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SAFETY FACTOR IN THE SUSTAINABLE FLEET MANAGEMENT MODEL

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Abstract:

In the era of rapidly changing market and consumer needs, there are dynamic changes in the services offered. This also applies to the car fleet market. Currently, the *approach to owning a vehicle* is *changing to other forms such as rental or subscription. Different types of funding are conducive to changes in the fleet management industry. More and more sophisticated services are offered for corporate clients, but also private customers. In the context of these changes, the approach to different aspects of vehicle use is also clarified, including what has been noticeable in recent years, increased interest in road safety, environmental issues and most importantly costs of use and possession of the vehicle. This puts high demands on fleet managers who sustainably need to match the structure of their fleets to the needs and capabilities of their customers while taking into account safety and ecology issues. This is a complicated task that requires decision-making assistance. This article addresses the support of the fleet manager decision, taking into account the sustainable management model. The article aimed to develop a model that takes into account the aspects of safety and ecology from the operator-financier the point of view. The result of the article is to provide a decision-making tool for the selection of vehicles and drivers, taking into account their characteristics to accomplish their tasks. The work presents the problem of fleet management, shows the characteristics of different forms of financing and the impact of market trends on the current approach to these problems. The analysis of safety aspects to the possibility of using different methods affecting its level was then presented. Another element of the article is a mathematical model of the problem of resources assignment for tasks. The developed model is universal and can be used for* evaluation *and optimisation. To this end, the function of the criterion has been formulated, taking into account the aspects of safety, ecology and financial aspects. It also takes into account the randomness of adverse events and the duration of the remaining appropriations in the out-of-order state. This Model can be used for the risk assessment of the driving staff. The developed model was implemented in the Flexsim* environment for a *computational example for a trading company. Computational experiments have indicated the correctness of the model and its high application potential, as well as further directions of model development to support complex management processes carried out by fleet managers.*

Keywords: *fleet management, assignment problem, mathematical modelling, flexsim, safety*

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1. Introduction

Planning and organising the travel of employees and, above all, optimising operational activities is complicated and difficult task. One of the main factors is the complexity of transport processes. A large number of factors, interdependencies and dynamics make it difficult for some of these processes to be reproduced in detail in a mathematical model. It is even harder to develop a suitable decision support algorithm for such a model. Therefore, in practice, intuitive methods are used to make decisions quickly. This approach is often used in the transport fleet management. Some of the areas in transport are well-researched, there are a lot of developed models taking into account different points of view and methods of decision support, e.g. Travelling Salesmen problem, Shortest Path, Vehicle Routing problem, Location problem, Inventory Management. However, managing the fleet of passenger vehicles, taking into account current market trends, is often overlooked in mathematical models and decision support methods, and is only considered conceptually (Bielli et al., 2011; Szczepański et al., 2018).

Cars owned by the company and used for business purposes are called fleet of business vehicles, and drivers for whom they constitute a working tool are called fleet drivers (Pérez et al., 2016; Witeska and Piechota, 2016). Fleet management in the enterprise is a set of activities aimed at ensuring the mobility of human resources or things through the use of technical and human resources in an efficient way. Besides, in each company (where fleet management is in place) clear rules should be laid down governing the use of official vehicles, avoiding many unwanted events and facilitating the execution of settlements. Such aspects are addressed by the fleet policy, which focuses on many elements from different departments such AS HR, administration or accounting department (Gospodarek, 2017; Oliveira, 2018).

The fleet policy is, therefore, a set of internal conditionalities and situations that accompany vehicle users in their daily work for the company.

Formulating the rules of use of vehicles, taking care of the vehicle, conducting training, replacing vehicles, its assignment to tasks is a complicated task. On the one hand, it is a set of procedures developed based on the company's principles and experience of the insolvency practitioners. On the other hand, it requires the development of specific rules supported by studies to what extent different activities are productive, improves safety and is sustainable in the context of the use of vehicles (Chen C.F and Chen S.C, 2014; Muslim et al., 2018; Rydzkowski, 2017). This article addresses the issues of sustainable management of the car fleet, taking into account safety. The purpose of the work was to characterisation the needs of fleet managers and on this basis, develop a decision support model. The article consists of 7 chapters. The first three are theoretical considerations and needs analysis, and they include an introduction, the characteristics of financing and fleet management models, the definition of market trends in fleet management, and the analysis of safety issues. Point 5 provides a mathematical model for decision-making support in a fleet management company. Chapter 6 provides a calculation example based on the model implementation in the Flexsim simulation environment. The work was completed with a summary and indication of the direction of further studies.

2. Vehicle fleet financing and management models

Fleet management is designed to align the rules of use of company cars to both the adopted Financial policy of the company, the model of human resources management as well as the determination of the rules of allocation, use and returning company cars (Trzaskkowski and Wasiak, 2017; Oliveira, 2018).

