of them wanted ACC and FCA on their next vehicles. Concerning LDW experience, only 71% of respondents wanted it in their future cars. The conclusion from these
numbers is that sensory-driven alarms are not so reliable and trustful, and together with false warnings could distract drivers rather than benefit to their driving style. The question of driver’s acceptance of such technologies arises. People need pre-education to know exactly how and what for these technologies are installed. Anyway, more advanced automatic systems can provide much better experience not by affecting driver, but affecting automobile provided that any changes in its speed or direction are justified by reliable sensors and cameras.

The study also showed quite different experience among testers’ gender and age: males were more often to get warnings from LDW system and younger drivers (less than 40) were more likely to hear or see FCA warnings. This means, that applying to vehicle fleet services it is worth taking into consideration driver’s features to provide more attractive experience.

Investigation of large truck fleets with and without LDW and roll stability control (RSC) (Hickman et al, 2015) resulted in concrete numbers of the systems’ efficiency. Large amount of data (88,112 crash records) was collected during observation period. The results were the following: 1) trucks with LDW had crashes related to lane departure 1.9 rarer than ones without LDW; 2) trucks with RSC had rollover accidents 1.55 times rarer than ones without this system. If these systems can really decrease crashes percentage they should be installed in every (at least) heavy truck vehicle fleet as accidents with heavy vehicles are more dangerous and more likely to cause fatal cases (Taylor & Francis, 2013).

2.1.2 On-road health monitoring for traffic safety

Quite big number of car crashes can occur due to health state of a driver, especially during sudden attack of a health disease, and it is impossible to prevent an accident. Such situations could be caused by several factors: medicine impairment (only around 2% of cases (Brubacher et al, 2018); heart attacks, poor eyesight, diabetes,
seizure disorders, etc. and driver’s on-road sleeping. These health circumstances are called pre-existing conditions, which could potentially cause a car crash. Some of these conditions are associated with driver’s age; some of them are reported to be in any age groups (Dischinger et al, 2000), but if there is a danger of medical-state-caused accident, relevant equipment for its prevention must be installed.

Considering all above mentioned health problems, there are several scenarios for action. Firstly, in case of a heart attack or any other disease event which doesn’t allow a driver to control vehicle, it must be immediately stopped by an autonomous system and, in ideal case, automatically call for emergency. The location of stop can be identified by GPS system, which would be especially useful if incident occurred in a deserted place. Secondly, in case of driver’s fatigue and falling asleep vehicle monitoring system should try to wake him up and in case of non-response stop the vehicle. And thirdly, in case of e.g. epilepsy seizure driver can uncontrollably rotate steering wheel which increases chance of collision. Vehicle safety system in this case should block steering wheel and stop the car. Usually, safety systems are aimed at one scenario only, but in the future comprehensive health monitoring solutions are likely to appear.

For falling asleep prevention one of the most reliable methods is usage of electro-dermal activity (EDA) registration (Ogilvie et al, 1991). Thanks to this method data analysis of driver’s condition (e.g. keeping awaken) can be provided. Based on electro-dermal activity systems analyze data and send sound signal to a driver in case of falling asleep (Dementienko et al, 2017). In heavy trucks fleets information about sleeping driver can be sent to control center, from where dispatcher can call the driver or take other sort of actions. This system could be potentially connected to emergency braking system (Lenard et al, 2018) to stop vehicle when a driver suddenly falls asleep.
Another type of health monitoring system is based on electrocardiogram (ECG) on-board system with highly sensitive electrodes, which monitors driver’s heart state (Jung et al, 2012). Due to correlation between heart rate and driver’s state it is possible for the system to understand if driver is in normal, fatigued or drowsy state. This system was called “nonintrusive” as the electrodes are situated under seat cloth and doesn’t suppose any on-body devices for its operation. Potentially, such approach can be used for heart attack or epilepsy state identification, and data receiver could be connected to braking system for emergency stop.

Less relevant, but still potentially useful technique is EDA stress analysis with usage of on-hand sensors for emotional driver state identification (Affanni et al, 2018). Gathering information about stress peaks and their frequency, advisory rest recommendation system could be developed to inform a driver about necessity of rest as due to stress probability of an accident increases. In general, collaboration of ECG or EDA stress analysis and rest alarm systems may result in a new technology for rest notification for heavy vehicles drivers.

2.1.3 Geographical features of safety systems necessity

Quite obviously, due to variety of cultures driving behavior differs from country to country. In some countries driving style is more dangerous than in the others, and theoretical possibility of car crashes is higher (Özkan et al, 2006). This difference can provide data for vehicle fleet safety systems installation. In countries with higher number of car accidents recorded per a certain number of population (usually 100,000) it is worth using safer vehicle to reduce car crashes frequency and severity. From economical point of view fleet owners may save financial resources by installing safety equipment relevant to driving habits of a certain place/country and preventing such causes of car accidents which could be related as a bottleneck in an every single country.
First of all, even without preliminary accident number assessment some evaluations could be done in dependence of ratio of different vehicle types. For example, in countries with high number of heavy trucks and motorcycles possibility of their collision is higher. Moreover, severity of collision in this case in high enough because, basing on simple correlation between vehicles mass, it could be concluded that a fatal case is more probable when vehicles with high difference in mass are collided. Thus, relying on results from Christoph et al (2013) it could be found out, that among 14 European countries the highest ratio between light motorcycles and heavy trucks is in Greece and, therefore, Greek truck fleets need the most advanced safety technologies for collision prevention (Fig. 1).

![Graph showing the ratio of motorcycles, passenger cars, and heavy trucks in European countries.](image)

**Fig. 1.** Share of motorcycles, passenger cars and heavy trucks in European countries. (Based on Christoph et al, 2013)

The above mentioned index of heavy and light vehicles ratio doesn’t mean, that Greece among other countries is really dangerous to drive. It only determines the
The probability of the most severe accidents, which according to other factors may not occur. There is another index exists, which really determines danger or safety of driving in an every single country – Road Traffic Death Rate (RTDR). RTDR is counted for every country in the world as number of deaths in road accidents related to 100,000 of population.

Vehicle fleet owners should take into consideration RTDR during making the decision which safety systems are to be installed to their vehicles. Fig. 2 presents the safest countries for driving with RTDR variety from 0 to 6.3 death cases per 100,000 of population (Burton, 2017a). It could be easily seen that such a low RTDR is presented in European, especially Scandinavian countries, and in some more distant ones like Australia, Japan, Israel, etc. For private fleet owners analysis of the reasons for car accidents in these countries (e.g. forward collision, rear-end collision, lane departure) will help to install safety systems dealing with these reasons. This data could save finances of fleet based businesses, preventing them from installing the systems which are unlikely to be intensively used.

![Map of countries with the lowest RTDR](image)

**Fig. 2.** Countries with the lowest RTDR around the world.
Counter situation is in top 25 countries with the highest RTDR, starting from 26.3 and going up to 36.2 deaths per 100,000 of population (Burton, 2017b). They are mainly concentrated in central Africa and some Asian countries (Fig. 3). African countries are the most dangerous for driving according to several reasons: poor traffic regulations, non-existence of good roads and sidewalks and poor emergency healthcare (Mohammed, 2015).

![Map of Countries](image)

**Fig. 3.** Countries with the highest RTDR in the world.

Operating in these countries, fleet owners should carefully choose and install safety equipment as severity of car accidents is the highest among the world. The best way there is to prevent road accidents by using advanced safety technologies in fleets and additionally introduce educative programs for drivers’ behavior change.
2.2 DRIVERS AS THE MAIN ACTORS IN FLEET COST REDUCTION

Every single vehicle fleet user has own driving style and pattern, which are different in accuracy of driving, aggressiveness, fuel consumption, accident rates, etc. Variations in driving styles generate threats and opportunities for vehicle fleet owners as there are plenty of points of view from which the issue of driving style could be examined. From the one hand, analysis of good driving styles is needed for their consequent spread among other drivers by educational programs, benefits and discounts proposals and other means. From the other hand, identification of the most dangerous drivers is needed to be done for equipment of cars with more advanced safety systems, development of relevant insurance plans and correction of driving aggressiveness for vehicle use optimization and reduction of related problems. In big vehicle fleets, the most aggressive drivers could be even sent to anger management courses for improving their driving safety.

2.2.1 Data-driven assessment of driving styles: benefits, safety issues and insurance plan predictions

Nowadays, for driving style identification and analysis telematics is widely used. Telematics is a branch of information technologies science dealing with long-distance transmission of computerized data (Oxford Dictionary, 2018). This means, that it could be used for real-time data gathering and transmission directly from GPS and on-board diagnostic systems of cars. Modern car manufacturers and fleet owners have already accepted benefits of telematics-based devices and services as they are used for variety of operations. For example, in 900-vehicle fleet equipped with telematics devices (Griffiths, 2016) the following results have been achieved: 1) 97% reduction in over speeding; 2) 7% better fuel economy; 3) 47% reduction in crashes and 4) overall reduction of maintenance costs. Such results are quite promising, especially when it comes to fleet safety.
As one of the possible means of telematics application, fleet owners can identify dangerous drivers online and set a limit for such type of behavior. In particular, modern OBD2 (On-Board Diagnostics) systems (Fleet Genius, 2016; Sinocastel, 2014) are created for centralized monitoring of vehicles’ speed, drivers’ aggressive starts, hard brakes, tachometers’ readouts and duration of engines’ idle modes. This system should be also retrofitted with driver sleep monitoring system which also heavily influences road safety. The main idea of the system is to gather information about every individual driver and related driving style to change unsafe road behavior in the future. Moreover, this is an issue of not only driving safety, but also of company’s prestige as every driver represents its name not only during making his duties, but also while driving a car, and such a type of aggressive behavior would spoil client’s impression of the whole company (Fleet Genius, 2016).

Another telematics based study was made by Jin et al (2018) where the authors have collected plenty of data about driving styles of tested drivers. The data included: 1) average number of hard accelerations and brakes during one hour of driving (aggressiveness identifiers); 2) fractions of mileage exposure (FME) while driving on urban or suburban roads; 3) mileage of driving during weekdays or weekends; 4) data on daytime and nighttime driving; 5) data on driving speed.

