Strategic vehicle fleet management–a joint solution of make-or-buy, composition and replacement problems

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Abstract

Purpose – The purpose of this paper is to develop an original model and a solution procedure for solving jointly three main strategic fleet management problems (fleet composition, replacement and make-or-buy), taking into account interdependencies between them.

Design/methodology/approach – The three main strategic fleet management problems were analyzed in detail to identify interdependencies between them, mathematically modeled in terms of integer nonlinear programing (INLP) and solved using evolutionary based method of a solver compatible with a spreadsheet.

Findings – There are no optimization methods combining the analyzed problems, but it is possible to mathematically model them jointly and solve together using a solver compatible with a spreadsheet obtaining a solution/fleet management strategy answering the questions: Keep currently exploited vehicles in a fleet or remove them? If keep, how often to replace them? If remove then when? How many perspective/new vehicles, of what types, brand new or used ones and when should be put into a fleet? The relatively large scale instance of problem (50 vehicles) was solved based on a real-life data. The obtained results occurred to be better/cheaper by 10% than the two reference solutions – random and do-nothing ones.

Originality/value – The methodology of developing optimal fleet management strategy by solving jointly three main strategic fleet management problems is proposed allowing for the reduction of the fleet exploitation costs by adjusting fleet size, types of exploited vehicles and their exploitation periods.

Keywords Strategy, Capacity planning, Outsourcing, Preventive replacement, Qualitative data analysis, Metaheuristic

Paper type Research paper

1. Introduction

Vehicles constitute the main resource used to meet transportation requirements both in-house (transportation activities taken by nontransportation companies) and external (transportation services delivered by common carriers). A whole of vehicles (transportation means) used by a given company to satisfy its in-house or outside transportation requirements is called a fleet. An appropriate fleet management is a key factor to a successful management of all transportation activities in a company. In the paper, a strategic level of the fleet management is

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considered. The considerations presented in the paper are given to road fleets of vehicles. However, the discussed fleet management problems and the proposed solution method can be applied to the other transportation modes as well.

Basic definitions of the analyzed problems are as follows:

(1) Make-or-buy – determination of whether it is more advantageous to make a particular item/to do a particular activity in-house or to buy it from a supplier taking into account both qualitative and quantitative factors (Nikolarakos and Georgopoulus, 2001; Ravindran *et al.*, 2018).

(2) Fleet sizing – matching transportation supply and demand by defining such a number of vehicles in a fleet that satisfies a complete fulfillment of incoming transportation orders (demand satisfaction, lost sales costs minimization) and, at the same time, allows to avoid high fixed costs associated with fleet underutilization (supply surplus) (Zak *et al.*, 2008).

(3) Fleet mix – selection of types and subtypes of vehicles in a fleet (Bojovic and Milenkovic, 2008).

(4) Fleet composition – defining both the fleet size and the fleet mix of vehicles in a fleet (Etezadi and Beasley, 1983).

(5) Fleet replacement – deciding on how long to exploit particular vehicles in a fleet or when to dispose/replace them and by what types of a brand new vehicles or used ones in order to avoid too high ownership or exploitation costs, including also a selection of vehicles' investment/acquisition option (e.g. outright purchase, credit, leasing or rental) (Redmer, 2016).

The most crucial and common factor influencing all the strategic fleet management problems is the demand for transportation services. Level, seasonal changes, trend, but also character of the demand result in particular types of transportation requirements to be fulfilled. Thus, the demand can be of different types according to the specific features of loads, distances, routes or locations of destination points/customers, their orders and many others. For example resulting in (Redmer, 2015):

(1) Transportation of commodities that require or not special treatment while moving or handling them (e.g. general freights vs. dangerous goods, loos materials, temperature controlled environment shipments);

(2) transportation of heavy and/or oversized loads;

(3) local, regional, domestic or international shipments (short- and long-distance haulage);

(4) urban, suburban or rural deliveries;

(5) less than truck-load (LTL) or full truck-load (FTL) shipments.

The demand for transportation services can be defined by a number of kilometers, ton-kilometers, tones, cubic-meters, pallets, liters or any other measure of the amount of loads (or passengers if applicable) to be transported/transports to be done within a predefined time period (the period of analysis).

As a result, different (universal, specialized or special) types of vehicles are necessary to transport particular types of loads. However, the range of load types being within transportation capabilities of particular types of vehicles is limited. It depends on both, vehicle/load characteristics and vehicle maximum productivity (e.g. mileage).

All the above-mentioned features of the demand (level and seasonal changes of particular demand types) can lead to an oversized fleet or to an unmet demand (transportation requirements not fulfilled by vehicles in a fleet) or even both concurrently. The unmet demand usually cannot be back ordered and has to be outsourced or lost. Moreover, some long-term changes of the demand can force fleet size increase or reduction that can be obtained by appropriate fleet replacement decisions. Planned fleet size changes can shorten or lengthen exploitation periods of particular vehicles in a fleet (Redmer, 2015).

All these observations are fundamental for the proposed joint solution method for the three main strategic fleet management problems. The combination of those three problems (i.e. make-or-buy, composition covering size and mix, and replacement) and the joint solution of them, taking into account interdependencies between them, constitute the main contribution of the paper.

The reminder of the paper is organized as follows. In the next section a literature review is presented to answer the question whether there are any optimization methods combining the three analyzed fleet management problems. Then, in Section 3, the integer and nonlinear mathematical/optimization model of the combined strategic fleet management problem (CSFMP) is described in detail. To solve the model, a spreadsheet/solver-based solution method is proposed in Section 4. A real-life implementation of the model and the proposed solution method is presented in Section 5, including obtained results. Finally, in Section 6, the research is concluded with a summary of results and an outlook to further research. The paper is completed with extensive references.

2. Literature review

One of the chronologically first types of optimization methods applied to fleet management problems was linear (including integer, mixed integer and binary) mathematical programming – LP. There are numerous and diverse applications of the LP to the fleet management including the following: the fleet sizing problem – FSP (Dantzig and Fulkerson, 1954; Kirby, 1959; Wyatt, 1961; Mole, 1975; Ceder and Stern, 1981; List *et al.*, 2003 – a bi-objective, stochastic model solved with a robust optimization technique; Balac *et al.*, 2020 – a mixed-integer linear programming (MILP) applied to a fleet of pooled automated vehicles, AVs; Zhang *et al.*, 2020 – an MILP applied to a fleet of autonomous electric vehicles, AEVs); the fleet composition problem – FCP (Gould, 1969; Mole, 1975; Etezadi and Beasley, 1983; Bojovic *et al.*, 2010 – problem solved with the Fuzzy Analytic Hierarchy Process method); the replacement problem – RP (Suzuki and Pautsch, 2005; Figliozzi *et al.*, 2011; Boudart and Figliozzi, 2012; Parthanadee *et al.*, 2012; Li *et al.*, 2015; Buyuktahtakin and Hartman, 2016 – an MIP formulation of the parallel RP under economies of scale and technological change; Ngo *et al.*, 2018 – an integer linear programming (ILP) model solved using a branch-and-bound algorithm; Emiliano *et al.*, 2020 – an integer programming model integrating both budgetary and environmental constraints); the vehicle assignment problem – VAP (Rushmeier *et al.*, 1997; Ziarati *et al.*, 1999 – problem solved with a customized branch-and-cut algorithm); the vehicle routing problem – VRP (Taillard, 1999 – HFFVRP); the mixed FCP/VRP (Golden *et al.*, 1984 – FSMVRP; Vis *et al.*, 2005 – FSMVRPTW solved with simulation) and the make-or-buy problem – MoB (Klincewicz *et al.*, 1990; Stojanovic *et al.*, 2011).