The choice of the management model should take into account the size of the fleet and then relate to the company's financial situation and policy. The proposals received should be confronted with the vision, mission and general strategy of the company, in addition to the assumptions of the company's HR policy and the emphasis on public care. An essential aspect of any economic activity costs. Cost generation is unavoidable so that each organisation strives to reduce it. The cost to the fleet of vehicles is generated primarily by its financing, fuel and service. These costs may have a different share of the costs associated with the means of transport, but it is estimated that on average funding is responsible for over 40% of the costs, fuel 30%, service more than 14%. Therefore, one of the main aspects of fleet management is choosing a financial model. By analysing market practices, four main models of fleet financing can be observed:

– own financing,
– credit,
– leasing,
– long-term rental.

Own financing is the most advantageous form of financing from a cost-effective point of view since it is wholly deprived of the so-called additional costs. The second form is a car loan, which is characterised by the need to pay an interest of the loan. However, the borrower may include interest as a business expense. Leasing is a civil law agreement concluded between a lessor (financing party) and a lessee (beneficiary), and its purpose is to make available for use a given item based on a contract for consideration. Based on data of PVRLA (2019) In Poland, close to 2/3 purchases of new cars are carried out by companies that willingly use this form of funding. A long-term rental is a form of financing that is continuously gaining popularity, and according to PVRLA (2019) In the I quarter of 2019 relative to the lease, reached 21.2% of the share. As part of this form is distinguished by Full-service Leasing and Leasing with service. The first includes a full range of car rental services including service and 2 additional services, e.g. Insurance, fuel cards, etc. In turn, the second form is also a rental with vehicle service, but with a smaller scope of additional services (Trzaskowski and Wasiak, 2017).

Financing the fleet is one of the main aspects of fleet management. The management itself can also be implemented in various business models (Trzaskowski and Wasiak, 2017). Three leading solutions can be indicated:

– own management,
– management by the financing party,
– outsourcing of the fleet department.

In the case of one-person business or a small fleet to five vehicles, most often chosen is the management of its own and purchase for cash or pure financial leasing. Very often, the person who is responsible for the fleet is the owner of the company or an employee of the company who realises it as part of his duties. Companies in the SME sector, with fleets, usually ranging from 5 to 50 cars, most often choose leasing and own management, but Fleet Manager is employed on both part-time or outsourcing basis. Large corporations most definitely choose long-term rental and management through Fleet Manager supported by CFM companies.

The costs associated with owning vehicles and the rules for assigning vehicles to positions are very often the decisive factors in choosing a car brand and model. At a later stage, a decision should be made regarding the version of the equipment, the type of fuel, engine capacity or version of the body. The type and structure of the fleet are also influenced by the method of financing it and the enterprise's ability to maintain it in terms of cost (Trzaskowski and Wasiak, 2017).

The available fleet policy enforcement mechanisms are KPI's (Key Performance Indicators), that is, performance indicators that allow assessing the functioning of the company, how to implement processes, etc. They concern each activity, but depending on its nature may vary. To assess fleet policy and related processes, one can identify such indicators as an accident, fuel consumption or revenue generated for a vehicle in a company. This allows further shaping of the fleet policy, including the development of a strategy of action depending on the situation (Chen C.F and Chen S.C, 2014; Jacyna-Gołda et al., 2017; Jacyna-Gołda et al., 2018; Świderski et al., 2018).

In the field of car fleet management, it should be emphasized that this is a complex task. In the case of a much more vehicles, it is necessary to support computer systems. This is due to a large amount of data to be processed that affects the effective planning and control of the fleet (Jacyna et al., 2018; Jacyna-Gołda et al., 2017). Such systems allow for control, expenses, fleet condition reporting and detailed supervision of each vehicle. Thus, it allows capturing irregularities and correcting the decisions made. Additional features of such systems allow for scheduling current activities related to the fleet (review, insurance, repairs, tire replacements), but also for access to online data and, for example, booking a car by an employee for business purposes. These programs have become some kind of communication platforms because thanks to them the fleet manager can easily communicate with the user by sending short e-mail or SMS messages, for example in the subject of driving techniques, the need to repair the car or the validity of technical tests or insurance policies (Cheung et al., 2008; Darby et al., 2009).

3. Market trends in car fleet management

Market trends indicate three key orientations for the development of car fleet management (Bielli et al., 2011; Trzaskowski and Wasiak, 2017; Oliveira, 2018; Szczepański et al., 2018). The first of them is the increasingly stronger position of outsourcing services, which reach companies all over the world. Also, concerning car fleet management, it can be noticed that companies are more likely to decide on such a solution. Nevertheless, this is a trend that will work mainly for micro, small and medium enterprises. The optimal solution for large fleets is the "hybrid" solution, in which only Fleet Manager is employed in the organisation to create a fleet management model suited to the company's objectives, and current tasks and service are outsourced to external companies or employees of companies financing the fleet.