The authors of the work (Jin et al, 2018) have made quite helpful conclusions based on the above mentioned factors. The first one is that probability of reporting a car accident heavily depends on number of hard brakes per hour (every single hard brake per hour increases the probability by 12.5%), speed mode (every 1% of FME with 90+ km/h increases the probability by 1.2%), nighttime driving existence (+1% of nighttime FME results in +1.2% to the probability) and driver’s familiarity with driving route. The later issue is worth separate mentioning: more a driver is familiar with a route results in 1.46 times higher probability of an accident report.
The second important result, especially applicable to fleet vehicle business, is identification and division of the tested drivers into two classes called “the high risk class” and “the low risk class”. In the first one, only 0.54% of drivers reporting accidents while in the second one 20.66% of drivers did so. It is worth mentioning that among 4683 drivers tested 402 vehicles were reporting accidents in a year period and among them 60.02% were referred to the low risk class and 39.98% to the high risk one. These results provide extremely important information for vehicle fleet owners, who could assess probability of car accident of every single driver via OBD and telematics (at least hard breaking rate, which heavily influences the probability) and consequently optimize strategy of safety equipment installation and insurance plans for every car, since more dangerous drivers require safer vehicles and more expensive insurance.

What comes to insurance issues, more often it is calculated with basic driver and automobile information only. It includes driver’s age, experience, vehicle’s year of issue, engine features etc. This way of insurance premium calculation is quite out-of-date as it doesn’t take into account driving behavior as an indicator for a car accident probability. In the future, it could be expected that insurance companies will fully give up conventional model of insurance calculation and switch to usage-based insurance (UBI) (Fig. 4).

**Fig. 4.** The models of insurance pricing. (Bian et al, 2018)
UBI includes two components which are different in amount of data needed and depth of its analysis. The first one, called pay-as-you-drive, is payment for mileage and time of driving which could be determined by quite simple on-board systems. The second model of insurance premium calculation deals directly with driving performance and is driven by probability of accident occurrence. By now, it is the most advanced and fair system of premium payment calculation with already mentioned systems of driving pattern identification involved. Based on this, there was a prototype for insurance premium calculator proposed with analysis of all accident risk factors at both vehicle and driver levels (Bian et al, 2018).

As influence of risk factors and methods of drivers’ division into low- and high-risk groups have already been identified and discussed, possible pattern of insurance calculation proposed is worth briefly mentioning (Fig. 5). The main outputs of the system are driving score and price of insurance. Quite obviously that better score generates lower price. The example of the end calculation is presented on the Fig. 6.

![Flowchart](image.png)

**Fig. 5.** The algorithm for UBI calculation. (Bian et al, 2018)
The system quite clearly represents basic factors on which calculation is operated. Driver’s style is compared to average driving pattern, and the performance is assessed. It could be also seen that based on the same parameters conventional insurance calculation would result in 48.5% more cost for this particular driver. This score calculation method could also be used in the gamification approach (see 2.2.3), encouraging drivers to behave safer by proposing them additional financial motivation from saved money.

For vehicle fleet, implementation of such an approach can become a real data-driven mean of cost reduction. Usually, the whole fleet is insured by one company, which provides discounts for such a big number of vehicles at once (Think Insurance, 2018). In the above examined case, vehicle fleet owner could save around 110 €/vehicle. Considering that calculation parameters are precise and easy to understand, fleet users could directly influence these parameters, at the same time improving driving safety and discount policy of fleet owner for them or their company. Additionally, the difference in premium for conventional insurance calculation and UBI one will increase together with drivers’ performance.

**Fig. 6.** Advanced UBI premium calculation (the currency is RMB: 10RMB≈1.3 EUR). (Bian et al, 2018)
improvement, and the absolute economy will be achieved with 100 driving score according to the system. It could seem that for insurance companies such an approach is not as profitable as they would get fewer premiums for every vehicle. However, it is worth saying that in case of car accident insurance compensations to vehicle owner could exceed insurance premium in dozens of times (Frontier Economics, 2015). Therefore, losing some money in premiums, insurance companies are decreasing uncertainties and acquire risk security from more number of compensational payments.

Additionally to driver’s behavior estimation, insurance companies and fleet owners could take into consideration two parameters of vehicles among its brands – crash worthiness (CW) and aggressivity (CA). CW defines ability of a car to protect its driver during crash and crash resistance in a whole. This means that car brands with higher CW would require less repair compensation, and therefore insurance premium could be lowered. What for CA, it determines damage to counterpart vehicle and its driver during car crash. In contrast to CW, crash aggressivity is better when it is lower. However, quite often these indicators have negative correlation between each other, and more crash protected car brings more damage to another one. But anyway, if fleet user was guilty in a car accident, lower CA of his/her car would require less compensation to counterpart vehicle or driver’s health.

To determine CW and CA among different car brands, a study was provided, involving data on 17,178 car accidents and including 23 the most widespread car brands (Huang et al, 2014). The brands have shown quite different results both for CW and CA: some of them advanced in both parameters (high CW and low CA), some had mixed ones, and others fell behind in both CW and CA (Fig. 7). Thus, among car brands they are luxury Volvo, Lexus, Infiniti and Cadillac have shown significantly higher than average self-protectiveness. More affordable Ford resulted in 5% more than average CW. Other brands have shown average or quite low CW.
In contrast, most of car brands show average CA except for Volvo with quite low value and Volkswagen among the widespread ones with higher than average CA. What comes to brands’ origin, European cars show the greatest CW while South Korean have the lowest one. However, all brands among different countries have average CA. The leader among all brands is Swedish Volvo with the highest performance of self-protectiveness and the lowest crash aggressivity.

Fig. 7. Crash worthiness and aggressivity among car brands. (Huang et al, 2014)
For safety issues, fleet owners should certainly take into consideration such analysis both to increase vehicle driving performance and decrease operational costs of their businesses. Data on CW and CA of car brands and their origins could also be used for insurance companies to optimize their insurance plans according to not only basic information about driver and vehicle, but also using advanced OBD and telematics systems, which could provide quite comprehensive and reliable data on car accident probabilities of an every single driver.

2.2.2 Collecting data from the best drivers for cost reduction

In vehicle fleet scales vehicles are used for different purposes. Some of them are for long-distance movements, others are for short trips within city line. Quite obviously, city traffic differs from the countryside one by fuel consumption as driving patterns of different people do. Drivers with higher fuel consumption generate additional costs for fuel for vehicle owners and usually drive vehicles in such a way which with higher probability will cause its deterioration. But in theory there is an ideal driving pattern exist which performs lower fuel consumption, more safety and accuracy, and it is a high chance that such drivers are present among vehicle users. This generates an opportunity for business owner to collect data about this driving pattern using OBD systems and later turn it to educational materials for all vehicle users to achieve lower fuel consumption and higher safety among the whole vehicle fleet.

To determine the features of ideal driving it is necessary identify key factors, influencing fuel consumption. In this case, emphasis is made on the factors dependent on driver rather than physical ones like vehicle’s air resistance. Thus, fuel consumption is influenced by (Berry, 2010): 1) driving speed – both too high and too low speeds increase fuel consumption; 2) number of abrupt accelerations and decelerations; 3) frequency of short trips – vehicle engine doesn’t have time to
gain full power; 4) irrelevant use of gear box; 5) unnecessary warming-up (Ainomugisha, 2016); 6) excessive weight; 7) irrelevant use of air conditioning.

Every factor from the above mentioned list could be influenced by a driver. To start fuel reduction strategy, general instructions for all fleet drivers could be elaborated, basing on the main factors of high fuel consumption. Several technologies are already available (Rogavichene & Garmonnikov, 2017) for driving pattern identification, analysis and correction. They are mainly based on sensors for acceleration and its abruptness measurements, speed trackers, GPS systems and OBD (Andria et al, 2016). Therefore, there are two approaches for fuel consumption reduction.

The first one includes data analysis of all drivers in a fleet. During a certain period of time data is gathered from all vehicles, which is connected with drivers using them. After this period, the best performing drivers are chosen, and analysis of their driving style is made, aiming to elaborate the best driving pattern which all vehicle drivers should follow. This ambition could be additionally motivated from the fleet business owner, e.g. providing discounts for the most fuel-saving drivers or any other means of reward.

The second approach to fuel saving can be called semi-autonomous. Again, collecting data on the best driving efficiency will provide exact patterns for low fuel consumption driving (e.g. exact speed on highways, in city). Later on, numerous alarm systems could be programmed to inform driver about deviation from established pattern and correct his driving. In the ideal case, drivers will get used to this style and their fuel consumption will decrease even without constant warnings. This approach is less user-friendly as not every driver is willing to get corrected, therefore more clear motivations and broad educational programs are supposed to be applied in fleet companies.
In general, such low fuel consumption initiatives are called eco-driving. Many scientific studies are dealing with it elaborating various educational courses aiming to teach people to drive ecologically and, consequently, reduce emissions. Such educational courses provide quite similar results in percentage of fuel consumption reduction. Light-duty vehicle drivers show results of 4.6% in city (Jeffreys et al, 2018) and 2.9% on highway (Barla, 2017) less fuel consumption. Heavy trucks provide data about 6.8% (Diaz-Ramirez et al, 2017) less fuel consumption due to educational program. These results are considered as quite significant by the studies, but in some cases it is also reported that after a time efficiency of fuel consumption reduction decreases and becomes negligible. To cope with it, such educational programs should be interconnected with data-tracking on-board systems for constant fuel consumption monitoring and drivers’ behavior correction to achieve even better results.

Except driver’s behavior only, several driving scenarios are also worth taking into consideration. Different ideal driving patterns exist in these scenarios as driving environment also influences fuel consumption and, consequently, driving style. Thus, the scenarios could be urban, semi-urban and countryside driving, where some additional dimensions (like main or secondary road driving) could be allocated. Then, there are several weather conditions among these scenarios to be taken into account. And finally, dimensions of day- or nighttime, heavy or soft traffic, etc. are also to be involved. Among the whole system, ideal driving styles could be found and a type of instruction created. For example, while driving in urban conditions during nighttime snowy weather and soft traffic, the ideal speed for fuel economy is X kph, the safe braking distance is Y m and so on. Such a precise instruction for every possible driving condition would make vehicle fleet management beneficial both for fleet owner and drivers as it decreases driving uncertainty and increases fuel savings and overall safety.
2.2.3 Gamification in increasing vehicle fleet drivers’ performance

Gamification in fleet business has taken its place comparably not long time ago. The term itself appeared in 2002 and only by 2010 it started to be used widely. By now, it is quickly developing trend among various types of businesses, which has already proved its efficiency. Gamification is the use of game-mechanics in a typically non-game context (Verizon, 2018). The process supposes using of software (usually mobile applications like on the Fig. 8) or sending e-mail with driver’s weekly results compared to other ones to increase involvement in a company’s business and at the same time learning of better driving patterns with higher performance. Usually, gamification in a vehicle fleet is a type of competition of a driver with himself or with other drivers for increasing efficiency of vehicle use.

