STRATEGIC VEHICLE FLEET MANAGEMENT - THE COMPOSITION PROBLEM

Adam Redmer

Poznan University of Technology, Poznan, **Poland**

ABSTRACT. **Background:** Fleets constitute the most important production means in transportation. Their appropriate management is crucial for all companies having transportation duties. The paper is the second one of a series of three papers that the author dedicates to the strategic vehicle fleet management topic.

Material and methods: The paper discusses ways of building companies' fleets of vehicles. It means deciding on the number of vehicles in a fleet (the fleet sizing problem - FS) and types of vehicles in a fleet (the fleet composition problem - FC). The essence of both problems lies in balancing transportation supply and demand taking into account different demand types to be fulfilled and different vehicle types that can be put into a fleet. Vehicles, which can substitute each other while fulfilling different demand types. In the paper an original mathematical model (an optimization method) allowing for the FS/FC analysis is proposed.

Results: An application of the proposed optimization method in a real-life decision situation (the case study) within the Polish environment and the obtained solution are presented. The solution shows that there exist some best fitted (optimal) fleet size / composition matching company's transportation requirements. An optimal fleet size / composition allows for a significantly higher fleet utilization (10-15% higher) than any other, including random fleet structure. Moreover, any changes in the optimal fleet size / composition, even small ones, result in a lower utilization of vehicles (lower by a few percent).

Conclusions: The presented in this paper analysis, on the one hand, is consistent with a widespread opinion that the number of vehicle types in a fleet should be limited. In the other words it means that the versatility / interchangeability of vehicles is very important. On the other hand, the analysis proves that even small changes in a fleet size / fleet composition can result in an important changes of the fleet effectiveness (measured for example by the utilization ratio).

Key words: management, optimization, fleet, transport, sizing, composition.

"Is your fleet the right size?" - David Kirby

INTRODUCTION

The decision of how many vehicles keep in a company's fleet to fulfil varying with time transportation requirements is called a fleet sizing (FS) problem [Gould, 1969]. Whereas, in case of a fleet composition (FC) problem types of vehicles should be defined as well [Etezadi and Beasley, 1983].

The most crucial factor influencing the FS/FC problems is a demand for transportation services. Its level, seasonal changes, trend, but also its character resulting in particular types of transportation requirements to be fulfilled. In practice, there can be observed not only seasonal changes of the demand but also more short-term fluctuations as monthly or even daily changes. In many economy branches transportation requirements increase significantly (even by 30%) at the end of every month, usually in a last week or a third decade

of a month (phenomenon so-called "the third decade syndrome").

The demand can also be of different types according to specific features of loads, distances, routes or locations of destination points / customers, their orders and many others. For example resulting in:

– transportation of commodities that require or not special treatment (e.g. general freights v. dangerous goods, loose materials, temperature controlled environment shipments),
– transportation of heavy and/or oversized loads,
– local, regional, domestic or international shipments (short- and long-distance haulage),
– urban, suburban or rural deliveries,
– 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 loads to be transported /transports to be done within a given time period.

As a result, different (universal, specialized or special) types of vehicles of different load capacity (small, light, medium, heavy or even very heavy trucks) 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, the interrelationship of vehicle and load features and vehicle maximum productivity that can be split among particular demand types.

All the mentioned above 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 at the same time. The unmet demand usually cannot be backordered and has to be outsourced or lost. Moreover, some long-term changes of the demand can force fleet size changes (increases or reductions).

There are also very important economic aspects of the FS/FC problems. In contrast to using outside transportation resources (buying transportation services in the market from common carriers), an in-house transportation solution results not only in variable, but, what is very important, in fixed costs as well. The fixed costs have to be bore even though particular vehicles in a fleet do not work (are not utilized) at a particular time period. These are the costs of unused resources - downtime, empty movements, and underutilized vehicles' loading capacity and/or productivity e.g. mileage (due to seasonal or other changes of the transportation demand). On the other hand, a company operating their own fleet of vehicles has to cover costs of all kilometers travelled (loaded and empty ones).

What can reduce level of the unmet demand or too high fixed costs and at the same time increase utilization ratio of an in-house fleet is the right interchangeability/versatility of vehicles in a fleet. The interchangeability /versatility means ability of particular vehicles to serve particular demand types.