The second trend that companies need to prepare soon is the management of a fleet of alternative-powered cars and, consequently, for several years - autonomous cars. On the other hand, as far as alternative drives are concerned, management should not change much because only the service of such cars will change, and all other factors, as it is done now; they will continue to evolve systematically. This trend results directly from care for the environment. In recent years, the development of transport in the direction of environmentally friendly is very dynamic. It should also be included in the vehicle selection criteria (Boutueil, 2016; Muslim, 2018).

The third strong trend concerns the direction of fleet management in the field of road safety. Currently, research regarding safety in various areas of transport plays an important role. In fleet management, research is required regarding the conditions for improving safety and risk assessment in this area. It is precise with the risk that the assessment of the level of safety and losses that may arise as a result of an undesirable event such as an accident. This applies to financial, social and human losses. In 2018, in Poland, it was as much as 4% of Polish GDP for 2018. The car fleets as part of corporate social responsibility (CSR) policy should pay particular attention to reducing the causes and effects of road accidents. This challenge also applies to legislation.

Safety issues are present in the awareness of users, enterprises and legislators. However, its improvement requires the integration of requirements and needs between these stakeholders. In the aspect of improving road safety, much research is carried out, including the use of various technologies, e.g. (Gaca and Pogodzińska, 2017; Hu et al., 2017). The car manufacturer Volvo announced that it plans to introduce a maximum speed limit of 180 km / h in all of its cars from 2021. Also, the European Parliament in early 2019 raised the resolution based on which cars should be equipped with speed limiters associated with the RSTA system from 2022. The European Transport Safety Council assumes that the introduction of speed limiters will reduce the number of accidents in the EU by 30%, which will translate into 25,000 people within 15 years. Another way of interference in reducing claims can be the example of solutions implemented by the Israeli Government, which abolished the excise duty on early warning systems for collisions in newly purchased vehicles, which caused a loss in claims by less than 50%.

It should be emphasized that the care for safety has firmly established itself in the consciousness of many enterprises and legislators. It must therefore also be taken into account by fleet managers in fleet policy and all transport management procedures.

4. Problems of employee safety in the aspect of fleet management

The car makes business much more manageable and affects the company's efficiency, advertises the company and is an element of corporate culture and allows to increase the employee's satisfaction from work without the need to raise his salary by the company (Janczewski, 2014). It is crucial to provide the employee with the appropriate conditions for using the vehicle entrusted to him, but at the same time enforce from him compliance with the rules set out in the company's fleet policy. The road user is exposed to many dangers, ranging from stress, time pressure to the possibility of participating in an accident and injury.

The analysis of data in terms of the number of road deaths indicates that Poland was the leader of statistics throughout the European Union. Currently, improvement in road safety and a decrease in the number of killed people in road accidents in most European countries is noticeable (Figure 1). This trend is mainly due to the development of technology, improvement of the quality of roads and greater safety for both the State and the participants of the traffic. It is worth mentioning that the number of accidents is falling despite the traffic growth in the number of transport means. Nevertheless, the number of accidents and collisions is still very high.

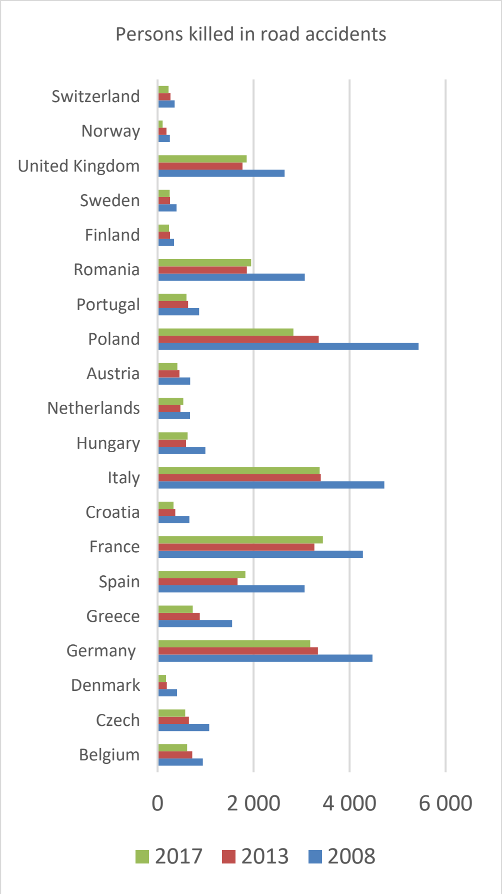

Fig. 1. Persons killed in road accidents in selected European countries (Eurostat, 2019)