Important extensions of the LP applications to the fleet management are nonlinear and goal mathematical programming. Nonlinear methods are applied to the FSP (Hall *et al.*, 2001) and the RP (Preinreich, 1940; Glasser, 1969; Grinyer and Toole, 1972; Jardine, 1973; Christer and Goodbody, 1980; Jardine and Buzacott, 1985; Spooner, 1989; Navon and Maor, 1995; Mathew *et al.*, 2010 – problem solved with genetic algorithm and branch-and-bound method) and the mixed FSP/RP (Navon and Maor, 1995). Whereas goal programming is applied to the mixed FCP/VRP (Calvete *et al.*, 2007 – FSMVRPTW – mixed integer goal programing combined with the enumeration-followed-by-optimization technique).

Dynamic programming is one of the most important methods in the fleet management. It is mostly applied to the RP (Eckles, 1968; Duncan and Scholnick, 1973; Kao, 1973; D'Aversa and

Shapiro, 1978; Hayre, 1983; Waddell, 1983; Lohmann, 1986; Ohnishi *et al.*, 1986; Jin and Kite-Powell, 2000; Hartman, 2001; Hartman, 2004; Hartman and Murphy, 2006; Cho and Rust, 2008; Martinez and van Wassenhove, 2009; Hsu *et al.*, 2011; Inegbediona and Aghedob, 2018) and in some cases to the other fleet management problems, such as the FCP (Fagerholt, 1999) or the mixed FSP/RP (Navon and Maor, 1995).

There are also other types of methods having more niche applications to the fleet management. One of them is queuing theory applied to the FSP (Parikh, 1977; Du and Hall, 1997; Koo *et al.*, 2005). The second is simulation applied to the FSP (Koo *et al.*, 2005 – stochastic model combined with a queuing theory as well; Fagnant and Kockelman, 2018 – an agent-based micro-simulation model applied to a fleet of shared autonomous/fully-automated vehicles, SAVs) and the FCP (Petering, 2011 – large scale simulation technique). The third is network models applied to the FSP (Beaujon and Turnquist, 1991; Sherali and Tuncbilek, 1997; Bojović, 2002), the FCP (Wu *et al.*, 2005) and the RP (Vemuganti *et al.*, 1989). Such types of methods are used rarely as optimal control theory applied to the FSP (Bojović, 2002); inventory control models applied to the FSP (Du and Hall, 1997) and neural networks applied to the VAP (Vukadinovic *et al.*, 1999a, b).

In the past, methods based on the deficit function concept were also widely applied to the FSP (Salzborn, 1974; Gertsbach and Gurevich, 1977; Ceder and Stern, 1981).

Heuristics are another important type of methods that had their application to fleet management problems over decades. There are a lot of heuristic methods usually dedicated to particular fleet management problems, especially to the VRP. The selected examples of the applications are as follows:

(1) savings algorithm applied to the VRP (Clarke and Wright, 1964) and the FCP/VRP (Bodin *et al.*, 1983 – FSMVRP; Golden *et al.*, 1984 – FSMVRP; Desrochers and Verhoog, 1991 – FSMVRP),

(2) sweep algorithm applied to the FCP/VRP (Renaud and Boctor, 2002 – FSMVRP);

(3) giant TSP-tour (also known as tour partitioning or route-first, cluster-second algorithm) applied to the FCP/VRP (Golden *et al.*, 1984 – FSMVRP);

(4) construction algorithms applied to the FSP (Ball *et al.*, 1983 – a route-first, cluster-second algorithm based on greedy insertion) and the FCP/VRP (Liu and Shen, 1999 – FSMVRPTW);

(5) multilevel composite algorithm applied to the FCP/VRP (Salhi and Sari, 1997 – FSMVRPMD or MDVFM – multi depot vehicle fleet mix problem).

Most recently metaheuristics have been also widely applied to the fleet management problems:

(1) local search applied to the FCP/VRP (Yepes and Medina, 2006 – FSMVRPTW; Braysy *et al.*, 2008b – FSMVRPTW) and the FCP/VAP (Redmer *et al.*, 2012);

(2) simulated annealing applied to the VRP (Tavakkoli-Moghaddam *et al.*, 2007 – HFFVRP) and the FCP/VRP (Tavakkoli-Moghaddam *et al.*, 2006 – FSMVRPTW – hybrid method);

(3) deterministic annealing applied to the FCP/VRP (Braysy *et al.*, 2008a – FSMVRPTW);

(4) threshold accepting applied to the VRP (Tarantilis *et al.*, 2004 – HFFVRP);

(5) tabu search applied to the VRP (Tarantilis and Kiranoudis, 2007 – HFFVRP), the FCP/VRP (Osman and Salhi, 1996 – FSMVRP; Gendreau, 1999 – FSMVRP; Taillard, 1999; Paraskevopoulos *et al.*, 2008 – FSMVRPTW – reactive variable neighborhood) and the VAP (Ichoua *et al.*, 2003 – a dial-a-ride problem);

(6) genetic algorithms applied to the RP (Ramachndran *et al.*, 1997), the VRP (Hwang, 2002), the vehicle scheduling problem – VSP (Wren and Wren, 1995) and the FCP/VAP (Redmer *et al.*, 2012).

And finally, a multiple objective decision making/aid – MCDM/MCDA finds its application in the fleet management area including the RP (Gopalaswamy *et al.*, 1993; Redmer *et al.*, 2000), the VSP (Singh and Saxena, 2003; Ghoseiri *et al.*, 2004), the MoB (Min, 1998) and the transportation problem – TP (Singh and Saxena, 2003).