THE METHOD FOR SOLVING THE FC PROBLEM

There exist many methods for solving the FS/FC problems using different computational /optimization techniques. One can distinguish methods based on: Linear Programing (including one of the very first FS solution procedures proposed in the year 1954 by Dantzig and Fulkerson [Dantzig and Fulkerson 1954]; Non-Linear Programing [Hall, Sriskandarajah and Genesharajah 2001]; Dynamic Programming [Fagerholt 1999]; Queuing Theory [Parikh 1977, Zak, Redmer and Sawicki 2008]; Simulation [Koo, Jang and Suh 2005, Petering 2011]; Network / Graph Theory [Beaujon and Turnquist 1991, Wu, Hartman and Wilson 2005], and Inventory management techniques [Du and Hall 1997] as well. The separate and large group of methods constitute those combining the FS/FC problems with the Vehicle Routing Problem - VRP. As a result, the FS/FC problems, which are strategic in nature, are treated more as tactic-operational ones. This group of methods usually includes heuristic [Ball, Golden, Assad

and Bodin 1983, Golden, Assad, Levy and Gheysens 1984, Renaud and Boctor 2002] and metaheuristic ones [Yepes and Medina 2006, Osman and Salhi 1996, Gendreau, Laporte, Musaraganyi and Taillard 1999].

Majority of the FS/FC solution methods balances supply and demand for transportation services. They adjust supply of transportation capabilities of a fleet to the demand for transportation services to be delivered. The supply is defined by a number of vehicles in a fleet and their capacity (e.g. tonnage or the Gross Vehicle Weight Rating - GVWR) and productivity (e.g. a maximum annul mileage). When considering the FC problem different types of vehicles serving different types of transportation demand are taken into account as well. The general aim of balancing supply and demand is to fulfil all the demand while minimizing overall costs or maximizing utilization ratio of a fleet.

The general drawback of the mentioned above solution methods is that they do not take into account an interchangeability of vehicles when serving different types of transportation demand. Usually a necessary numbers of vehicles in a fleet to serve particular demand types are calculated separately. While in practice vehicles of particular types are utilized to fulfill interchangeably different demand types, with lower or higher effectiveness and under some limitations of course. When it is not taken into account it can result in an oversized fleet.

The question arises how to balance transportation supply and demand assuming that particular vehicle types can serve particular demand types interchangeably? What will be the distribution of vehicles' productivity between particular types of demand?

The point is to assess the most probable number of kilometers that vehicle of a given type will travel carrying loads (serving demand) of a given type. Let assume that a vehicle of a particular type, having the maximum productivity of 100 kilometers per given period of time / analysis, can serve for example three types of demand (1, 2 and 3) requiring the following number of kilometers

to be covered: 100, 200 and 300 per period of analysis (600 kilometers in total). The probability that the vehicle will be engaged in carrying loads of the type 3 (the demand 3) is three times higher than the probability of carrying loads of the type 1, since the overall workload to be done associated with the demand type 3 is 300 kilometers, whereas for the demand type 1 it is 100 kilometers only. Based on this assumption, the maximum productivity of the vehicle can be most probably divided between the three demand types as follows: 17 kilometers traveled carrying loads of type 1 (it comes from 100 kilometers multiplied by 1/6 that is 100 kilometers being the total quantity of kilometers associated with the demand type 1 divided by 600 kilometers being the total number of kilometers to be covered within the period of analysis), 33 kilometers traveled carrying loads of type 2, and the rest that is 50 kilometers traveled carrying loads of type 3. But if there in the fleet are too many vehicles that can serve, for example, demand number 3, let assume 10 vehicles of the same type as the analyzed one, it means that each one of them can travel 30 kilometers only when serving demand type 3 (300 kilometers divided by 10 vehicles), not 50! And they are underutilized.