Each traffic incident covers the costs for society, but also for the employer whose employee participated in the accident. The manager - not only the fleet manager - should create his mathematical model, which in its assumptions should have information and solutions securing the increase in costs due to employee absences. Here the critical role is played by the fleet policy, in which the issues of safety, ecology and responsibility for the vehicle should be taken into account. Shaping the culture of employees in using the vehicle allows fighting waste and loss, thus reducing costs and allowing to increase revenues (Rydzkowski, 2017).
An important factor affecting the safety of employees is the awareness of threats and the learning of correct behaviours. It can be concluded that, globally, prevention is a key factor in improving safety and saving lives. Appropriate training for employees, a system of motivations and competitions promoting drivers driving the safest and most economically allow to achieve tangible results in terms of safety and culture of vehicle use (Boutueil, 2016; Rydzkowski, 2017; Warmerdam et al., 2017).
On the one hand, accident prevention in the form of training is crucial for improving safety and reducing loss ratio. On the other hand, it is possible to influence the level of safety by using appropriate systems that are the equipment of vehicles or employees. Such systems can be installed by the manufacturer or as part of additional procedures and affect active and passive safety. The AXA survey conducted in 2009 shows that it is enough to warn 2 seconds that there is an obstacle or pedestrian in front of the vehicle to minimise the risk of fatal accidents by 98%. This shows how advanced safety systems play an important role.
Systems that affect active safety are those that prevent collisions and accidents. Here can be included all kinds of brake assist systems, active line assist, speed, etc. In turn, passive safety is influenced by systems that reduce the effects of an incident if it occurs, ie safety belts, airbags, the appropriate vehicle design, etc. In recent years, there has been significant development of systems preventing events and even lower class vehicles are not equipped with basic versions. The most advanced systems supporting the driver and caring for his safety are still expensive and require additional financial resources. An issue that requires analysis is how much for the company it is worth to pay extra for more expensive solutions and invest in them, as in the case of training.
Additional support for fleet managers are systems based on telematics and GPS monitoring. In the aspect of improving safety, a system for evaluating driving style comes with help. On its basis, it is assessed how the driver accelerates, brakes, changes the course and overcomes obstacles. In addition to analysing the recorded data and creating a personalised profile in real time, can inform the driver about the dangers and poorly performed manoeuvres using an audible signal. In addition, fleet managers can supervise the driver's driving style online. Such systems are, according to the authors, the future-oriented system for improving road safety. It is worth

noting that the Insurers have started using this type of solutions to promote safe driving and thus make the premium amount of insurance depends on the driving style (Darby et al., 2009; Muslim, 2018).
GPS monitoring and other telematics systems are already widely used in transport activities, including caring for cargo safety, the correctness of tasks performed, working time settlement or accounting for fuel consumption. It is a natural consequence to expand these systems with new possibilities that will further increase the driver's safety (Łukasik et al., 2017; Żochowska and Karoń, 2016).

5. The mathematical formulation of fleet management model with safety aspects

As already indicated, Car fleet management is a complicated decision-making process. It is possible to use mathematical modelling tools to map existing problems and support decision-makers. Due to the purpose of the research presented in this article, a mathematical model and an optimisation task for the problem of managing the fleet of passenger vehicles in a commercial and service enterprise were formulated. The model presented below is universal and can be adapted to other areas. In addition, the possible development paths of the model are also presented. To construct the model, the following assumptions were made:

– the fleet management model is constructed using set theory,
– decision problem concerns a commercial and service enterprise and is built for the needs of fleet and driver management,
– the fleet composition includes passenger cars,
– the model includes the issues of safety and Eco driving,
– each driver and vehicle serve one region during a given period (e.g. 1 day), during this time all areas are serviced, and their service requires a certain distance to be covered,
– every served one region brings income,
– handling 1 region in one working day is the implementation of 1 task,
– the probability of not servicing the area is taken into account, resulting from damage to the vehicle and / or employee's indisposition,
– the probability value can be influenced by the use of newer and / or safer vehicles and driver training,
– an assessment is taken into account over a long time horizon, most often corresponding to the length of vehicle financing,
– it is permissible to include various forms of vehicle financing,
– the vehicle fleet can be varied, but the same for the same area throughout the analysis period,
– the optimisation criterion is the company's profit presented as the difference between revenues (resulting from the number of areas served) and between fixed costs and variable involvement of vehicles and drivers,
– additional criteria for solution assessment may include, for example, the number of unrealised tasks or the emission of harmful substances.

The developed model includes elements such as drivers, vehicles, service areas. In addition to the formalisation of the optimisation task, it was necessary to define the decision variables, the criteria function and constraints.