![Fig. 8. Example of Telogis software for gamification. (Wolski, 2015)](image-url)
Gamification is closely connected with telematics systems as the whole information about drivers’ performance is got by means of remote controlled OBD and geolocation systems. It in a certain extent diminishes possible drivers’ inconvenience from using “Big Brother” monitoring as not every driver would be happy of the fact of being watched. Instead of that, every driver is given a set of performance goals to be achieved in a certain time period like reducing hard accelerations, brakes or idle working of engines. After this time period, drivers are compared to each other and the best ones are identified. Many companies offer different prizes for drivers whose results were recognized as the best ones: from gift cards and souvenirs to large cash bonuses and other significant motivators (Wolski, 2015). The main advantages of gamification implementation include better fleet management, vehicle maintenance cost reduction and adoption of drivers to better driving style as they are able to get feedback during all stages of a trip.

The experts note, that despite the idea of gamification and its operations are quite simple, there are some rules for the best results achievement. The main one is that a company should concentrate on a couple of driving issues only during setting of goals. This means, that improvements are to be made one by one, e.g. firstly eliminate idle engine working to save fuel in one period of time, and only then set a goal for drivers to reduce hard accelerations and hard braking in another period. If fleet drivers would concentrate on plenty of improvements at once, it would be both hard for them to control their behavior and for a company to manage their success. The second rule is setting short duration of time (around 14-90 days for a period) to keep drivers willing to change their behavior and not to get them bored from too continuous process.

The main idea and advantage of gamification is incentivizing good driving behavior rather than detecting and punishing bad one. Up to 30% of vehicle maintenance costs depend on the way the vehicle is driven (discussed in 2.2.2) and it is possible to reduce them by changing drivers’ behavior by a positive approach. Thus, there
are the following results reported to have been achieved by means of gamification among vehicle fleets in different industries (Chisman-Duffy, 2018): 1) ventilation specialists EnviroVent have experienced 10% drop in fuel consumption and consequent £36,000 of annual savings; 2) road transport and plant hire companies Pentavler and Garichave gave their drivers quarterly bonuses for their achievements of pre-determined targets, which lead to benefits of £50,000; 3) traffic control solutions company Traffex reduced its fuel bills up to 50%. In average, the companies which applied gamification in their businesses have experienced return of investment within 9 months which makes gamification quite low-cost, but still simple and efficient mean of vehicle fleet management improvement.
2.3 ECONOMICAL MODELS FOR FLEET SCALE COST REDUCTION

One of the most common facts is that every business tries to reduce its costs as much as possible. Vehicle fleet businesses are not exceptions for this as transport management very often requires high amount of expenses on maintenance, operations optimization, etc. For a vehicle fleet owner there are lots of opportunities for cost reduction, because big number of cars in a fleet creates new ways of financial economy unavailable for private vehicle users.

2.3.1 Re-purposing in vehicle fleets

Usually, vehicles are supposed to be used no more than 4-5 years, and in case of vehicle fleets this time period is even less – around 3 years or 100,000 kilometers of mileage. After that, they can be either utilized or resold for e.g. private use or to other company. The main problem is that during vehicle fleet operations cars are used quite intensively which can result in automobile parts’ worn out and, therefore, lots of maintenance needed for that. This generates either high cost for fleet company to bring a car to an appropriate state for sale or low price for the car in case if fleet company doesn’t wish to deal with the car’s fixing and maintenance.

Therefore, it is highly important to monitor vehicle state and maintenance conditions for not loosing vehicle’s value when time of possible resale will come. For these purposes, systems of dynamic decision making are under development to help fleet owners not rely only on pre-determined patterns of car utilizing or replacement based on car age or faulty conditions, but also track vehicles’ state for necessary operations. Aimed on that, the system by Stasko & Gao (2012) uses approximate dynamic approach in making vehicle purchase, resale and retrofit decisions based on stochastic vehicle breakdowns.
The main parameters for evaluating vehicles’ cost and calculating decisions are car’s age, maintenance status (no maintenance needed, some maintenance needed and completely faulty) and statuses for retrofit (compliant or non-compliant). The initial aim of the system is to determine how much money is needed to be spent on vehicle’s maintenance and repairs to keep using it. Based on this data, the system assumes if it is more feasible to fix some faults, to resale the vehicle or to utilize it if it is completely faulty. The second core operation is to maximize discounted future value of car as together with its mileage and parts worn out potential price for its resale is being reduced.

As for randomness in the system, its functions based on previous data generate random variables for breakdown events description for pre-determining vehicles’ state for the future periods of time. Vehicles with serious faults are sold to scrap; other vehicles are allocated to different type and intensity of maintenance according to probabilities of faulty situations occurrence. Additionally, the system determines feasibility and compliance of vehicles for retrofitting. Even if potential costs of this operation are quite high due to equipment for retrofit and related set up expenditures, retrofitting can be feasible as it increases overall vehicle value for resale and offsets these additional costs.

Quite interesting results of the system implementation could be seen on the Fig. 9. The assessment was made for a fleet of dump trucks with quite long service period. The solid curve represents actual probability of vehicle retirement depending on its age. This means that practically proven lifetime of vehicle in a fleet is 10 years. After that, the probability of its serious fault or feasibility of resale increases, and it is not longer used in the fleet. The vertical curve refers to deterministic model of vehicle retirement. The model supposes vehicle retirement in a certain age without any dynamic values assessment. The third curve was calculated by the system and strongly correlates with practical pattern. Therefore, it could be easily seen that not taking to account dynamic variables may result in loss of efficient vehicle usage.
time and lead to early vehicles’ retirement at the age of 12 years while some of them could potentially serve up to 19 years. On the other hand, up to 15% of vehicles need serious repair or maintenance before deterministically assessed 12 years. Thus, approach with dynamic variables more efficiently determines real state of vehicles and helps to get maximum performance from the fleet.

Fig. 9. Probability distribution of a given vehicle to stay in a fleet for X years.

(Stasko & Gao, 2012)

All in all, the system adapts to stochastic state of the fleet and provides cost-minimizing approach for fleet management. Of course, such an approach is much more complex that the deterministic one, but its dynamics and potential efficiency will provide certain benefits to fleet owners, paying back their investments to it.

Based on the above mentioned model, several ways of car resale could be developed. The first one is conventional car resale with discounted price for its
actual condition and positive correlation of its mileage and state. This model takes into account average market car prices with some possible discounts for serious faults and maintenance necessity. The second model could be referred to vehicle repurposing and described as follows. A new vehicle from a car fleet is sent to collects thousands of kilometers per year, but the conditions for that would be “soft” (only highway traffic, no continuous usage during low temperatures, good ecological environment for use and so on). As a result, after few years the car will have pretty high mileage, but still pristine state as the most destructive environment of e.g. urban traffic or freeze hasn’t made an impact on it. Thus, the value of this car will be quite high even despite high mileage, and it could be used for other purposes in the fleet where cheap car (just because it is old) with excellent condition is needed, or it could be resold with relatively high price (compared to the same model of car used in “hard” or mixed conditions) and value for a customer. This is just a new opportunity for fleet owners not only for making profits from usage of car, but also for lower costs of maintenance and for getting significant payback from its resale.

2.3.2 Profitable Vehicle-to-Grid model for electronic vehicle fleet owners

Nowadays, more and more vehicles in fleets are becoming electric as they keep big set of advantages compared to conventional ones: greater energy efficiency, braking energy recovery, emission level reduction and possibility to obtain electricity input from renewable sources (Fiori et al, 2016). Electric vehicle (EV) fleet owners are highly dependent on electric grid for charging their vehicles, and cost of electricity varies from peak periods to peak off ones. This means that during peak period prices for electricity due to high demand increase up to 53% more than during low demand periods (Nord Pool, 2018). This generates profitable economic model for EV fleet owners as they can keep quite big reserve of electricity in their vehicles’ accumulators. This approach was described and assessed in Kahlen et al (2012) study.
The main idea of the approach is to act as electricity prosumer using EVs. Electric cars are charged during peak off periods with lower prices for electricity. After reaching daily peak period the electricity is sent to the grid with higher prices. Considering that batteries will be charged and discharged more often while participating in this type of business rather that during normal car exploiting operations, breakeven point for batteries was calculated with depreciation costs and arbitrage profits taken into account. In average, it was around 0,058 euro per kWt·h.

Considering breakeven point, profitability of the possible business was also assessed. However, it had predictive nature as authors assumed that within some years from investigation EV batteries will increase their capacity of working cycles and decrease prices. Two scenarios for profitability were developed assuming that EV batteries could last for 5000 and 10000 life cycles (affecting depreciation costs). Therefore, taking to account EV market penetration of 13% or around 5.5 million EVs (as was assumed in Germany), the profits were the following: 1) 3.2 million euro per month with EV batteries of 5000 cycles and 2) 10.6 million euro per month with 10000 battery cycles.

As the study was held in 2012, now more information is available about modern EV batteries and authors’ assumptions can be estimated. Thus, batteries with 5000 life cycles exist, but they are not so widely spread, and usual battery capacity is estimated around 500-1500 life cycles (CleanTechnica, 2016). What comes to batteries with 10000 cycles, they are also exist in general, but yet not even for electric vehicle use.

All in all to operate in such a kind of business EV fleet owner should get access to low cost batteries with quite high number of cycles as they will be charged and uncharged more often than during EV energy consumption only. Yet, this model with modern batteries can’t be fully applied in vehicle fleets as it is unlikely to be profitable at least with current state of technological development. Anyway, in the
future cost of batteries with a high probability will decrease, and fleet owners will be able to profitably use their EV batteries as electricity keepers for high demand periods.