As a result a generic formula for calculating the number of vehicles of particular types j (j = 1, 2, 3, …, J) in a fleet, the number that maximizes utilization ratio of a fleet and allows for fulfilling the whole transportation demand divided into I types (i = 1, 2, 3, …, I) can be written as follows:

$$K_P(l_j) = \sum_{i=1}^{I} \left[Min\left\{ 1, \frac{P_i}{\sum_{j=1}^{J}\left(W_j \cdot l_j \cdot zW_{ij} \cdot \frac{P_i}{\sum_{i=1}^{I}(P_i \cdot zW_{ij})} \right)} \right\} \cdot \frac{P_i}{\sum_{i=1}^{I} P_i} \right]$$

under the condition:

$$\sum_{j=1}^{J} (W_j \cdot l_j) \geq \sum_{i=1}^{I} P_i$$

where:

$K_P(l_j)$ - average utilization ratio of a fleet composed of vehicles of particular types j in the quantity of l_j vehicles of particular types j [-],

l_j - number of vehicles of particular types j in a fleet, including 0 that allows for fleet composition adjustments as well - DECISION VARIABLES [-],

P_i - demand for transportation services of a type i per period of analysis; i = 1, 2, 3, …, I [kilometers - km, tones - t, ton-kilometers - tkm, pallets - p, m³, liters - l, routes - r, …/… e.g. one year],

W_j - average, real productivity of one vehicle of a type j per period of analysis, expressed in the same units of measurement as the demand [km, t, tkm, p, m³, l, r, …/…],

zW_{ij} - productivity range of particular vehicle types j in relation to demand types i denoting what types of demand can serve given type of vehicles; $zW_{ij} \in \{0, 1\}$ - binary value or $zW_{ij} \in \langle 0, 1 \rangle$ [-],

Min{…} - minimum value of elements of a set.

THE CASE STUDY – SOLVING THE FC PROBLEM IN POLISH CIRCUMSTANCES

Let's consider a domestic transportation company operating in Poland. The company exploiting a fleet composed of 14 types of vehicles and serving 5 types of transportation demand (carrying 5 types of loads).

As for the demand types i, there are the following ones:

- i = 1: long-haul - regular loads - an average number of customers per one route 3 - an average weight of a load per one route 18t - an average number of cargo units per one route 30 pallets - an average length of one route 715 km - the total annual number of kilometers 2 000 000,

- i = 2: short-haul - regular loads - an average number of customers per one route 3 - an average weight of a load per one route 13.5t - an average number of cargo units per one route 27 pallets - an average length of one route 235 km - the total annual number of kilometers 900 000,

- i = 3: short-haul - temperature controlled loads - an average number of customers per one route 4 - an average weight of a load per one route 12t - an average number of cargo units per one route 12 pallets - an average length of one route 270 km - the total annual number of kilometers 1 100 000,

- i = 4: urban distribution - regular loads - an average number of customers per one route 6 - an average weight of a load per one route 6t - an average number of cargo units per one route 12 pallets - an average length of one route 135 km - the total annual number of kilometers 800 000,

- i = 5: urban distribution - regular and temperature controlled loads - an average number of customers per one route 4 - an average weight of a load per one route 6t - an average number of cargo units per one route 8 pallets - an average length of one route 185 km - the total annual number of kilometers 700 000.

As for the vehicle types j, there are the following ones:

- j = 1, 2, 3 and 4: tractors with semi-trailers - full tilt (curtain sided) - load capacity of 20, 24 and 26 tones / 33 pallets - maximum annual mileage 50 to 80 000 km - emission standard EURO3, 4 and 5 - age 3 to 10 years,

- j = 5: trucks - closed body - load capacity of 6 tones / 12 pallets - maximum annual mileage 82 000 km - emission standard EURO5 - age 1 year,

- j = 6,7 and 8: trucks - full tilt - load capacity of 8 and 10 tones / 14 and 16 pallets - maximum annual mileage 42 to 71 000 km - emission standard EURO3 and 5 - age 4 to 12 years,

- j = 9 and 10: trucks - isolated - load capacity of 14 tones / 18 and 20 pallets - maximum annual mileage 66 to 79 000 km - emission standard EURO4 and 5 - age 3 to 6 years,

- j = 11: trucks - refrigerated - load capacity of 16 tones / 18 pallets - maximum annual mileage 55 000 km - emission standard EURO3 - age 8 years,

- j = 12 and 13: vans - closed body - load capacity of 1.5 and 2 tones / 2 and 6 pallets - maximum annual mileage 59 to 69 000 km - emission standard EURO4 and 5 - age 1 to 5 years,

– j = 14: vans - isolated - load capacity of 2 tones / 4 pallets - maximum annual mileage 67 000 km - emission standard EURO5 - age 2 years.