Nowadays fuzzy, stochastic, random approaches or mix of them can be pointed out as a main direction of the development of optimization methods applied to the fleet management problems. They are mostly applied to the FSP (Milenkovic and Bojovic, 2013 – fuzzy optimal control approach), sometimes combining the FSP with the other fleet management problems (Milenkovic *et al.*, 2015 – stochastic model predictive control combining the FSP with the allocation problem; Cap *et al.*, 2018 – stochastic model combining the FSP with the allocation problem for a fleet of shared vehicles). Also the RP gains some interest when applying fuzzy (Stojic *et al.*, 2018 – fuzzy logic model of the fleet investment problem combined with the RP; Riechi *et al.*, 2017 – a combined model of the life cycle cost, Monte Carlo simulation and stochastic analysis considering both vehicle age and mileage), stochastic (Ansaripoor and Oliveira, 2018 – a multi-stage stochastic programming model; Zheng and Chen, 2018 – the RP model combined not explicitly with the VRP and the FCP solved using the multi-option least-squares Monte Carlo simulation, LSM algorithm) and random (Ahani *et al.*, 2016) approaches.

Only a few researches can be found in the literature presenting some attempts to combine explicitly main strategic fleet management problems and solve them jointly. One of the examples uses the econometric global model to solve the RP combined with the FSP (Raposo *et al.*, 2017). However, the FSP is solved analyzing availability of vehicles and its dependence on maintenance and maintenance costs. Thus, these factors help to determine the size of the reserve fleet only to guarantee expected availability of the whole fleet. The second example (Li *et al.*, 2018) is the ILP model combining the RP with the FSP/FCP and also with the VRP (the route assignment). And the last element, i.e. the VRP, makes the model inapplicable to unscheduled transports, e.g. freight ones. The model skips the MoB problem too. There are also two other and the last examples of researches combining the RP with the FSP (the fleet mix only). The first and chronologically earlier research (Feng and Figliozzi, 2013) proposes a deterministic, integer programming model that decides on the number of vehicles of a given age and type used in a given year (however their sum, thus, the fleet size remains constant through particular years of the planning horizon), the number of vehicles of a given age and type salvaged at the end of a given year and the number of new vehicles of a given type purchased at the beginning of a given year. However, it is required that all the demand will be fully satisfied by the analyzed fleet. Thus, the use of outside vehicles (MoB problem) is skipped. The second research (Ahani *et al.*, 2016) extends the previous one by the use of the portfolio theory to reduce total risk (associated with an uncertainty of selected parameters) by diversification of the fleet mix aiming to achieve an optimal value of total cost of ownership (TCO). However, mentioned above drawbacks remain valid. The both researches take into consideration diesel engine vehicles, DVs, and electric vehicles, EVs.

Summarizing, there are no optimization methods combining all the main strategic fleet management problems, i.e. FCP, RP and MoB, solving them together, even though the strong interdependencies between them exist. The most frequent combination (mix) of problems is to solve together the FCP and the VRP being the combination of completely different problems, i.e. strategic and operational ones. This combination, however, typical for scheduled transport systems, seldom if ever occurs in non-scheduled transport ones (e.g. freight road transport). Moreover, the application of very popular and modern solution methods which are heuristics and metaheuristics available in commonly used spreadsheets (e.g. MS Excel) is limited when solving strategic fleet management problems, especially solving them jointly. Also from the practical point of view, the use of spreadsheet based problem modeling and solving (using solvers) technics significantly reduces the effort of managers/analysts in terms of required expertise (e.g. programming/modelling skills) in comparison with the other.

3. Mathematical model of the optimization problem

The CSFMP encompassing composition (size and mix), replacement and MoB subproblems for a fleet consisting of O company's "own" (currently exploited) vehicles i ($i = 1, \ldots, O$) and N potential (perspective) vehicles i ($i = O + 1, \ldots, O + N$), that can be acquired in the future, is considered. Vehicles in a fleet are referred to as a company's "own" independently of their form of ownership (financing). The suggested value of N is not lower than value of O to allow for the replacement of a whole fleet if necessary. A fleet serves/fulfills demand for the transportation services of different types k ($k = 1, \ldots, K$).

The proposed model is a single criterion, nonlinear (due to Equations (2)–(4) which are of *if* type), deterministic, static and discrete (integer) mathematical representation of the CSFMP.

3.1 Assumptions

(1) The demand for the transportation services can be of different types k, according to the specific features of transported loads, traveled distances, carried out routes, etc.

(2) The types of demand k that can be served/fulfilled by particular company's "own" or perspective vehicles i are limited/defined in advance.

(3) The transportation capacity (e.g. annual mileage) of particular vehicles i is distributed between particular demand types k proportionally to the share of the demand type k in all (a sum of) demand types that can be served/fulfilled by vehicle i.

(4) The total capacity utilization index of vehicle i is calculated as a weighted average of the total demand of type k divided by the total transportation capacity of all vehicles i assigned, according to the assumption (3), to the demand of this type to serve/fulfill it (reduced to value of 1, i.e. 100% if higher). The weights used to calculate the weighted average are the share of the demand type k in all the demand types that can be served/fulfilled by vehicle i.

(5) The unmet demand (not served/fulfilled by vehicles being in a fleet) is outsourced (option "make" in the MoB problem).

(6) Exploitation costs of nonengine vehicles (trailers, semi-trailers) are added to the exploitation costs of engine vehicles (trucks, truck-tractors) as a percent of their own costs.

(7) The currently exploited vehicles i already being in a fleet (company's "own" vehicles) are considered to be individual (particular) ones, whereas perspective vehicles to be included into a fleet ("new" ones) are considered at their type level only (including the number of vehicles of a given type in a fleet).

(8) Perspective/"new" vehicles can be added to a fleet as a brand new (with age = 0) or as a second hand/used ones (age > 0) – that is a result of the optimization process (decision variable). "New" refers only to the fact that they are new in a given fleet.

(9) As a result, input data (parameters of the optimization/mathematical model) for company's "own" vehicles are defined for particular vehicles, whereas for "new" vehicles input data are defined for their potential types only. It is a result of the optimization process of which type (according to the value of a decision variable VT_i)

will be particular "new" vehicle i put into a fleet and exactly which input data will be assigned to it (data characterizing the type assigned to vehicle i).

(10) Parameters of the model (input data) are divided into two groups. Constant parameters (marked by a prime) that depend on the vehicle i age a_i only and recalculated (temporary) parameters that depend on the vehicle i age in particular time periods of analysis $j - a_{ij}$ and are subject to change with time.

(11) Company's "own" vehicles i if not sold by the end of the planning horizon J are replaced by vehicles at the same acquisition age as they have been at the beginning of their exploitation.

(12) Company's "own" vehicles i if sold by the end of the planning horizon J cannot be put into exploitation again.

(13) "New" vehicles i put into a fleet are replaced by the vehicles at the same acquisition age as they have been at the beginning of their exploitation.

(14) "New" vehicles i put into a fleet cannot be sold/removed from the exploitation until the end of the planning horizon H.