The set of vehicle recorded as $V=\{v: v=1,\ldots,\overline{V}\}$ and $v \in \mathbb{Z}^{+}$; each vehicle is characterized by fixed costs of engagement expressed for the period of analysis, costs per task and other costs. The set of drivers is $K=\{k: k=1,\ldots,\overline{K}\}$ and $k \in \mathbb{Z}^{+}$. The analysis period is usually one year, the set of periods was recorded as $D=\{d:\ d=1,\ldots,\overline{D}\ \}$ and $d \in \mathbb{Z}^{+}$ the number of analysis periods corresponds to the assessment period (e.g. vehicle financing or depreciation time). Each analysis period is divided into the number of days, i.e. the number of possible services for each area (or tasks carried out differently), this is recorded as $\overline{H}$ and it is constant for every analysis period. The individual tasks were marked as $h(d)$ where $\forall d \in D\ \ H(d)=\{h(d): h(d)=1,\ldots,\overline{H}\}$ and $h(d) \in \mathbb{Z}^{+}$. The vehicle and driver team support the i-th area belong to the set $I=\{i:\ \ i=1,\ldots,\overline{I}\}$ and $i \in \mathbb{Z}^{+}$, only one vehicle unit and driver (respectively v-th type and k-th category) can be used to operate each region. Each region is characterised by a distance to be travelled to handle it, i.e. $dist(i)$ and the revenue it generates in the case of proper service ($inc(i)$). The number of tasks handled in the i-th region is a random variable. In the model, it was considered as the expected value of a random variable X_{idh} taking the value of $x(i,d,h) = 1$ when the area is served with probability $p(i,d,h)$, 0 – when it is not supported, i.e. with probability 1-$p(i,d,h)$. The probability of operating the area is related to the operation of the vehicle and driver set. The transition to the state of incapability takes place with the intensity *U* described by a certain distribution, while the state of disability has three substitutions related to the effect that the occurrence of an event that led to the disability would trigger. It is possible to distinguish a collision that will occur with the α_1 probability, an accident with the α_2 probability and the heavy accident with the α_3 probability. Respectively for these states, the intensity of restoring to a proper functioning as μ_1, μ_2, μ_3, with this, the number of unrealised tasks is also associated. It was assumed that for a sufficiently long observation time the probability of the object remaining in the state of ability, i.e. $p(i,d,h)$ would be recorded as *P(i)* and it will take the same value for every *t, h*:

$$p\left(i,d,h\right)=P(i)=\frac{\mathrm{E}\left[U\right]}{\mathrm{E}\left[U\right]+\mathrm{E}\left[N\right]} \tag{1}$$

where:

$$\mathrm{E}\left[N\right]=\sum_{q=1}^{3}\mu_q\alpha_q \tag{2}$$

It was assumed that the expected value of the number of tasks served in *i*-th area will be written as follow:

$$\forall i\in I \quad \mathrm{E}(Zi)=\sum_{d\in D}\sum_{h\in H}x(i,d,h)\,p\left(i,d,h\right) \tag{3}$$

The optimisation task consists in determining the decision variables about the interpretation of the assignment *v*-th car and *k*-th driver for *i*-th are. Variables assume values from a set of binary numbers, and they are ***Y***=[*Y*1,*Y*2]:

- $Y1=\left[y1(v,i):\quad y1(v,i)\in\{0,1\}\right]$
  takes the value 1 when the variables determine the assignment of the *v*-th vehicle to service the *i*-th area, takes 0 otherwise,
- $Y2=\left[y2(k,i):\quad y2(k,i)\in\{0,1\}\right]$
  takes the value 1 when the variables determine the assignment of the *k*-th driver to service the *i*-th area, takes 0 otherwise.

The criterion function has a profit interpretation. Included in it is revenue, which results from the number of regions served and unit profit. The number of areas served in turn is the sum of the probability of service after all regions and the number of days resulting from the analysis period. The criterion function has been written as a formula (4).

$$\boldsymbol{F(Y)}=D-Cv1-Cv2-Ck\rightarrow\max \tag{4}$$

$$D=\sum_{i\in I}\left[c_{inc}(i)\mathrm{E}(Zi)\right] \tag{5}$$

$$Cv1=\sum_{i\in I}\left[\begin{array}{l}\mathrm{E}(Zi)\dfrac{dist(i)}{100}\cdot\\ \displaystyle\sum_{v\in V}\sum_{k\in K}\left(\begin{array}{l}cf(v)dcf(k)\,fp(v)\cdot\\ y1(v,i)\,y2(k,i)\end{array}\right)\end{array}\right] \tag{6}$$

$$Cv2=\sum_{i\in I}\left[\begin{array}{l}\displaystyle\sum_{v\in V}\sum_{k\in K}y1(v,i)y2(k,i)\cdot\\ \left(\begin{array}{l}\mathrm{E}(Zi)czv(v)+\\ \overline{D}\left(\begin{array}{l}cav(v)+\\ cins(v)dcins(k)+cserv(v)\end{array}\right)+\\ cp(v)+cs(v)\end{array}\right)\end{array}\right] \tag{7}$$

$$Ck=\sum_{i\in I}\left[\sum_{k\in K}y2(k,i)\left(\begin{array}{l}\mathrm{E}(Zi)bk(i,k)+\\ \overline{T}\cdot cstk(k)+\\ cszke(k)+cszks(k)\end{array}\right)\right] \tag{8}$$