2.3.3 Fleet scale re-routing for better performance

One of the most important issues contributing to fleet business optimization is vehicle routing. Appropriately created routes for vehicles, especially heavy ones, are essential for the following business resources: 1) less fuel consumption due to shorter and potentially quicker routes for goods delivery; 2) timing as vehicles should follow delivery deadlines to avoid related penalties; and 3) finances in general. There are many vehicle pre-routing means available now, but the congestion effects on fuel consumption are not taken into consideration in some route planners and transport demand models (García-Castro & Monzon, 2014). Therefore, more important for company’s services to concentrate on implementation of dynamic routing systems as there is always a probability of road accident ahead, which can create quite long traffic jam resulting in time delays and increasing vehicle fuel consumption for fleet owners. To provide an example, typical middle-size automobile in congested traffic would increase its fuel consumption up to 180% compared to free traffic conditions (Treiber et al, 2007). Thus, more advanced dynamic technologies for quick vehicles re-routing are needed to prevent them from above mentioned problems.

To start with, there are several new systems for dynamic routing control, serving for a number of purposes. One of the systems called ICARUS (De Souza et al, 2016) uses inter-vehicle connections for getting traffic events notification, calculation of new routes and informing drivers approaching to congested area. Typically, data gathering and analysis is provided by vehicle OBDs. They are collecting data on vehicles’ geolocation, speed and direction for traffic jam detection and send information to other vehicles connected to re-route them (Pan et al, 2012). The main
problem there is that such types of systems don’t use real-time predictions and are centralized. ICARUS system in its turn is monitoring traffic jams, accidents and other congestions as soon as they appear, and beforehand informed vehicles don’t enter to the blocked / overloaded area. The implementation of the system in vehicle fleet may result in, as authors ensure, 68% reduction of travel time, savings of fuel consumption up to 48% and similar 48% less carbon oxides emissions.

The system for tasks allocation and vehicle deployment was developed by Billhardt et al (2011). It was tested on ambulance fleet for their operations optimization and can potentially be adapted to other types of fleets. It is based on dynamic architecture and determines its operations as allocating the nearest vehicle to a certain task and relocating it for potential tasks predicted by event-driven approach. The system is based on three layers: 1) vehicles as agents, 2) fleet coordination modules and 3) other components for fleet operations (Fig. 10). It monitors vehicles’ state and positions and by analysis of incoming events informs fleet operator if any changes in pre-determined plan are needed. Additionally, predictive module, basing on historical data and current fleet state, calculates the probability of potential tasks and determines the best positions for idle vehicles. As a result of the system testing, it showed 15.8% better time of response to arising tasks. In commercial fleet case this would bring a certain additional amount of money to the fleet owner whereas in case of ambulance fleet this response time reduction would save patients’ lives.
Another solution for routing processes is invented algorithm for GPS systems based on driving trajectories, revealed by routing data collection (Li et al, 2018). Typically, GPS services aim to provide routes for drivers to let them to be at destination point as soon as possible, providing the shortest route with minimal traffic congestion. In this case, trips are relatively short or irregular. But in the case of a fleet business, the main aim is optimization of logistic processes, and just the fastest way and the earliest time of arriving is not enough. Instead, routing system should also take into account appropriate time of departure, on-route parking points for rest and relevant time of e.g. good delivery. Thus, the system is aiming to solve minimal on-road time problem, using analysis of historical driving trajectories.

There are three scenarios of the system usage provided by the authors. The first application is just the fastest path for a trip with the latest time of departure. This
means, that if user wants to achieve whatever place by the certain time, the system will provide information about the latest time user should depart considering traffic jams and other issues. In vehicle fleet, this application could be quite useful just for better services.

The second opportunity is for heavy trucks drivers, which allows designing route with minimal on-road time for quick destination achievement and with forced time periods for rest on special parking places. These stops for rest are called force waiting points which are taken into consideration during route timing. Thus, route design ensures the fastest possible delivery together with sufficient time for driver’s rest on pre-defined on-road service stations.

The third application is for long-journey travelers, which allows planning their route considering desirable on-the-way stops in some preliminary determined places. The main difference from truck drivers’ application is that during a journey there is no need to hurry, and driving at nighttime is excluded from route calculations even though exactly at night driving conditions (from congestion point of view) are the best. Taking to account fleet business implementation, such an application would be just an attractive addition to a leased car.

To sum up, it is worth saying that modern widespread technologies although provide online and quite quick reacting GPS services for routing, they are still lack of solutions for time and fleet management. The main technology needed for fleet operations is time of departure prediction with as much as possible traffic jams avoidance. For this reason, there is quite big number of specially developed technologies which could provide user-friendly and affordable means of vehicle fleet optimization, whether it will be a fleet of heavy good carriers or just one of cars for leasing.
2.3.4 Data-driven analysis of geographical enquiry rates in carsharing for better availability

Carsharing is a relatively new vehicle fleet business model of providing cars for drivers with minute-by-minute or hour-by-hour payment. This model is operated in B2C mode, very often via mobile application. This system could be used by any driver who has signed an agreement with carsharing company and satisfies all requirements like driving age, experience, etc. According to recent studies, carsharing positively contributes to ecological situation. Thus, 1) 30% of users gave up owning cars, especially when it was the second or third car in one family; 2) car sharers drive 15%–20% less kilometers than when they owned a car, and the main conclusion from that is 3) car sharers emit from 13% to 18% less CO₂ than during car ownership (Nijland & van Meerkerk, 2017). These results are quite significant and demonstrate one of the most positive impacts of carsharing.

Carsharing business usually uses geolocation systems on its cars, thanks to which drivers are able to find available cars and choose the closest one to their location. Quite obviously, that there can be different types of car users. For example, one user needs a car anyway and, therefore, will go to its place even if it is not so close to him. Other user has some alternatives, e.g. either to use shared car or to go by public transport or taxi. His decision is likely to be affected by the proximity of shared car. It is also worth taking into account that public transport and even taxi (depending on time and distance of a trip) could be much cheaper than shared car. Additionally, carsharing sometimes supposes partial financial responsibility in case of car accident even despite the fact that fleets are insured by vehicle owners. However, more comfort and freedom during self-driving play quite important role in customer’s choice. Thus, to gain the highest share of users, fleet companies need to know where the most active users are located and elaborate a special system of user services to track the frequency of enquiries in dependence from geolocation. Basing on this data, carsharing companies could distribute cars around these places.
with higher efficiency to increase the probability of choosing their transport rather than alternative ones.

Therefore, this issue could be referred to a problem of vehicle distribution. Owning a certain number of vehicles, carsharing companies need to identify locations of car parking, taking into account that every station needs to be in a walking distance from potential users’ location. This would prevent them from discarding car sharing in favor of public transport or taxi. For these purposes, some automatic services for car stations distribution have already been developed. For example, Rickenberg et al (2013) have proposed an automatic carsharing distribution system which could help carsharing businesses to plan their activities. The system is hardly dependent on maximum acceptable distance to vehicle stations and based on geographical coordinates. It also takes into account the number of demanded cars on an every single station, which determines not only the issue of proximity, but also availability. Additionally, quite big number of variables could be adjusted for better calculations and vehicle cost reduction, but without going very deep to mathematics, visualized example of calculation is presented on the Fig. 11.

![Optimization Result](image)

**Fig. 11.** Visualized calculation for carsharing geographical optimization. (Based on Rickenberg et al, 2013)
The calculation was provided for German city Hanover with optimal population number and density. For this calculation the maximum distance to a car station from any demand location was set to 300m. “Kp” value here is customer parameter which determines number of people using one car per day. Considering costs of vehicle maintenance and stations, annual costs of the model are presented. For the system quite little time is needed for a good solution development, and, as the most influential parameters are taken into account, the calculation can be considered as reliable.

Besides just physical distribution of vehicles around stations, they also need maintenance and refueling by fleet staff as these duties are not supposed to be done by carsharing users. This task has several dimensions as carsharing is operated in different modes. First of all, it could be either round- or one-way trip which defines if car user is supposed to return a car to the place of pick-up or not respectively (Barth & Shaheen, 2002). The second dimension is either to park shared car to a certain pre-defined place (station based approach) or to any available place in pre-defined zone (floating system) (Santos & Correia, 2015). Obviously, round trip with station system makes maintenance, fueling and relocation of vehicles much easier for staff; however, user-friendliness in carsharing expects not forcing users to return shared car to the same station of pick-up.

For meeting the requirements of high quality services in carsharing mathematical models of staff optimization can help for this task. Santos & Correia (2015) have developed a system for optimization of staff working hours for maintenance and fuelling based on mixed integer programming (MIP). The system is aimed on cost reduction during maintenance operations, taking into account demand from consumer’s side, ability of staff to use carsharing vehicle and to move by the same car, considering number of seat places in it, and other dynamic parameters which influence maintenance operations. Basing on quantity of stations and staff members, the system allows calculating probable decisions within time period from 5 seconds.
to 15 minutes. In general, the system was tested for semi-operational mode of one-way trip and station based approach (the main problem of this combination is unbalanced car distribution), but it could be modified to be used both with more user- or staff-friendly approaches.
2.4 MAINTENANCE OPERATIONS WITH DATA ANALYSIS

Every vehicle needs maintenance from time to time. Unfortunately, by now there was no any vehicle detail invented for unlimited time of service, and worn out parts are needed to be replaced by spare parts. Usually, such a worn out part is detected when there is something visibly wrong with a vehicle. Sometimes, it could result in a car accident or at least waste of driver’s time during sudden fault and other undesirable consequences. Therefore, there is a need for vehicle owners to detect potentially faulty car detail in advance and replace it by a new one when it is not too late.

2.4.1 OBD systems for maintenance prediction

Typically, faults in car mechanics occur not as suddenly as it could seem. Lots of identifiers of faulty operations exist, letting know drivers that something is not right: unwonted sound, lack of performance, visual damages, etc. Conventional approaches to faulty part detection included just visual inspection which didn’t always allowed detecting faults at once. Anyways, this direction in car industry is now under development, and data tracking via OBD technologies can make the process of fault detection more quick and reliable, applying new methods for car diagnostics.