(15) The length of a single period of analysis j has to be predefined, e.g. one month.

(16) There are three planning horizons taken into account:

- J – Decision planning horizon, in which all the decisions concerning analyzed problem are to be made, covering periods of analysis 0, 1, …, j, …, J (the suggested values of J are 36 or 60 months);
- L – Data planning horizon equal to the maximal exploitation period of vehicles, e.g. connected with their durability; all data describing vehicles are given for this horizon covering periods of analysis 0, 1, …, j, …, J, …, L ($L >> J$; the suggested values of L are 240 or 360 months);
- H – Total planning horizon, covering periods of analysis 0, 1, …, j, …, J, …, L, …, H ($H > L$; the suggested values of H are $2 \,.\, L$, i.e. 480 or 720 months).

It is worth mentioning that the total planning horizon H is used for the mathematical purposes only. It is connected with the replacement problem to assure comparability of different, possible to apply replacement periods. Such long planning horizons are typical for the replacement problem (Sousa and Guimarães, 1997).

3.2 Decision variables

There are five following types of decision variables:

(1) AT_i – acquisition time of a "new" (perspective) vehicle i; $\mathrm{AT}_i \in \langle 0, J \rangle$, $\mathrm{AT}_i = 0$ indicates that vehicle i is not acquired, otherwise it is included into a fleet at the beginning of period $j = \mathrm{AT}_i$;

(2) ST_i – sell time of a company's "own" (currently exploited) vehicle i; $\mathrm{ST}_i \in \langle 0, J \rangle$, $\mathrm{ST}_i = 0$ indicates that vehicle i is not removed from a fleet, otherwise it is removed at the end of period $j = \mathrm{ST}_i$;

(3) AA_i – acquisition age of a "new" vehicle i; $\mathrm{AA}_i \in \langle 0, L-1 \rangle$, age a_{ij} of vehicle i in its first exploitation period j ($j = \mathrm{AT}_i$) equals to $\mathrm{AA}_i + 1$ (acquisition age of company's "own" vehicles is predefined for each vehicle individually);

(4) RA_i – replacement age of vehicle i; for a company's "own" vehicle i ($i \le O$), $\mathrm{RA}_i \in \langle A_i(0)+1, L\rangle$, whereas for a "new" vehicle i ($i > O$), $\mathrm{RA}_i \in \langle \mathrm{AA}_i + 1, L\rangle$, thus depends on AA_i; vehicle i is replaced at the end of period $j = \mathrm{RA}_i$;

(5) VT_i – type of a "new" vehicle i, one of the T possible types; $\mathrm{VT}_i \in \langle 1, T\rangle$ (types of company's "own" vehicles are predefined for each vehicle individually).

One should note that variables AT_i are used only for "new" vehicles, $i > O$, whereas variables ST_i describe company's "own" vehicles only, $i \le O$. Additionally, acquisition ages AA_i, vehicle types VT_i and vehicle age in period $j = 0$, $A_i(0)$ are predefined for company's "own" vehicles and are not subject to optimization.

As far as "new" vehicles ($i > O$) are considered, there is a relationship between variables AA_i and RA_i. The values of variables RA_i have to be higher than or at least equal to the values of variables AA_i ($\mathrm{RA}_i \ge \mathrm{AA}_i$, for given i). Hence, it is crucial for the solution procedure to calculate values of RA_i taking into account values of AA_i.

Since decision variables ST_i and RA_i concern company's "own" vehicles, whereas variables AT_i, AA_i, RA_i and VT_i concern "new" vehicles, the total number of all decision variables can be calculated as $2 \cdot O + 4 \cdot N$.

3.3 Criterion function

The goal of the optimization is to determine:

(1) The strategy of selling or replacing O company's "own" vehicles. It is represented by variables ST_i (sell time) and RA_i (replacement age) for each owned vehicle i ($i = 1, \ldots, O$).

(2) The strategy of acquiring (including decisions on vehicles' age and type) and replacing N "new" vehicles. It is represented by variables AT_i (acquisition time), AA_i (acquisition age), RA_i (replacement age) and VT_i (vehicle type) for each potential "new" vehicle i ($i = O+1, \ldots, O+N$).

(3) The MoB strategy that is indirectly derived from the two above strategies, since the all demand unsatisfied due to the limited transportation capacity of company's "own" vehicles (a fleet) is subcontracted to outside transportation companies.

The VRP, as the operational management problem, is not addressed in the proposed optimization procedure that encompasses strategic fleet management problems only. However, it has to be stressed that in some transport systems, i.e. scheduled ones as mentioned above, there is a bi- or even tri-directional relationship between operational, tactical and strategic fleet management problems. Thus, the applicability of the proposed model can be (but does not have to) partially limited to non-scheduled transport systems only.

The objective function is to minimize the total discounted cost, TDC, defined as follows:

$$\min \mathrm{TDC} = \sum_{j=1}^{H} \frac{\sum_{i=1}^{O+N}\{[\mathrm{FC}_i(j) + \mathrm{VC}_i(j)\cdot P_i(j)\cdot \mathrm{VUI}_i(j)\cdot \mathrm{EURO}_i]\cdot \mathrm{ba}_{ij}\cdot \mathrm{acf}_i\} + \sum_{k=1}^{K}\{\mathrm{TP}_k\cdot \mathrm{UD}_k(j)\}}{\mathrm{DF}(j)} + \sum_{l=1}^{H/12} \frac{\mathrm{BO}(l)}{\mathrm{DF}(j = 12\cdot l - 6)}, \tag{1}$$