Formula (5) is responsible for determining the total revenue, which is the product of the value of the expected number of completed tasks and unit revenue $c_{inc}(i)$ from *i*-th area. Formulas (6) i (7) they are related to the costs of the vehicle. The costs of the vehicle include the costs resulting from the distance travelled *dist*(*i*) in the *i*-th region and fuel consumption *cf*(*v*) and its unit cost *fp*(*v*), the fuel consumption reduction coefficient *dcf*(*k*). The reduction of fuel consumption is associated with *k*-th driver and his training in eco-driving. Another pattern is responsible for the costs of vehicle maintenance (fixed per year *cav*(*v*)), serives *cserv*(*v*) and insurance *cins*(*v*) per one period *d*, fixed costs counted for the completed task *czv*(*v*). Insurance costs can be reduced by a coefficient *dcins*(*k*) depending on experience *k*-th driver experience and training. The purchase cost of the vehicle *cp*(*v*) was also taken into account, and the additional cost incurred to equip the vehicle with

additional safety systems *cs*(*v*). The last component of the criterion function was written with a formula (8) and applied to the driver's costs. It includes a bonus *bk*(*i*,*k*) for the task performed, the annual cost of employee *cstk*(*k*) and the costs of t eco-driving *cszke*(*k*) and safe driving *cszks*(*k*) training.
It should be noted that the above model includes the costs of training, vehicle and additional safety systems. This affects the expected value of the number of completed tasks. The following formula gives the time interval U between consecutive events:

$$U = 2 \cdot G(t) - G(t) \cdot sf(k) \cdot de(k) \cdot sv(v) \tag{9}$$

where *G*(*t*) it is a random variable depending on the time *t* described by the probability distribution. It should be selected based on statistical surveys. The interval between consecutive events is reduced and takes the value from the range (*G*(*t*);2*G*(*t*)>. Driver safety indicator *sf*(*k*) and his experience *de*(*k*) It affects the extension of the time between events. In addition, the quality of the vehicle influences the lengthening of such time *sv*(*v*) (better safety systems as standard) and additional safety systems. The above coefficients take values from the range (0; 1>, the lower the value is better.
The second element in the model where safety coefficients apply is the probability of an event having a specific effect. As mentioned earlier, three types of events of varying intensity have been adopted to restore the vehicle-driver set to ability. The probability for these events was determined as follows α_1, α_2, α_3 and assumed:

$$\begin{aligned} \alpha_1(k,v) &= 1 - \alpha_2 - \alpha_3 \\ \alpha_2(k,v) &= 0{,}2 \cdot sf(k) \cdot de(k) \cdot sv(v) \\ \alpha_3(k,v) &= 0{,}05 \cdot sf(k) \cdot de(k) \cdot sv(v) \end{aligned} \tag{10}$$

Basic constraints have been formulated to the above model, although not all of them are mandatory. This model can be used to support decisions as an optimisation task, and then the restrictions are obligatory. It can also be used to evaluate existing solutions, and then the constraints serve as auxiliary functions. The restriction on assigning one driver and one vehicle to each region was formulated (11), the minimum number of completed tasks to the number of tasks possible to implement – Level of Service (12), limitation on the scope of probability(13), limitation on working time(14). In the limitation for working time, the driving time was taken as the distance to the average speed of the vehicle in the area and the additional working time of another *toj*(*i*,*k*) performed in the *i*-th area by *k*-th driver and it can not exceed the driver's admissible standard, i.e. *ndj*(*k*). The record of the indicated constraints is presented below:

$$\forall i \in I \qquad \sum_{v \in V} y1(v,i) = 1 \;\wedge\; \sum_{k \in K} y2(k,i) = 1 \tag{11}$$

$$\forall i \in I \qquad \frac{\mathrm{E}(Zi)}{\overline{\overline{D}} \cdot \overline{\overline{H}}} \geq LOS \tag{12}$$

$$\forall k \in K \;\; \forall v \in V \qquad \begin{matrix} 0 < \alpha_1(k,v) \leq 1 \\ 0 < \alpha_2(k,v) \leq 1 \\ 0 < \alpha_3(k,v) \leq 1 \end{matrix} \tag{13}$$

$$\forall i \in I \;\; \forall k \in K \qquad y2(k,i)\left(\frac{dist(i)}{avgs(i)} + toj(i,k)\right) \leq ndj(k) \tag{14}$$

The above model is flexible. It can be quickly adapted to the needs of the problem under consideration. At the same time, it takes into account the main aspects that are currently being considered by fleet managers. In addition, it is planned to extend the model with aspects of vehicles exploitation by users. Research that will be used to build the mapping is presented in the works (Świderski et al., 2018, Świderski et al., 2019; Wasiak et al., 2019). The model can also be built in a different approach, namely determining the probability of occurrence of an event and the related break, the comparison of these two approaches will be the subject of other research. The formulated model was implemented in the *Flexsim* simulation environment and its operation verified. This is presented in the next section.