The core process of OBD systems during faults detection is continuous measurement of vehicle parameters and their comparison with standard ones. For example, in a study by Prytz et al (2011) the authors tested OBD system for relationship discovery between signals from sensors and deliberately injected faults into a Volvo truck. This time, the faults included air filter and grill clogging, charge air cooler lack and partial congestion of exhaust pipe. Firstly, normal operations mode was recorded several times to have a sample for comparison. Later, trips with different faults combinations were recorded. It was found that signals responsible
for faults like air filter clogging were quite easy to distinguish from normal operations while others were not so obvious. The authors reported that the accuracy of data recording was not ideal as the data set was pretty sophisticated. Anyways, for faults detection the accuracy isn’t expected to be high as there is a need to detect a faulty part in a certain time proportion for its replacement rather identifying exact hour or minute of its failure. All in all, it was only a method for future diagnostics system, which will be able to detect anomalies in vehicle operations in an autonomous way.

Another possible example is an implementation of COSMO approach, which is short for Consensus Self-organizing Models (Rögnvaldsson et al, 2014). In the case of the investigation a fleet of buses was used. The main idea of the approach is to install OBD systems on a fleet of similar vehicles which would provide a normalization of collected data. This means, that the system monitors normal operations of vehicles and detects deviations which later could be considered as faults to provide information to a fleet maintenance for their identification and elimination. As amount of data is quite large, the system supposes autonomous data filtering for dealing with only interesting deviations which could potentially predict a fault in vehicle mechanics. For more accurate fault identification, the system also needs information about previous maintenance operations in vehicles.

After collection of data about possible model configuration, it is send to central server for its analysis and possible faults identification. The consensus between each other vehicles is checked and vehicles with deviations and corresponding to them sub-systems are flagged as potentially faulty. To predict the exact vehicle system with a fault, quite large library of already detected faults is needed for comparison.

Another approach to it is using special off-board system for fault simulation. It would allow modeling offline faulty situation to compare it with online vehicle
performance right on the way. This will diminish demand for quite advanced on-board hardware for faults detection.

The main problem with both approaches is quality control, because faults detection is still not as perfect as it is expected to be. Anyways, it is possible to design self-learning approaches with existing technologies to improve quality of maintenance databases.

Using data-based approaches for the maintenance prediction generates one more opportunity for fleet company costs reduction. It could be used together with conventional maintenance prediction as well, but with smaller reliability anyway. The idea is based on that in big vehicle fleets cars are served by groups as they have approximately similar maintenance status. This is done when a car achieves new 10–30 thousand kilometers of mileage or after a certain time period of its use. Relying on maintenance prediction techniques there is an opportunity to predict the peak for a number of cars needing regular service and, most likely, maintenance companies would be glad to take such a big order and propose a batch price to a fleet owner. In this case, vehicle fleet business gets not only reduced costs of maintenance, but also benefits from diminished management costs as organization of one big maintenance event for some dozens or hundreds of cars is much cheaper than move them one by one to a service station. For example, a group of cars could be moved to a service place by a large car transporter and by one driver only at once rather than paying to several drivers for their work hours or wasting much time in case there are no enough drivers to move every single car to the service.

All in all, it goes without saying that maintenance operations are needed to be delivered not only qualitatively, but also before faulty situation is actually occurs. For this reason, fleets owners need to apply modern technologies for faulty parts identification and maintenance as most of vehicle’s details are interconnected, and fault in one part can potentially cause wearing out of other one. Irregular vehicle
maintenance can potentially lead to loss of company’s money and decreasing of its performance and customers’ loyalty.

2.4.2 Tire maintenance: potential problems and solutions

Even with some dozens of cars in a vehicle fleet changing of tires after their working term expiration can cause quite high financial costs for a fleet company. Good tires which provide safety and control are expensive and need to serve as long as possible. The most common reason for any tires related problems is simple under- or over inflation which relatively often causes more severe faults leading to car crashes and other incidents.

The most severe circumstance of irrelevant tire pressure include tire blowout. The mechanism of it is that due to under inflation too much tire surface touches road, causing increase of friction and overheating (Greer, 2017). On-way tire blowout can make harm not only to a car driver, but also to nearby vehicles and people. Crashes of heavy trucks are statistically associated with tire problems (Teoh et al, 2017). Other related problems are: poor fuel economy, wasting of estimated 3.5 million gallons daily (in the United States); increased CO\textsubscript{2} emissions proportionally to tire power loss due to incorrect pressure (Sina et al, 2015); dangerously longer stopping distances, ineffective and sluggish handling, reducing the safety of defensive driving techniques; faster tire wear, leading to more failures and accidents (Aleksintser, 2014).

Fortunately, modern data-driven technologies allow monitoring tires state and potentially prevent trips with under inflated tires. One of the most sensitive and reliable sensors is based on Microelectronic Mechanical system (Zhang et al, 2011). Special device in attached to every wheel, providing data about their pressure and warning driver if any of wheels is under inflated. More advanced, but presumably more expensive are the systems with automatic tire inflation (Reiter & Wagner,
In any case, technologies for tire pressure monitoring are available and fleet businesses can invest finances to install them on owned vehicles. Data provided by pressure monitoring systems can prevent fleet owners not only from quick tires deterioration, but also losses for car repair due to tires fault related crashes.

To provide economical evaluation of relevant tire pressure importance, average costs for worn out tire replacement could be estimated. Usually, fleet vehicles are actively used, and tire deterioration is conducted under average time horizons. As vehicle fleet owners need to install high quality tires for better services, average tire price will be around 150$ per tire or 600$ per full set of 4 tires (CostHelper, 2018). Their warranty under proper conditions is estimated around 4 years. Alternatively, during constant operations under too low or high pressure conditions lifetime of tires decreases up to 25% (DriveSure, 2012), i.e. to 3 years. This means that after each 6 years of operations fleet owner would save 300$ from every single car due to tire pressure monitoring only.

All in all, it could seem that tire pressure is not an issue of very high importance, and maybe investing to active safety systems would result in more benefits for a fleet company and its partners; but, according to above provided analysis, tire pressure monitoring is one of the most basic things to be done, and together with pretty low-cost monitoring systems it could be provided quite easily.

### 2.4.3 Comprehensive solutions supply

Together with single services aimed to one of the vehicle’s parameters, some companies suggest complex solutions for the whole vehicle fleet. A fleet company and a solution supplier allocate goals which are needed to be achieved by fleet vehicles by the end of a certain period. Some companies may even guarantee the result or pay back money if some of the goals were not achieved. Usually, such complex solutions are directed on fuel consumption reduction, some maintenance
operations provision, fleet drivers’ training and so on. Both of the companies have profits from such a kind of cooperation as the fleet owner reduces its management, operational, etc. costs, and the solution provider gains income from operations in which it is really proficient.

One of the companies doing this holistic solutions provision is famous tire producer Michelin (Michelin Solutions, 2013). Together with Michelin Solutions establishment in 2013, the company started to cooperate with heavy truck vehicle fleets to provide complex solutions for fleet management. The company decided to make this step in its business according to the following background: 1) forecasts saw an annual increase in fuel prices up to 4% each year, which generated a need of its consumption decrease; 2) fuel consumption accounts for 30-40% of heavy trucks maintenance costs in average around Europe; 3) for 120,000 km mileage per year truck monthly fuel consumption equals or exceeds annual tire budget; 4) annual net profit of a tractor-trailer in Western Europe is estimated to be around 3,000 €, and it could be increased by higher level of fleet management (Michelin Solutions, 2013).

Thus, aimed to solve the above mentioned problems, Michelin created multi-directed program for truck fleets management called EFFIFUEL. The company in its press release (Michelin Solutions, 2013) allocates four the most important applications for their system. The first one is drivers’ behavior monitoring and consequent training courses by professionals for its improvement or correction (see also 2.2.1 and 2.2.2). The second direction is fuel consumption monitoring and analysis, which also includes development of possible means of fuel economy. The next one is telematics display units installation for remote analysis of vehicle parameters. And the forth application is tire management optimization based on a per-kilometer price and pressure monitoring systems. The main advantages for a fleet company are based on guaranteed performance objectives, comprehensive driver management, support of an ecosystem of Michelin’s expert partners and risk taking and money compensation in case of not meeting pre-determined objectives.
During preparation to the fleet management program, objectives for fuel consumption are determined in liters per 100 km. The idea is that every 2.5 liters/100 km fuel consumption reduction generates annual savings of 3,200 € for long-haul and 2,400 € for regional vehicles.

Whereas three of four directions of Michelin’s solutions have been already mentioned and discussed, the forth one is worth separate mentioning. It is a completely new solution for vehicle fleet tire management, which the company itself calls “Switch from selling tires to selling kilometers” (Michelin Solutions, 2013) or, to say it in more clear way, switching from product (tires) to service (tire management) supply. Thus, the company takes commitments to monitor tire state and appropriate utilization operations for the whole fleet via tire pressure control systems and other means of inspection aiming to prolong tires’ life of service and, consequently, vehicle fuel consumption and relevant emissions. Moreover, the company suggests management of tire lifecycle called 4-lives program.

The main idea of the program is based on comparison with competitors’ tire suggestions and prices. The main reason for tire change is tire tread wearing out, and the time of this process is hardly dependant on tire quality provided by manufacturers. For example, Asian import tire costs 250 € and designed for 150,000 kilometers (1.667 €/tkm). Michelin’s tire price is 400 € and the mileage for it is 200,000 kilometers (2 €/tkm) (Renault et al, 2010). Quite obviously, that Michelin’s tires are more expensive, but at this stage two tire recovery techniques are taking place for tire economical value addition – tire regrooving and retreading. The first process supposes cutting out a layer of rubber right from the pattern of used tire to improve tread’s state to appropriate for use condition. The process of retreading is provided in three stages: 1) almost full tread shear off of used tire; 2) adding some layers of new rubber to the tire; 3) molding of new tire tread under pressure and heat influence. Thus, regrooving requires additional 50 € and prolongs tire life for 50,000 km, and retreading needs 150 € of cost and adds 200,000 km of mileage.
The consequence of operations is the following: conventional use of a tire (the 1\textsuperscript{st} life) – its regrooving (the 2\textsuperscript{nd} life) – retreading (the 3\textsuperscript{rd} life) – regrooving of the retreaded tire (the 4\textsuperscript{th} life) (Table 1).