where

TDC	The TDC of satisfying the whole demand for transportation services within horizon H, including costs of an in-house transportation – the make option, and an outside transportation – the buy option (monetary units – m.u./H)
$FC_i(j)$	fixed cost of vehicle i in period j, including the ownership and utilization cost components (m.u./period of analysis)
$VC_i(j)$	variable utilization cost (operating and maintenance – O&M) of vehicle i in period j (m.u./vehicle productivity unit)
$P_i(j)$	maximum productivity (mileage, tonnage carried, amount of loads transported) of vehicle i in period j (km, tkm, tone, m^3, pallet, liter, . . ./period of analysis)
$VUI_i(j)$	vehicle productivity utilization index of vehicle i in period j (–)
$EURO_i$	coefficient of variable cost $VC_i(j)$ of vehicle i, representing the emission-based (the European Emission Standards or any other) road tolling (–)
	$EURO_i = 1$ for $i \in \langle 1, O \rangle$ (company's "own" vehicles) or $i \in \langle O+1, O+N \rangle$ ("new" vehicles) providing that $2009 \leq Y + AT_i/12 - AA_i/12$ (age threshold 1)
	$EURO_i = 1.012$ for $i \in \langle O+1, O+N \rangle$ ("new" vehicles) providing that $2005 \leq Y + AT_i/12 - AA_i/12 < 2009$ (age threshold 2)
	$EURO_i = 1.017$ for $i \in \langle O+1, O+N \rangle$ ("new" vehicles) providing that $2000 \leq Y + AT_i/12 - AA_i/12 < 2005$ (age threshold 3)
	$EURO_i = 1.029$ for $i \in \langle O+1, O+N \rangle$ ("new" vehicles) providing that $Y + AT_i/12 - AA_i/12 < 2000$ (age threshold 4)
Y	current calendar year, at the moment of analysis (–)
ba_{ij}	„binary age" of vehicle i in period j denoting if vehicle i is exploited/in a fleet in period j (value 1) or not (value 0); $ba_{ij} = \text{sign}(a_{ij})$ (–)
acf_i	additional costs factor of vehicle i (when an engine vehicle is combined with a non-engine vehicle, such as a trailer, semitrailer) (–)
TP_k	unit transportation market price for satisfying demand of type k (m.u./vehicle productivity unit)
$UD_k(j)$	unmet (=outsourced) demand of type k in period j (the buy option) (km, tkm, tone, m^3, pallet, liter, . . ./period of analysis)
BO(l)	budget overrun in fiscal year l; $l = 1, \ldots, J/12, \ldots, H/12$ (m.u./fiscal year)
DF(j)	discount factor in period j, based on interest rate r_j in period j (–)

The TDC consists of the following three cost components (all of them discounted using DF(. . .) factor):

(1) The first term is the total cost in the total planning horizon H, of a make option, taking into account all company's "own" O and "new" N vehicles exploitation costs; fixed (including road taxes, insurance, environmental taxes, licenses e.g. TIR carnet, drivers' salary – a fixed part, independent of millage and ownership cost as well) and variable (including all O&M costs as fuel, maintenance – spare parts and labor, tires, single/one-time licenses, parking fees, phone calls, road tolls, drivers' salary – a variable part, depending on working/driving time and/or millage) (the first line of Equation (1)– the first two sums).

(2) The second term is the total cost in the total planning horizon H, of a buy option, taking into account costs of buying transportation services in a market to fulfill particular demand types k not satisfied within a make option (the first line of Equation (1)– the first and the third sums).

(3) The third term is the penalty cost added to the TDC if the budget constraint is not met in a given fiscal year l (when the real, necessary budget $B_{real}(l)$ exceeds a maximum, available budget $B_{max}(l)$). Thus, all the solutions of the problem having values of

decision variables within predefined boundaries can be treated as feasible regardless of the budget constraint (a weak one). However, it forces the solution procedure to search for the solutions that fulfill budget constraint, have no penalties added to the TDC (the second line of Equation 1).

Many of the terms/parameters in Equation (1), such as $FC_i(j)$, $VC_i(j)$ and $P_i(j)$ relate to vehicle i in period j and depend on its age. The age a_{ij} of owned vehicle i ($i = 1, \ldots, O$) in period $j \geq 0$ is defined/calculated as follows:

$$a_{ij} = \begin{cases} AA_i + 1 + \mathrm{mod}(A_i(0) + j, RA_i - (AA_i + 1)) & j \leq ST_i \vee ST_i = 0 \\ 0 & j > ST_i \wedge ST_i \neq 0 \end{cases} \tag{2}$$

whereas, the age a_{ij} of a "new" vehicle i ($i = O + 1, \ldots, O + N$) in period $j \geq 0$ is defined as follows:

$$a_{ij} = \begin{cases} AA_i + 1 + \mathrm{mod}(AT_i + j, RA_i - (AA_i + 1)) & j \geq AT_i \wedge AT_i \neq 0 \\ 0 & j < AT_i \vee AT_i = 0 \end{cases} \tag{3}$$

Similarly, many of the terms/parameters in Equation (1), concerning "new" vehicles i ($i = O + 1, \ldots, O + N$), such as $FC_i(j)$, $VC_i(j)$, $P_i(j)$, $EURO_i$ and acf_i relate to/depend on their types VT_i (the first three of the listed ones also apart from period j, and thus the vehicles' age). These terms in Equation (1), i.e. parameters of the model characterizing "new" vehicles i are defined not for particular vehicles (as for owned ones), but for their potential types only – see assumption (9). For example, value of the $FC_i(j)$ is defined as follows (the other parameters similarly):

$$FC_i(j) = FC_{VT_i}(j) \Rightarrow i = VT_i \tag{4}$$

The most crucial element of Equation (1), allowing for interchangeability of vehicles when satisfying particular demand types k, is $VUI_i(j)$ index that joins vehicles' productivity $P_i(j)$ with the demand types k by the productivity range PR_{ik} parameter. The $VUI_i(j)$ index, being a weighted average, is calculated as follows:

$$VUI_i(j) = \begin{cases} 0, \quad \text{if} \quad TD_i(j) = 0 \\ \displaystyle\sum_{k=1}^{K} \begin{cases} 0, \quad \text{if} \quad SMD_k(j) = 0 \\ \dfrac{PR_{ik} \cdot D_k(j)}{TD_i(j)} \cdot \mathrm{Min}\left\{ \dfrac{D_k(j)}{SMD_k(j)}, 1 \right\}, & \text{otherwise} \end{cases} & \text{otherwise} \end{cases}, \tag{5}$$

where:

The $VUI_i(j)$ consists of the following two components:

$TD_i(j)$	total demand of all types in period j being appropriate, according to the PR_{ik} parameter, to be satisfied by vehicle i (km, tkm, tone, m^3, pallet, liter, . . ./period of analysis)
$SMD_k(j)$	supply meeting demand type k in period j, calculated as the total productivity of all vehicles i being able, according to the PR_{ik} parameter, to satisfy demand type k taking into account their engagement to satisfy other demand types – interchangeability of vehicles with demand types k (km, tkm, tone, m^3, pallet, liter, . . ./period of analysis)
PR_{ik}	productivity range of vehicle i in relation to demand of type k denoting if vehicle i is suitable to satisfy demand of type k (value 1) or not (value 0); $PR_{ik} \in \{0, 1\}$ (–)
$D_k(j)$	demand of type k in period j, expressed in the same unit measure as $P_i(j)$ (km, tkm, tone, m^3, pallet, liter, . . ./period of analysis)

other notations as in Equation (1)

(1) The first term under the sum represents mathematically the weight and physically the part of vehicle's i total productivity assigned to satisfy demand of type k calculated as a value of demand k divided by the total demand for services of vehicle i (the sum of weights for particular vehicles i equals to 1),

(2) The second term under the sum is the utilization index when satisfying demand of type k, calculated as a value of demand k divided by the total supply (vehicles' productivity) meeting demand of type k and if the demand exceeds the supply equal to 1.