6. Simulation example using the developed model of car fleet management in a trading company

The Flexsim environment is used to conduct simulation studies of various processes. The process of service of the regions with an emphasis on the vehicles and drivers assignment was subjected to the research. The study was carried out in three variants. The first variant as the basic one does not include the operations that increase the level of safety, while the second option takes into account the possibility of using a better fleet and training, etc. The third option is assigning the same set to each region. The study was carried out for a simplified example in which it was assumed:

– 5 service areas,
– 5 available vehicle types,
– 5 categories of drivers,
– *G(t)* is described by the Erlang distribution with scale parameters equal to 6000 hours and shape 3,
– driver's working time limit in the area has been set at 8 hours (driving time and working time of others),
– the designation was adopted in accordance with the model,
– the analysis period is 1 year, the number of analysis periods is 5 years, while 250 tasks can be completed within 1 year, which gives the total number of 1250 tasks per area,
– it was assumed that the number of drivers and vehicles of a given category is infinite,
– simulations were carried out for three variants and 20 replications for each variant.

The first variant will be implemented for drivers numbers 3, 4, and 5 and vehicles with numbers 4 and 5. The second variant will be assigned to drivers numbered 1 and 2, and vehicles with numbers 1, 2 and 3. The combination of drivers with vehicles and assigning to a specific area is done intuitively to show the possible differences. Optimisation of this problem (crews and vehicles assignment) will be the subject of further research. In the third variant, all regions will be serviced by vehicle and driver number 2. The assignment is presented in table 1. Other data for calculations are presented in Table 2.

Table 1. Vehicle and driver numbers assigned to service areas

scenario	area	*i*=1	*i*=2	*i*=3	*i*=4	*i*=5
S1	vehicle number	4	5	4	5	4
	driver's number	5	3	4	5	3
S2	vehicle number	3	2	1	1	3
	driver's number	1	2	1	2	1
S3	vehicle number	2	2	2	2	2
	driver's number	2	2	2	2	2

For the data entered in this way, the results presented below were obtained. Table 3 presents selected results regarding incidents, a number of orders handled and LOS values. Figure 2 shows the number of events of particular types, the number of completed tasks and the level of service. Figure 3 shows income, costs and profits.

Table 2. Data for calculations in the simulation model

Vehicle - v	unit	*v*=1	*v*=2	*v*=3	*v*=4	*v*=5
$cav(v)$	EUR/year	3000	2500	3000	2500	2500
$czv(v)$	EUR/task	10	10	10	15	15
$cserv(v)$	EUR/year	600	500	600	500	500
$sv(v)$	-	0,6	0,85	0,9	1	1
$cp(v)$	EUR	30000	25000	30000	25000	25000
$cs(v)$	EUR	5000	3500	0	0	0
$cins(v)$	EUR/year	500	550	550	750	750
$cf(v)$	l/100km	5	5	5	7	7
$fp(v)$	EUR/l	0,9	1	0,9	1	0,9
Driver - k	unit	*k*=1	*k*=2	*k*=3	*k*=4	*k*=5
$cstk(k)$	EUR/year	12000	12000	12000	12000	12000
$bk(i,k)$	EUR/task	45	45	45	45	45
$f(k)$	-	0,65	0,85	1	1	1
$dcf(k)$	-	0,85	0,9	1	1	1
$cszks(k)$	EUR	550	200	0	0	0
$cszke(k)$	EUR	500	250	0	0	0
$de(k)$	-	0,85	0,85	0,85	1	1
$dcins(k)$	-	0,5	0,7	0,8	1	1,3
Area - i	unit	*i*=1	*i*=2	*i*=3	*i*=4	*i*=5
$c_{inc}(i)$	EUR	300	300	200	250	300
$dist(i)$	km	150	210	120	160	220
$avgs(i)$	km/h	50	50	50	50	50

Table 3. The average value for 20 replications of the same plan

Scenario	S1	S2	S3
Numbers of collisions	3,85	2,7	2,9
Numbers of accidents	0,2	0,1	0,1
Numbers of heavy accidents	0	0	0
Number of tasks	6190,8	6216,1	6210,4
Income	1672138	1678495	1676915
Cost	961059	942994	921147
Profit	711078	735501	755768
LOS	0,9905	0,9946	0,9937