Table 1. Michelin value adding compared to a competitor. (Based on Renault et al, 2010)

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<th>Competitor</th>
<th>Michelin</th>
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<td></td>
<td>Asian import (no recovery</td>
<td>1\textsuperscript{st} life: no</td>
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<td></td>
<td>operations)</td>
<td>1\textsuperscript{st} life: no</td>
</tr>
<tr>
<td>Cost, €</td>
<td>250</td>
<td>400</td>
</tr>
<tr>
<td>Wear, km</td>
<td>150,000</td>
<td>200,000</td>
</tr>
<tr>
<td>Cost/tkm</td>
<td>1.667 €</td>
<td>2 €</td>
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As a result, the same tire after all operations serves 500,000 km of mileage and costs only 1.3 €/tkm. It is not only cheaper, but also more eco-friendly as during conventional tire use for the same mileage one vehicle needs at least three sets of tires. Moreover, after the 4\textsuperscript{th} life the tire could be recycled for retreading operations. All in all, regrooving decreases tire rolling resistance and weight which results in around 5.4\% less fuel consumption; retreaded rolling resistance is a bit higher compared to initial tire, but service period equals to the later (Lonca et al, 2018). Michelin affirms that only with appropriate tire management these results could be achieved, and Michelin Solutions provide such a service.

Michelin experts emphasize that the approach was not created for managers’ replacement, but to provide them more “resources, visibility and advice to optimize their operations”. Such comprehensive approaches to solutions provision are based on complex data-driven analysis, and in the nearest future it is quite likely for fleet owners to appeal to the companies like Michelin for their management improvement and expert technologies acquisition.
2.4.4 Data-driven CO₂ emissions monitoring for their reduction

High emissions of CO₂ and other contaminants from anthropogenic activities have become a serious problem of the mankind. At the same time, transport is assessed to emit the highest amount of contaminants to the atmosphere due to its quantity and using of fuel combustion. Not a secret that any vehicle fleet business, determining itself as sustainable, should take care about this problem and reduce emissions from its vehicles as much as possible. Fortunately, the world’s scientists and other inventors concerned are already dealing with the problem of high emissions, and some technologies have already been proposed for emissions reduction.

Modern cars nowadays are aimed to be produced with the lowest emissions, and governments are contributing to these initiatives by new laws and financial aids. Of course, such activities will certainly reduce ecological impact of new cars. However, elder cars are still in use, and probably there is nothing to do with it as it is not possible at a time stop using all cars with not appropriate ecological indicators. Moreover, there is one big problem remains due to which contaminants emissions will anyway increase over car’s age. Some studies provide the following information about a period of car usage: diesel car with less than five years in use show 60% less black carbon emissions than those with 5-10 years of use. Similarly, new petrol cars show 47% less emissions (Jezek et al., 2015). In average, every single car should be used no more than 4.7 years before its contaminants production starts to increase sharply (Kagawa et al., 2013). Obviously, almost any car working capacity exceeds this period of use at least thrice and it is much better to concentrate on emissions reduction techniques for vehicle fleet owners rather than just utilize old cars and acquire new ones.

The first step for emissions reduction in vehicle fleet is detection and monitoring of contaminants in exhausted gases. This step at least would help fleet owners to identify which vehicles are the most ecologically dangerous and start emissions
reduction policy in a whole company from these particular machines. It is firstly worth making sure that all vehicles meet the governmental standards of a country, moreover, there are some technologies for emissions composition and amount are available.

One of them is next-generation wireless ODB system for evaluating real CO₂ and NOₓ emissions (Yang et al, 2016). The system includes Controller Area Network interface, GPS receiver and GPRS (General Packet Radio Service), connected to a monitoring center. CO₂ emissions are calculated indirectly by reliance on several factors: fuel consumption rates, temperature of exhausts, humidity and mass air flows. NOₓ ones were measured by direct sensors. In the study, the system was used for bus emissions measurement, but it is also suitable for use for both heavy trucks and light vehicles OBDs. Also, some more scientific methods for emissions rate calculations are available (Oh et al, 2017), but in the case of vehicle fleet mainly technology based methods are more suitable and easy to implement.

Considering technological means of emissions reduction, the most obvious ones are particulate filters (PF), aiming to reduce particle matter contamination, carbon oxides and NOₓ emissions. More often, PFs are used for diesel vehicles exhausts filtration, but petrol PFs are also available and were firstly used in a large scale by Mercedes (Daimler, 2018). Particulate filters are installed on vehicles’ exhaustion systems and serve for filtering mostly contaminating particles from exhausts. However, they also reduce emissions of carbon and nitric oxides.

To prove the effectiveness of particulate filters, some numeric results were obtained during scientific studies. Thus, the study of diesel particulate filter (Yelverton et al, 2015) has shown mass removal of particle matter up to 80-99%, 73.3% carbon oxides and 34.3% of NOₓ removal. For petrol PFs comparable results are expected as both types of filters are working quite similarly. For example, petrol PF according to the study (Demuynck et al, 2017) filters from 70% to 95% of particle
matter mass. Additionally, financial costs and benefits were calculated for PF implementation on gasoline vehicles. Several factors were taken into account: manufacturing costs for filter’s production and its installation, penalty for CO₂ emissions from vehicles, fuel consumption penalty and exhausted filter’s utilization costs. The results have shown that overall societal effect related to gasoline particulate filter installation is around 78 €/vehicle of net benefits and 217 €/vehicle of net cost (Mamakos et al, 2013). Particle filters are needed to be cleaned and renewed from time to time which also could result in some additional costs.

In general, installing filters on fleet cars is not so financially beneficial compared to other systems like safety or active driver’s assistance ones. Conversely, emissions reduction and monitoring systems very often may result in additional costs without any direct paybacks. However, emission reduction is one of the global key issues the mankind facing with, and vehicle fleet owners are responsible for as much as possible eco-friendly business operations. Therefore, on-time emission increase identification by OBD systems is essential for vehicle fleet owners as it allows fleet maintainers changing filters for better business performance and sustainable development.

2.4.5 Tires-related emissions reduction

Rubber as tire material is assumed to be not eco-friendly with its long period of decomposition and highly toxic emissions in case of burning (Lönnermark & Blomqvist, 2005). Therefore, as vehicle fleets are the biggest producers of worn out tires there is a very serious reason for them to use one set of tires for every vehicle as long as possible. In this work, the means of tire service period prolonging have already been discussed (see 2.4.2), but together with financial benefits of long-going use of tires ecological advantages are still worth mentioning.
According to statistics, around 17 million tones of used tires are wasted annually all over the world (Czajczyńska et al., 2017). Typical tire decays for around 50-80 years (Korzeniewski, 2009), and, taking into consideration that new tires are produced and wasted from year to year, tire wastes will only grow together with wheel vehicle production. There are plenty of initiatives for tire recovery and re-purpose programs aiming to use these wasted tires for production of other materials and substances (Maroufi et al., 2017; Song et al., 2018; Godlewska, 2017), but still they are not so widely spread and developed to recycle all the amount of wastes. Therefore, while looking forward for tire recycling programs development, vehicle fleet owners can already do their best to prolong periods of tire efficient usage.

Thus, there are around 1.2 billions of tires wasted annually (Maroufi et al., 2017), and highly possibly that most of them haven’t achieved their full period of efficient use due to under inflation. Assuming that every car would use systems described in 2.4.2 chapter for tire pressure controlling, it is possible to make rough assumption of tire wastes annual reduction. As proper conditions of tire usage increase their life period from 3 to 4 years, annually 25% less tire wastes would be produced. Therefore, there are 0.9 billions of tires in pieces or 12.75 million tones. This means, that the moment of tire wastes full recycling could potentially come much earlier. Of course, this case is quite idealized, but still usage of pressure monitoring systems, starting from vehicle fleets, would further develop and spread this initiative. Tire lifetime prolonging would also reduce wastes from tire production sites, tire changing services and so on.
2.5 SECURITY APPROACHES FOR VEHICLE FLEETS

Right now, technological development of vehicles is operated with rapid pace, and from simple conventional car locks vehicle manufactures had switched firstly to key-controlled automobile alarms and later to keyless vehicle access, using Internet of Things and advanced connectivity systems. Unfortunately, car thieves have also developed new approaches for avoiding these systems, and, if earlier only mechanical manipulations helped them to get unauthorized access, now more advanced car hackers are able to hijack whole fleets of vehicles, which have up-to-date technologies for car access, but lack of sufficient security for theft avoidance. Therefore, security issues of car fleets are also worth mentioning in the work as their threats and opportunities are entering a new era of technological advantage.

2.5.1 Threats and security issues for modern high-tech vehicles

Usually, a modern car is equipped with several wireless devices, e.g. GPS system or simple radio station. Every car system has its range of service, more often shown on images as “waves” for data transmission (e.g. Wi-Fi sign). In recent years, a new term for vehicle equipment appeared based on such an association, and this term is “wireless communication fog” (Silberg et al, 2017). It describes all on-board systems, communicating to each other and surrounding vehicles (in fleet case). Together with better performance of driving, it creates new risks for cyber attacks, which are only increase with continuous communication between fleet vehicles. Having one connected vehicle’s security system hacked, thieves may potentially launch chain reaction of hacking. Moreover, experts predict that by 2020 75% of cars produced will have on-board connectivity systems for traffic control, diagnostics etc., and such a number of devices on each vehicle potentially increases risk of hacking (Greenough, 2016).
Therefore, in the nearest future fleet businesses will need to change their operational schemes, taking into consideration not only better services for physical safety, user-friendliness, etc., but also cyber security. To explain the importance of this, it is worth comparing a modern car with personal laptop. All information on movements, phone contacts, sometimes even credit card requisites could be kept somewhere in car’s computer, and it is potentially available for hackers, even if they won’t hack exactly a certain user’s car, but any car in the fleet connected to others. This means that new fleetwide approaches are to be developed and implemented in vehicle fleet businesses as cyber attack is a real threat for them now and will be even more in the future.

By now, some recommendations for vehicle fleet cyber protection have been proposed by recent studies, which not only provide possible means of protection, but also identify potential directions and bottlenecks for attacks (Silberg et al, 2017):

**Consolidation of entry points.** Growing communication “fog” around vehicles generates new ways and directions for hacker attacks. However, car manufacturers more frequently are using multiple devices from different suppliers for their vehicles to be retrofitted. The main thought is that every service on a single vehicle shouldn’t be unique, and operated by different devices. Much more cost effective to manage fewer entry points to “shrink” potential attack surface without any loss of performance.