Whereas, $\mathrm{TD}_i(j)$ and $\mathrm{SMD}_k(j)$ parameters are calculated as follows:

$$\mathrm{TD}_i(j) = \sum_{k=1}^{K} (\mathrm{PR}_{ik} \cdot D_k(j)) \tag{6}$$

$$\mathrm{SMD}_k(j) = \sum_{i=1}^{O+N} \left(P_i(j) \cdot \mathrm{ba}_{ij} \cdot \frac{\mathrm{PR}_{ik} \cdot D_k(j)}{\mathrm{TD}_i(j)} \right) \tag{7}$$

where notations as in Equation (1) and Equation (5).

3.4 Constraints

Due to construction of the decision variables and the criterion function, in the TDC model there are two types of constraints only. They are an integer constraint for all the decision variables and their minimum and maximum values. Due to construction of the criterion function – TDC no budget constraint is required. Budget limitations are taken into account in the model as the penalty cost added to the TDC always if the presumed budget is exceeded.

4. Spreadsheet/solver based solution method

The defined previous section model of the CSFMP has been implemented in the MS Excel 2016 spreadsheet. A compatible MS Excel spreadsheet professional solver named Evolver developed by the Palisade Corporation has been applied to solve the problem/model. The Evolver is equipped with a so-called "engine" (solution procedure) based on a genetic algorithm combined with a local search procedure that improves generated solutions locally.

The genetic algorithm based "engine" of the solver has been used taking into account the problem/model characteristics. At first it is the nonlinear, combinatorial optimization problem with well-defined objective function, however, practically with no constraints. It is recognized that if the space to be searched is not so well understood and relatively unstructured but a genetic algorithm representation of that space can be developed, then genetic algorithms provide a powerful search heuristic for large, complex spaces (De Jong, 1990). In the analyzed problem/model, the well-defined objective function constitutes a clear way to evaluate fitness and the search space is not well-constrained, that is why the genetic algorithm based "engine" solver has been applied.

The spreadsheet is organized as follows:

4.1 Input data

Particular parameters of the model are given in separate tables/sheets (see Figure 1). The dimensions of particular input data tables depend on the parameters they contain. As it was mentioned in Section 3.1, parameters of the model are divided into two groups. Constant parameters (marked by a prime) that depend on the vehicle i age a_i and recalculated (temporary) parameters that depend on the vehicle i age in particular time periods of analysis

$j - a_{ij}$ that is subject to change with time of exploitation. All the input data are constant parameters and are recalculated into temporary ones, according to the following scheme:

(1) for $i \leq O$ (company's "own" vehicles): e.g. vehicle productivity $P_i(j) = P'_i(a_i = a_{ij})$;

(2) for $i > O$ ("new" vehicles of type VT_i): $P_i(j) = P'_{O+\mathrm{VT}i}(a_i = a_{ij})$.

For example, if there is a company's "own" ($i \leq O$) vehicle i = e.g. 2 being in the period of analysis j = e.g. 3 at the age of $a_{ij} = a_{i=2\,j=3} = a_{23}$ = e.g. 24 months, its recalculated (temporary) parameters in the period of analysis 3, e.g. productivity $P_i(j) = P_{i=2}(j = 3) = P_2(3)$, equals to the constant productivity $P'_i(a_i = a_{ij}) = P'_{i=2}(a_{i=2} = a_{i=2\,j=3}) = P'_2(a_2 = a_{23} = 24) = P'_2(24)$ taken from the input data table.

The constant parameters constitute the input data, whereas the elements of the criterion function, Equation (1), are temporary parameters only.

4.2 Decision variables and constraints

The decision variables have been implemented in a spreadsheet as a vector containing $2 \cdot O + 4 \cdot N$ cells. With every variable (cell) there are associated two parameters/constraints – its minimum and maximum values. Some of these constraints (those for RA_i; $i \geq O$) are dynamic constraints having right-hand side (RHS) values calculated on the basis of the value of the other decision variables (AA_i) (see Figure 2). All the decision variables and their minimum and maximum values are integers.

4.3 Calculations

During the optimization process, in every iteration, all the elements of the criterion function depending on the age of vehicles (temporary parameters) are calculated based on the decision variables' values and the input data (constant parameters of the model) (see Figure 3). As a result, current value of the criterion function is calculated.

	$P'_i(a_i)$	Vehicle age a_i					J		L
	Vehicle i	0	1	2	3	...	36	...	240
	1	8250	8250	8232	8214	...	7619	...	4004
	2	8250	8250	8232	8214	...	7619	...	4004
	3	8250	8250	8232	8214	...	7619	...	4004
	...	...	...	...	...	...	...	...	...
O	50	6750	6750	6735	6721	...	6234	...	3276
	51	8500	8500	8481	8463	...	7850	...	4125
	52	8500	8500	8481	8463	...	7850	...	4125
	...	...	...	...	...	...	...	...	...
O+T	60	8000	8000	7983	7965	...	7388	...	3882

Figure 1.
An exemplary input data – constant parameters of the model (vehicle productivity in kilometers per month for 50 company's "own" vehicles, 10 types of "new" vehicles, 3-year long decision planning horizon and 20-year long data planning horizon – maximum exploitation period of vehicles)

	RA_1	...	RA_{50}	ST_1	...	ST_{50}	AT_{51}	...	AT_{100}	RA_{51}	...	RA_{100}	AA_{51}	...	AA_{100}	VT_{51}	...	VT_{100}
Decision variables	240	...	164	9	...	0	25	...	21	198	...	132	171	...	61	8	...	7
Min	25	...	61	0	...	0	0	...	0	=N2+1		62	0	...	0	1	...	1
Max	240	...	240	36	...	36	36	...	36	240	...	240	239	...	239	10	...	10

Figure 2.
Exemplary decision variables and their minimum and maximum values – constraints (for 50 company's "own" vehicles and 50 "new" vehicles – the whole table contains 300 variables)

4.4 Solver

The solver (in this case the Evolver) minimizes value of the function in a cell (in this case KP4) being the criterion function – TDC calculated based on the values of the decision variables (in this case cells B5:KO5 – 300 cells) and constraining these values to the integer ones only. All the other constraints (minimum and maximum values of the decision variables) come down to a one cell containing logical function giving value of 1 if all the values of the decision variables are in the assumed ranges and 0 otherwise. That is why there is only one, hard constraint for the cell containing mentioned logical function (see Figure 4).