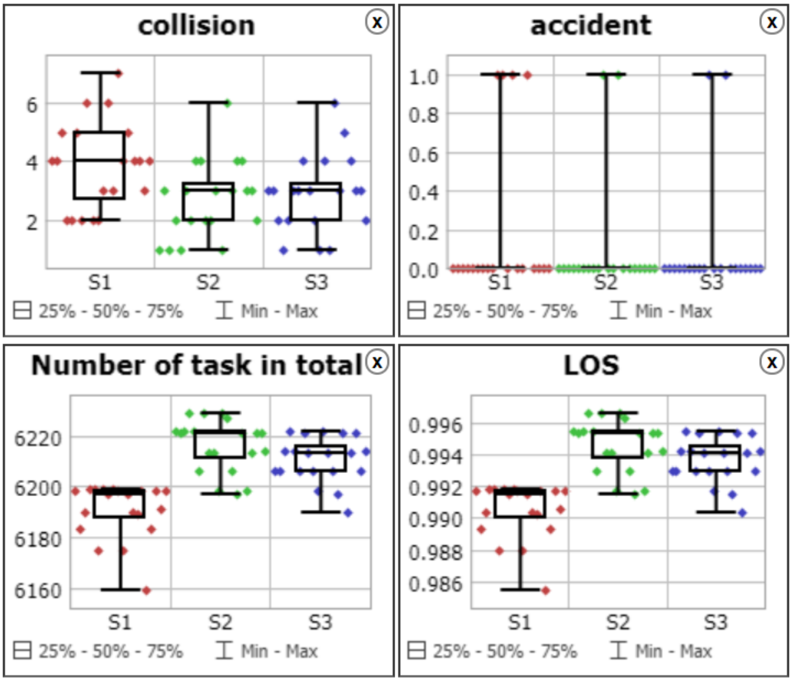

Fig. 2. Number of collisions and accidents, number of completed tasks and level of services

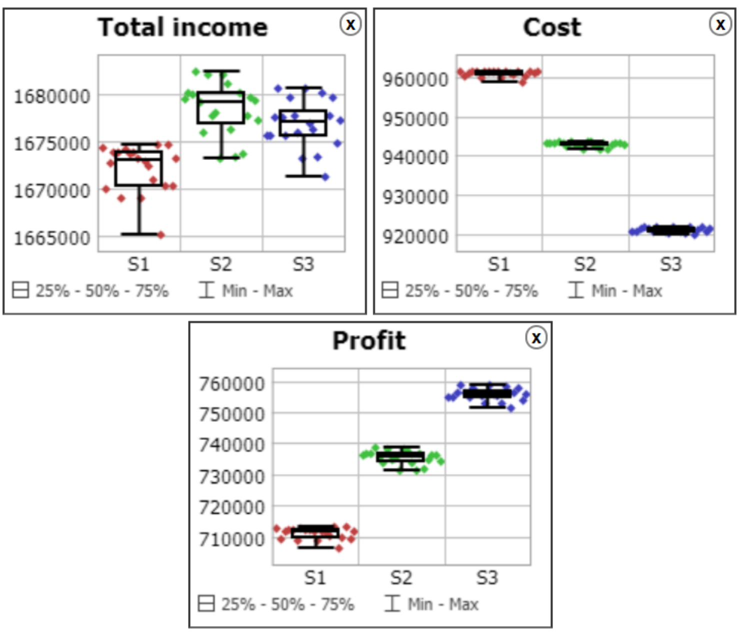

Fig. 3. Income, costs and income for individual scenarios

It should be noted that the revenues to the company's budget are highest for scenario 2. The highest level of safety characterises the same scenario. However, scenario 3 is the most profitable one. It is balanced with the lowest costs and a reasonable level of safety, similar to scenario 2. The scenario in which one does not invest in safety in terms of each criterion turned out to be worse. These results are the starting point for research into the efficiency of fleet management, including safety, absenteeism and ecology.

7. Conclusions

This article presents the problem of decision support in car fleet management, taking into account safety and ecology aspects. The purpose of the work was to present a mathematical model and a case study.

The presented research results allow stating that the developed model has a broad implementation and development potential. Due to the importance of safety issues and current trends in this area, it is necessary to conduct research taking into account various factors and points of view.

In subsequent surveys, it is planned to conduct experiments taking into account the impact of various forms of financing, motivation system, various company procedures in the event of an undesirable event occurring, or vehicle exploitation depending on the driving style. In addition, it is planned to establish cooperation with a real company, which will allow for the calibration of the model and the inclusion of real statistical data on the damage and its impact on the functioning of the company. Work on the development of the model will be continued and will be the basis for the development of a decision support procedure in the selection of cars, drivers, additional equipment and driver training for fleet managers.

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