**Cyber security design on all stages of production.** Dealing with security of an individual part will not be enough for security of the whole vehicle. Re-thinking of each stage of production is needed for multilayer security of all cars’ interconnected systems.
**Privacy security before new design implementation.** Before any new technology installation on a vehicle, privacy security assessment is needed to be done. Any private data could be potentially used against fleet users; therefore, it is quite important to think about prevention of unauthorized access to users’ data. Another though is that local privacy requirements (of every country of operations) should be also integrated to the security provision.

**Building cyber security organization.** This means reorganization of business and creating special units in a company for dealing with cyber security. The authors suggest paying attention to organizational structure of successful aerospace and defense enterprises as they are dealing with security of their operations and technologies on everyday basis.

**Centralized monitoring of fleet operations.** As more and more vehicles are becoming retrofitted with different OBD systems, the data from them should be monitored, analyzed and checked for every single vehicle. Therefore, specially established centers would have time and resources for providing relevant operations by getting data from vehicles and detect possible threat in advance. Also, there would be a potential mean of identifying by whom the attack was perpetrated. Fleet centers also could serve for better driver’s services, such as fuel reserve monitoring, navigation systems etc. to increase user’s confidence and safety.

**Fail-resistant protocols.** In the future, electronically controlled accelerators, also known as “drive-by-wire” technology, will be even more spread among new cars. Later on, even more advanced automatic steering wheel technologies will be installed on vehicles. They together with higher driving performance generate new threats as electronic systems can suddenly fail and ignore physical inputs, especially being hacked. In this case, a driver will be in a real danger as he can lose control over his car due to faulty electronics. Therefore, the authors emphasize the
importance of creating priority protocols for such systems, which will allow overriding control over car to driver if conflict of different data inputs occurred.

**Collaboration on cyber security solutions.** There are several parties involved in the cyber security process, e.g. manufacturer, technology supplier, insurer etc. Due to competitive issues, most of information and know-hows are not disclosed to other participants. However, partly due to collaboration of different parties cyber threats could be diminished, and means of cyber protection can potentially be raised to a new level.

**Reduction of third-party risks.** As cyber attack can occur not only due to fleet security management, but also because of weaknesses of third parties (e.g. suppliers), there is a very essential need for enhancing their certification and transparency of operations. By establishing standards and requirements of third parties, both vehicle manufactures and fleet owners would reduce cyber risks for their businesses.

All in all, the main dilemma of cyber attack threat for a vehicle fleet is that its probability is quite low thanks to the most advanced security systems and electronics; however, the severity of attack can be disastrous for fleet business as once getting access to only one vehicle, due to connectivity hacker can potentially hijack or make any other harm to every vehicle in the fleet. So, even relying on the security systems fleet owner should take care of upgrading fleet cyber and physical security, developing new methods and approaches because, unfortunately, car thieves and hackers do the same to avoid high-tech solutions and make their unfair “work” anyway.
2.5.2 Unauthorized access security

As already have been mentioned, conventional siren systems are based on electronic algorithms which are quite hard, but still possible to hack. Therefore, more or less advanced hacker can get access to a car and hijack it or at least steal something left inside. For this reason, additional systems of authorization are needed to prevent car hijacking even if someone have got an access to it. They are usually restrict driving by block of engine starting if a driver has no a special device with him (Rajendran & Francis, 2011) or hasn’t authorized by other more advanced means like fingerprint scanning.

It’s worth saying that key access (and based on it means of authorization) is quite unreliable as any key could be potentially stolen. Therefore, if there are no additional means of security car thief gets full access to a car, and most probably only hijacked car searching and identification operations would help to return it (see 2.5.3). This means, that for higher security it is not enough to have only one device. Each fleet driver should also have personal ID (card or key) for driving or, in ideal case, use unique means of authorization (like fingerprints).

Quite simple and reliable for authorization process in vehicle fleet could be ID cards or chip keys, which some of the systems already use (Roseman, 2018). In such cases besides conventional car access systems each driver is allocated to one or several cars in a fleet. Access is provided by fleet management and is strictly controlled. Electronic device reads data from a key or an ID card and allows starting engine and drive a car. Such an approach allows not only controlling cars’ security from hijacking, but also making sure that within a fleet there is no car misuse by unauthorized drivers.

Probability of stealing both key and e.g. ID card is quite low, but, anyways, it exists. For example, a driver can keep both of them in one place which easily
provides access to a thief. Therefore, the most advanced system of authorization by now tends to use unique biometric identification which can’t be stolen and almost impossible to fake. Biometric identification is not only limited by fingerprints. There are also such means like voice, signature, face recognition, etc., but still fingerprint authorization is the most reliable one (Fig. 12). Within the fingerprint method there are two techniques of matching: minutiae-based and pattern-based. Between them, the first one is more reliable as it not only matches two images of input and stored patterns, but also checks location and direction of separate points of them (Walia & Kumar, 2011). Ultrasonic minutiae scanning by now is the most reliable technique as it avoids fake authentication and has low false rejection rate (0.1%) and false acceptance rate (0.01%) (Kiruthiga et al, 2015).

Fig. 12. Working model of fingerprint authorization. (Based on Kiruthiga et al, 2015)

Thus, the system developed by Kiruthiga et al (2015) involves the best of above mentioned technologies for vehicle security. It can work both with and without battery supply. In case if a person fails identification, SMS (Short Message Service) is send to its owner, and the car’s engine immobilizes. If the owner’s network is faulty, the system can send emergency message to the nearest police station. Also, as a car could be moved away without even opening it (e.g. loaded to other vehicle),
GPS tracking is also switched on even without actual working of engine or battery supply. Thus, parking location of car is stored in the system, and in case of vehicle lifting up or unauthorized movements SMS is sent to its user for possible theft detection.

It is worth mentioning, that in the above example security systems based on different technologies are serving for similar needs. This means, that rather than installing a bunch of different devices for separate functions, in the future vehicles will be retrofitted by only 2-3 ones, aiming to improve the main features of safe, secured and user-friendly driving. For example, Roseman’s (2018) Fleet Journal besides driver’s authorization combines some more applications in one device only: records of trip data (see 2.2.2, 2.2.1), speed limit warnings (see 2.1.1), automatic vehicle identification at entrance, speed recording, automated fuelling unit and some more minor applications (Fig. 13).

![Multifunctional vehicle management system](image)

**Fig. 13.** Multifunctional vehicle management system. (Based on Roseman, 2018)
Such an approach would allow fleet companies to manage their vehicles efficiently (as less number of devices requires less maintenance) and without high expenses (as one multifunctional module would replace operations of several single task-oriented ones).

2.5.3 GPS data analysis for hijacked vehicle detection

Over the years, car manufacturers have been upgrading their vehicle security systems making them more reliable and sophisticated. Compared to earlier times, now car theft activities have begun harder, less lucrative and more severely punished (Barro, 2014). Anyway, depending on region auto theft can still remain a big problem. Almost every car despite level of security can be stolen because technological progress not always serves for positive needs of people. Black market or self-made devices are still able to cheat vehicle security systems. Moreover, auto thieves have switched to less secured cars without security systems. Usually, they are old cars with year of issue around 2000.

Surprisingly, the highest auto theft rates are in well developed countries. The leader among them is Switzerland with 768.8 thefts per 100,000 of population. In average, there are 178.84 thefts in European Union in 2006 (NationMaster, 2018). From this figures it can be concluded, that operating even in well developed countries, vehicle fleet owners should take care of security systems of their vehicles to minimize any potential risks of auto theft. To evaluate risks numerically, the average financial lost in the US due to auto theft is around 7,680$ (Insurance Information Institute, 2018).

The most widespread mean of auto security is car alarm which, unfortunately, is not as effective as it should be for theft prevention. There are several reasons why alarm protection is quite limited even despite it is used almost on every single car: 1) due to longer distance (range), siren cannot be heard; 2) most of the cars have similar sounds; 3) physically, alarms can be disabled on theft attempts; 4) alarm sound can
be mitigated in crowded areas (Kiruthiga et al, 2015). Therefore, more advanced, but still affordable high-tech solutions are needed for car protection as alarms have become quite old-fashioned mean among security systems.

Quite clear, that even in fleet scales there will be no really big numbers of theft cases, but anyway any business aims to minimize unpredicted financial lost. Moreover, it would be easier with just additional implementation of already existing on-board systems, and there will be no high investment needed for them.

One of the best solutions based on existing systems is just GPS tracking of vehicle by fleet business operator to identify location of any auto on the map. Such a system is available with use of continuous operational reference station (CORS) approach and Mobile GIS (Geographic Information System) technology (Huang et al, 2011). The system allows tracking vehicles from monitor service center (Fig. 14) from several mobile terminals, installed in vehicles. This system also utilizes special data storage systems for efficient vehicle tracking, but for stolen car identification only this might be unnecessary. Anyway, for permanent location tracking if needed such an approach can be more useful.

![Vehicle tracking process design](image)

**Fig. 14.** Vehicle tracking process design. (Based on Huang et al, 2011)

Quite similar, but more single user oriented is the system (Behzad et al, 2014) with possibilities of mobile application controlling and SMS exchanging with on-board
system. The main advantage the system use is permanent opportunity to monitor location of vehicle just sending SMS from mobile phone and getting back information about not only vehicle’s location, but also its speed and status. The system supposes using online service Google Maps for vehicle positioning or Android application for such type of mobile phones users (Fig. 15). It also allows turning vehicle’s ignition on and off to protect it from moving away during theft.

Fig. 15. Web portal and Android application interfaces for vehicle tracking. (Behzad et al, 2014)

One of the most important features of such GPS tracking systems for vehicle fleet owners is that it is just an augmented function for conventional GPS operations such as navigations or routing. With data from tracking systems it is possible to inform police about exact location of thieved vehicles and to get it back as soon as possible. Moreover, it is highly unlikely that a thief will be somehow informed about existence of the system in a car and might influence its operation or switch it
off. Therefore, GPS tracking system is highly useful technology both for better fleet operations performance and theft prevention. Considering that the solution is quite affordable, vehicle fleet owners should invest in it to minimize risks of business operations.
3 DISCUSSION AND CONCLUSIONS

The main results and findings of the work are summarized in this chapter. They are divided by the topics discussed earlier. Some of them have additional comments to explain reasons for a certain type of operations/behavior of a system. The Conclusions sub-chapter summarizes the whole work and makes assessment of research objectives achievement.