5. Numerical example

5.1 Problem instance

A fleet composed of $O = 50$ vehicles of different types (including trucks, tractor-trucks with semi-trailers and vans) is considered. The fleet is exploited by a transportation company offering domestic transportation services (including long- and short-distance haulage,

	Productivity of vehicle *i* in period of analysis *j* - $P_i(j)$						J		L		H
Vehicle *i*	**Period *j***	0	1	2	3	...	36	...	240	...	480
1	**P1(j)**	7835	7817	7799	7781	...	8250	...	8250	...	8250
2	**P2(j)**	7835	7817	7799	7781	...	8250	...	8250	...	8250
3	**P3(j)**	6970	6952	=IF('Sheet1'!$C6=0;0;INDEX(Tab_vehicles_Pi_aij;$A335;E129+1))							6430
...	**P4(j)**	6549	6532	6514	6497	...	5920	...	5081	...	6340
O = 50	**P50(j)**	5880	5865	5851	5836	...	5349	...	4759	...	6057
51	**P51(j)**	5029	8000	8000	8000	...	4819	...	4557	...	4610
52	**P52(j)**	7179	8000	8000	8000	...	7109	...	5746	...	5955
53	**P53(j)**	5396	8000	8000	8000	...	8000	...	8000	...	8000
...	**P54(j)**	6305	8000	8000	8000	...	5798	...	5483	...	5623
$O+N$ = 100	**P100(j)**	6951	8000	8000	8000	...	6672	...	6829	...	6357

Note(s): Vehicle productivity in kilometers per month for 50 company's "own" vehicles, 50 "new" vehicles, 3-year long decision planning horizon, 20-year long data planning horizon – maximum exploitation period of vehicles and 40-year long total planning horizon

Figure 3. An exemplary recalculated (temporary) parameter of the model

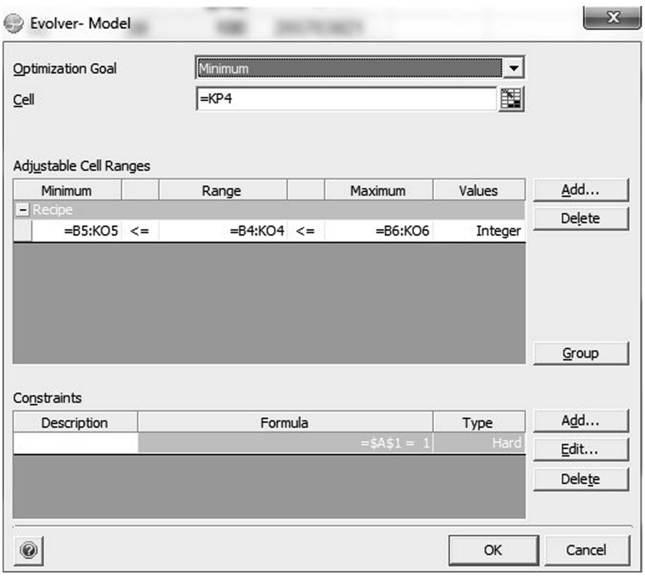

Figure 4. An exemplary solver's (Evolver) dialog window

local and urban ones). Different types of loads are transported (including general freights and perishable goods as well). Up to $N = 50$, “new” vehicles of $T = 10$ types can be put into the fleet, possibly replacing the existing ones. The current fleet and the perspective vehicles are characterized in Table 1.

Moreover, there are $K = 5$ types of the domestic transport demand to be served, as shown in Table 2.

To transport together general freights and perishable goods (temperature controlled loads) special isotherm containers/boxes are assumed to be utilized.

Due to the specific features of the particular vehicle types and the specific features of the particular demand types, there are some rigid limitations when assigning vehicles to transportation tasks (demand types). As a result, particular vehicles can serve selected demand types only.

Table 1. The characteristics of vehicles

Vehicle type t	Load capacity (ton)	Average age (year) At the moment of acquisition	Current	Number of vehicles In the fleet
Company's "own" (currently exploited) vehicles				
Tractor with semitrailer	20	0.7	3.3	3
Tractor with semitrailer	24	2.7	8.1	15
Tractor with semitrailer	26	3.6	10.3	7
Truck	6	0.0	1.0	2
Truck	8	1.6	5.6	7
Truck	10	0.0	12.0	2
Truck	8	4.3	9.3	3
Truck	14	1.0	4.5	4
Truck	16	3.0	8.0	2
Van	1.5	0.0	5.0	2
Van	2	0.0	1.5	2
Van	2	0.0	2.0	1
"New" (perspective) vehicles to be put into exploitation				
Truck with tandem trailer	28	–	–	–
Truck with tandem trailer	28	–	–	–
Tractor with semitrailer	20	–	–	–
Tractor with semitrailer	20	–	–	–
Tractor with semitrailer	24	–	–	–
Tractor with semitrailer	24	–	–	–
Truck	14	–	–	–
Truck	14	–	–	–
Truck	12	–	–	–
Truck	12	–	–	–

Table 2. The characteristics of demand types – kilometers to be covered in particular years of the decision planning horizon J

Demand type k	Description	Year 1	Year 2	Year 3
–	–	(1,000 km)	(1,000 km)	(1,000 km)
1	Long-haul, general freights	1,831	1,981	2,064
2	Short-haul, general freights	849	896	920
3	Short-haul, temperature controlled loads	1,058	1,097	1,126
4	Urban distribution, general freights	718	777	816
5	Urban distribution, general freights and temperature controlled loads	633	682	716
Total	–	5,089	5,433	5,642

There are also many other data characterizing the analyzed problem, including acquisition and salvage/market residual values (RV) of particular vehicles according to their age, monthly productivity (mileage) of particular vehicles according to their age, fixed and variable exploitation costs of particular vehicles according to their age, prices in the market for transportation services satisfying particular types of the demand, cost of capital when investing in the fleet, the tax rate, company's budget available to invest in the fleet in particular fiscal years and the other.

The following time frames are considered: a 3-year long decision planning horizon (J = 36 months), a 20-year long data planning horizon (L = 240 months) and a 40-year long total planning horizon (L = 480 months).

5.2 Optimization process

The solution algorithm (the "engine") used by the solver (in this case the Evolver) was a metaheuristic approach (a genetic algorithm combined with a local search procedure). As a result, the optimization process was asymptotic (taking into account improvement of the criterion function – see Figure 5) and obtained (solutions) approximate results.

It took 63 min and 2,850 trials, i.e. the number of all the generated and examined solutions to find an optimal, however still approximate one.

5.3 Optimization results

Since the optimization problem (the CSFMP) defined in the paper is novel, there is no possibility to assess the accuracy of its model and the performance of the proposed solution method in relation to the other approaches. Therefore, it was decided to compare the obtained optimal 3-year long fleet management plan (the solution denoted as an "*optimal*" in Table 3) with two reference solutions:

(1) Random – values of particular decision variables drown randomly within assumed feasible ranges;

(2) Do-nothing – representing status quo, i.e. no changes in the fleet (exploitation of the current fleet over the next three years).

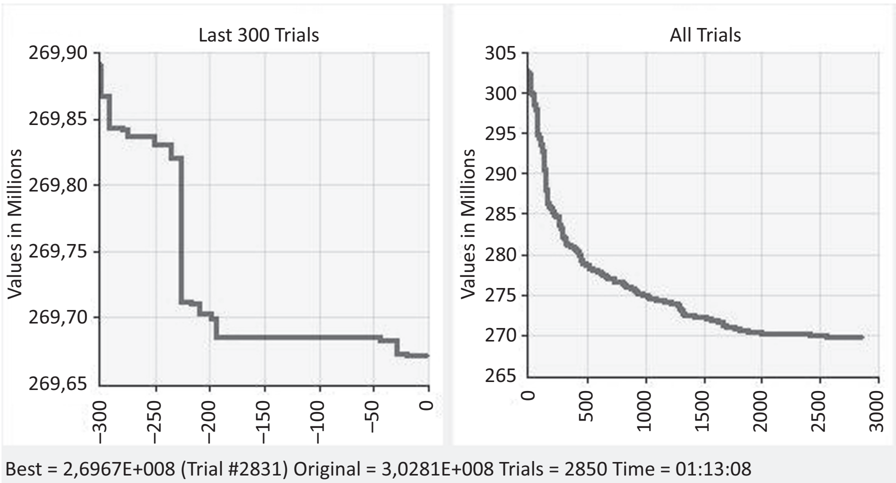

Figure 5. An improvement of the criterion function value within the optimization process – solver's (Evolver) screen view

	Do-nothing	Solution Random	Optimal
Fleet size – total number of vehicles	50	57	68
Including company's "own" (currently exploited)			
Tractor with semitrailer curtain sided 20*t*	3	3	1
Tractor with semitrailer curtain sided 24*t*	15	6	12
Tractor with semitrailer curtain sided 26*t*	7	5	7
Truck closed 6*t*	2	2	0
Truck full tilt 8*t*	7	4	0
Truck full tilt 10*t*	2	1	2
Truck insulated 8*t*	3	3	0
Truck insulated 14*t*	4	1	0
Truck refrigerated 16*t*	2	0	2
Van closed 1.5*t*	2	2	1
Van closed 2*t*	2	1	0
Van insulated 2*t*	1	1	0
Including "new" vehicles			
Truck with tandem trailer full tilt 28*t* (outright purchase)	–	4	0
Truck with tandem trailer full tilt 28*t* (leasing	–	4	0
Tractor with semitrailer curtain sided 20*t* (outright purchase)	–	1	0
Tractor with semitrailer curtain sided 20*t* (leasing)	–	1	0
Tractor with semitrailer curtain sided 24*t* (outright purchase)	–	2	0
Tractor with semitrailer curtain sided 24*t* (leasing)	–	6	0
Truck full tilt 14*t* (outright purchase)	–	2	9
Truck full tilt 14*t* (leasing)	–	5	34
Truck insulated 12*t* (outright purchase)	–	2	0
Truck insulated 12*t* (leasing)	–	1	0
Number of *O*/*N* vehicles in the fleet	50/0	29/28	25/43
Average values of ST/AT decision variables, in months	–/–	20/20	2/6
Age – average within the decision planning horizon, in years	8.4	7.1	7.3
Age – at the moment of acquisition in years (average / min / max)	–/–/–	4/0/19	5/0/12
Vehicles versatility – ability to serve particular demand types	45%	47%	59%
Average vehicles utilization index	98%	96%	90%
Make-or-buy (% of total kilometers = % of total demand) option make	67%	75%	83%
option buy	33%	25%	17%
Costs*			
Total discounted (within the decision planning horizon)			
In total	100%	98%	89%
Company's "own" vehicles (the make option)	100%	115%	116%
Outside vehicles (the buy option)	100%	75%	51%
Unit discounted			
In total	100%	98%	89%
Company's "own" vehicles (the make option)	100%	104%	95%
Outside vehicles (the buy option)	100%	96%	94%

Note(s): *In comparison to the do-nothing option

Table 3. The results of the optimization – the different solution types

A detailed comparison of these three solutions is presented in Table 3.

Based on Table 3, it can be concluded that the worst approach is to do nothing, make no changes in the fleet structure for the next three years. The do-nothing option turns out to be even worse than the random one, giving a little bit higher costs. The optimal solution is more than 10% better/cheaper when taking into account the total and unit transportation costs, even though the utilization of the vehicles decreased (from 98% or 96%–90%), it turned out to be profitable after all. Moreover, the optimal solution leads to the significantly increased fleet size (from 50 or 57 to 68 vehicles) and to the significant reduction (from 33% or 25%–17%) of the transports outsourced (a one-third or double reduction of the share of the buy option in the total number of kilometers covered). It can be also observed that the average age of the vehicles in the fleet within the decision planning horizon J has remained almost constant (about 7–8 years). And finally, the brand new and the second hand vehicles have been put into the fleet concurrently. However, only 4 of the 43 vehicles put into the fleet have been brand new. The second hand vehicles were of age up to 12 years, while the average age at the moment of acquisition was 5 years.

6. Conclusions

The presented CSFMP solution method (the model and the solution procedure) allows for defining the fleet management strategy in transportation and nontransportation companies and institutions exploiting small and large fleets of vehicles. The strategy results in the reduction of the total costs of transportation and the improvement of a technical and an economic condition of a fleet.

The proposed model of the analyzed problem is relatively simple and allows for an intuitive/natural representation of a solution. Particular decision variables are associated with strategic decisions to be made with regard to particular currently exploited and perspective vehicles. For the currently exploited vehicles, the decisions are keep them in or remove from a fleet? If keep, how often to replace them? If remove then when? For the perspective vehicles: how many vehicles, of what types, brand new or used ones and when should be put into a fleet? The crucial issue is not how to mathematically model the joint problem, but how to control an optimization process to obtain expected feasible solutions. From this point of view, an objective function applied in the optimization process is of utmost importance. The function proposed in this research is sensitive to changes in company's "own" vehicles parameters as well as parameters of "new"/perspective vehicles, transportation prices in a market for services fulfilling different types of transportation demand and also budget limitations influencing the whole process. All these aspects have been taken into account in the proposed criterion function.

Worth mentioning is that the proposed method deals with the different types of vehicles serving the different types of transportation demand. In the other words, the method deals with interchangeability of vehicles when serving partially particular types of demand.

The main contribution of the paper to the literature/research is that particular and different strategic fleet management problems are solved jointly. It allows taking into account all the interdependencies between them.

The further research will be focused on searching for better, specialized (heuristic) solution algorithms assuming that the goal is to find not only fast and effective ones but also robust and, thus, effectively dealing with instances of the problem having different properties.

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