3.1 FLEET SAFETY

In the safety sub-chapter the main directions of vehicle safety equipment development and issues of its installation have been analyzed and described. Safety provision in every vehicle fleet should be of #1 priority as a vehicle owner is partly responsible for fleet users’ health and even life. Therefore, safety is an issue of high concern among scholars and vehicle manufacturers, who invest big amount of time and money to its development.

In this work, the main conclusions from the safety part can be described as follows:

1. Previously, efforts of vehicle manufactures were concentrated around diminishing of damage and saving drivers’ lives during car crash. By now, during-crash assistance is quite well developed even in previous vehicle generations, and the main direction of modern research is accident prevention by means of the most advanced digital and data-driven technologies. Quite significant results have already been achieved by now, but such technologies should be not only efficient and reliable, but also affordable. This direction of research seems to be the core one in the future as not only expensive cars should be equipped with accident prevention systems.
2. According to scientific investigations, automated safety systems are more preferable among drivers rather than sensory affecting ones. This means, that most drivers are more likely to use such a system which doesn’t suppose any actions from him, but operates in fully autonomous way and prevents potential crash by itself. Sensory affecting warnings (sounds, light signals) were assessed as distractive especially during false alarms.

2.1. As tested drivers were distracted during operations of sensory affecting systems, possible pre-education before their use would provide drivers more information about the systems and will help to understand importance of safety systems implementation. As long as most vehicle fleet businesses can afford running special educational courses for fleet drivers, this issue is possible to be discussed during the lessons. Anyway, it would be useful for vehicle fleet management to track the frequency of safety systems activations to gain some additional data about drivers’ on-road behavior.

2.2. Reliability of accident avoidance systems is a key issue for their implementation in vehicle fleets. Both false alarm and non-operation of a system could cause an accident. Therefore, every single safety system should undergo thorough quality testing and control to meet demands and safety requirements of vehicle fleet users.

3. Health state of every driver in a fleet is a vital issue which couldn’t be neglected. However, vehicle fleet services are unlikely to restrict some of the users from driving a vehicle as sometimes full information about customer’s health state could be even unavailable to a fleet manager (e.g. in carsharing). Therefore, for vehicle fleet owner it is crucial to collect health information from drivers and to equip fleet vehicles with relevant technologies for car accident avoidance to protect a driver, passengers and a vehicle itself from health-affected car crashes.
3.2 EDUCATION OF DRIVERS: BENEFITS AND CONCERNS

Every fleet driver has own driving pattern as every person has unrepeatable fingerprint. Anyway, these patterns could be referred to “safe” and “dangerous” ones, and this feature creates certain threats to fleet company operations. But luckily, problems of driving style differences have already been noticed by fleet owners and scholars, and relevant measures are being developed and applied:

1. Modern OBD systems together with telematics make possible driving patterns identification available. Centralized fleet monitoring allows measuring the main identifiers of driving behavior, including those influencing fuel consumption, vehicle parts deterioration, safety, etc. Correction of drivers’ behavior is partly an issue of imagination as there are plenty of opportunities how to improve driving performance. They could be educational courses, monetary motivation, gamification and so on, which allow drivers not only re-thinking their approach to driving, but also being more involved in their company’s business and gain some benefits from their results. Most of the approaches for driving pattern monitoring require quite simple tracking systems, which make the process easy, reliable and inexpensive.

2. As every vehicle in a fleet should (and very often must) be insured, insurance operations account for a significant part of vehicle fleet expenses. Therefore, there is an opportunity both for fleet owners and insurance companies to optimize their expenses and risks involving driver’s performance and vehicle features into insurance premium calculation. Such “pay-as-you-drive” systems have already found their implementation by calculating score-based driver’s performance and relevant insurance premium. The benefits are the following: fleet business gets lower price for good driving performance as better drivers provide lower chance to have an accident; insurance company acquires more predictable risk management and lower probability of paying high compensations for accident occurrence; and
fleet drivers according to personal driving scores in a fleet could get discounts from insurance companies for their private automobiles.

3.3 POSSIBLE DIRECTIONS OF VEHICLE FLEET COST REDUCTION

The main finding from the economical part of the work is that most of cost reduction systems involve dynamic approaches for new opportunities creation. This means that static solutions of vehicle resale, re-routing, etc. have already become out-of-date, and dynamic models are taking their place to provide better business management and performance.

As could be noticed from the sub-chapter, dynamics has been involved to every single process. Firstly, dynamical approach was used to prolong vehicles’ useful life in the fleet based on its real state assessment rather than just resale or scrap them after a certain period of time. Secondly, dynamics in electricity prices and their monitoring have provided a basis for profitable V2G model in electronic vehicle fleet. Thirdly, dynamical re-routing results in fleet maintenance cost reduction as vehicles don’t need to waste time in traffic jams and could easily be re-routed to uncongested roads. And finally, dynamical fleet relocation and maintenance operations in carsharing provide additional profits to business and attracts more customers to use this business model of new generation.

It is worth mentioning that only few of possible economical models have been discussed in the work, but the main conclusion from them is that other models are likely to base on the same dynamic approaches in fleet management as despite making the whole business more complex and recourse demanding, they also provide plenty of opportunities for better fleet performance and additional profits, which later on will pay back all expenditures for these approaches implementation.
3.4 DATA-DRIVEN MAINTENANCE

A human is assessed to be not an ideal mean of faults detection in a vehicle as it is impossible for him to catch minor changes in a vehicle’s mode of work, which in the future could result in its failure. However, the mankind has understood how to create and manage quite complicated devices and mathematical models for vehicles’ state monitoring, allowing them to detect and eliminate potential mechanical, electrical, etc. failures in advance.

1. According to human’s imperfection in detecting vehicle’s pre-faulty conditions beforehand, the future of this direction belongs to automated vehicle state monitoring systems, some of which are already available or under development. Quite often, fault identification involves comparison of a current vehicle’s state with historical data of the same vehicle to detect deviations from normal operation mode and inform fleet maintenance about potential pre-faulty condition. In the future, it could be expected that checkup of a vehicle won’t anymore be an issue of a human concern as fully autonomous systems will be able to provide comprehensive information about vehicle’s state, and maintainer’s effort will be needed only for faulty part repair.

2. Nowadays, fleet businesses are dealing with vehicle maintenance operations, and, even if they use special car repair shops outside a fleet company, maintenance organization and management are still issues of their concern. In the future, appearance of new economical models based on comprehensive maintenance solutions provision is likely to occur in wider scale. Therefore, in certain cases it would be more feasible to use services of a special company for all maintenance operations, providing comprehensive maintenance for the fleet vehicles, including its equipment with advanced devices, maintenance events organization and provision with a network of professionals in different fields.
3. What comes to vehicle fleet eco-friendliness, a lot of countries have already accepted regulations for vehicle emissions control. As vehicle fleets are the sources of increased carbon oxides, NO\(_x\) and other types of emissions, they are supposed to support and follow eco-friendly image of their business, and lots of different means are already available for this mission.

### 3.5 DATA-DRIVEN AUTHORIZATION AND CYBER SECURITY

Together with number of devices within one car increasing, so does number of possible vehicle attack directions. Whereas earlier only mechanical manipulations with vehicle lock would be enough for car access, today’s unauthorized access could be provided by electronic hacking or cyber attack. And as long as cars in a fleet are interconnected, attack on one vehicle only could potentially provide access to the whole fleet. Thus, the main directions of fleet security development could be described as follows:

1. Connectivity in car fleets requires thorough control and management to provide high degree of security as new technologies and connectivity fog generate cyber attack threats. Quite often, a fleet company should re-design the whole organizational system dealing with security to match modern requirements of safe fleet business. Security issues in vehicle fleets haven’t disappeared – they have just changed their appearance from mechanical to cyber and electronic ones.

2. The most important directions of car security are protection from unauthorized access and stolen vehicle return if theft has actually occurred. The most promising methods among those aiming to satisfy these needs are biometric authorization with unique for a person identifiers and GPS vehicle search for its quick detection and relevant returning actions. One of the best means of car protection from hijacking is automated engine immobilizing, for which it is essential to work even without battery supply.
3.6 CONCLUSIONS

To conclude, it is worth saying that the main objectives of the work have been achieved and the research questions have been answered. All above mentioned technologies, solutions, models of economical value adding and services have led us to several directions of fleets’ future development. The first one is automation of the processes, whether it would be autonomous accident prevention, vehicle failure detection or automatic means of security provision. The second is dynamics in decision making, business operations, service distribution, etc. And the third direction is involving of fleet drivers, other companies and third parties in fleet operations. All three directions are leading to improvements in the whole business and its economical component in particular (Fig. 16).

![Mind map for research conclusions.](image)
For evaluation of the work some limitations are worth to be mentioned. First of all, even considering reliability of the literature sources, some of results of a technology implementation could be heavily dependent from specifics of vehicles, conditions and variety of other factors. The results (especially in percentage) can vary from fleet to fleet and it can’t be certainly said that previously mentioned performance values could be achieved. Anyway, taking into account advisory nature of the work, dimensions of practical performance are likely not to differ too much from the theoretical ones. Secondly, one more limitation could be referred to information availability. As the work was fully based on the literature sources, there can be a probability of not mentioning of non-published directions of development and technologies in the work. Therefore, for future studies it would be feasible to increase specificity of the work and its results by investigating performance of specific technologies in certain cases, providing fleet owners more reliable and valid information for each of them. The work mainly provides common directions of development of data-driven services in vehicle fleets, which could be a starting point of investigation for future researchers.
4 SUMMARY

Fleet companies are nowadays at the threshold of new era of advanced solutions and opportunities for their business as modern technological development from year to year provides plenty of new inventions for vehicles all over the world. Most technical solutions of the previous and the beginning of this century have already become out-of date, and new data-driven approaches are taking their place to provide the same and even better operations. The main aim of any business is to get the highest possible profits, at the same time providing the best services for its customers and taking care of its staff. According to this, the most essential ways of fleet businesses development are automation of its processes, dynamic approaches to planning activities and management and involvement of new parties, which previously haven’t taken active participation in value adding. In the future, even more directions are expected to appear as by now it is quite hard to predict which technological paths will arise in general and which ones will be useful for vehicle fleet economical value provision in particular.
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