An optimal fleet composition balancing described above transportation supply and demand has been constructed maximizing the average, weighted utilization ratio $K_P(l_j)$ (taking into account a maximum annual mileage) of vehicles in the fleet under the constraint that the numbers l_j of vehicles of particular types j will be high enough to fully satisfy the transportation demand of all types i.

In the analysis the limited ability of particular vehicle types to serve particular demand types has been taken into account. In details the maximum annual mileage of vehicles of particular types has been divided between the 5 demand types taking into account the matching of vehicles (their load capacities) to particular demand types (an average weight of loads and number of cargo units per one route) - see Table 1. For example, tractors with semi-trailers - full tilt (the vehicle types j = 1, 2, 3 and 4), irrespectively of their load capacity (20, 24 or 26 tones / 33 pallets), are suitable to serve the long-haul - regular load shipments (the demand type i=1), characterized by an average weight of a load of 18t /30 pallets per one route being 715-kilometer long on average and, however, with the less efficiency, the short-haul - regular load shipments (the demand type i=2), characterized by an average weight of a load of 13.5t / 27 pallets per one route being 235-kilometer long on average. And, they are not suitable to serve the short-haul - temperature controlled load shipments and the urban distribution as well (the demand types i = 3, 4 and 5).

Using the proposed above mathematical model of the FS/FC problem, the above described data and a professional solver for the MS Excel the problem has been solved. The results are presented in Table 2.

Table 1. Ability of particular vehicle types to serve particular demand types
Tabela 1. Możliwości obsługi danego rodzaju popytu przez dany rodzaj pojazdu

Vehicle type j	Demand type i				
	1	2	3	4	5
1	√	√			
2	√	√			
3	√	√			
4	√	√			
5				√	√
6		√		√	√
7				√	√
8	√	√		√	√
9		√	√	√	√
10		√	√	√	√
11			√		√
12				√	
13				√	
14				√	√

Source: author's research

Table 2. Selected solutions of the analyzed FC problem
Tabela 2. Wybrane rozwiązania analizowanego problemu kompozycji taboru

Vehicle type j	Number of vehicles of type j in the fleet – l_j		
	Smooth solution	Random solution	Optimal solution
1	6	8	15
2	6	10	0
3	6	3	11
4	6	2	17
5	6	9	0
6	6	8	0
7	6	11	0
8	6	2	0
9	6	9	0
10	6	3	0
11	6	7	32
12	6	8	0
13	6	1	0
14	6	2	13
Total fleet size	**84**	**83**	**88**
Utilization ratio – $K_p(l_j)$	**87%**	**86%**	**100%**

Source: author's research

As it is shown in Table 2 the optimal solution is significantly better than the smooth and the random ones. To assure a comparability of the solutions it was assumed that the value of the LHS of the constraint can exceed the value of the RHS by no more than 1% in all the solutions. As a result the total size of the fleet is similar in all the selected solutions (in fact, it is the highest in the optimal solution, and from this point of view the worst one, however, the best fitted). The utilization ratio for the optimal solution turned out to be the best one, assuring the very high fleet utilization that is always the most

economical. Of course the presented calculations are based on some assumptions and are significant simplification of the reality. However, one can expect that even though the real life utilization of a fleet will be lower than calculated, it will be lower for all the solutions (possible fleet compositions) to the same degree (a methodological error). So, the optimal solution should still denote a fleet composition assuring its best utilization.

It is also worthwhile to notice that based on the optimal solution the fleet is composed of 5 vehicle types only. The low number of vehicle types in a fleet, the easier to manage it.

The carried out sensitivity analysis revealed that any changes in the optimal composition of the analyzed fleet decreases its utilization. For example random changes of the number of vehicles of particular types by only 1 vehicle (increased number of vehicles of a one type, and at the same time decreased number of vehicles of another type, kipping the fleet size constant and the demand satisfaction constraint fulfilled) result in the decrease of the utilization ratio by 0.5%. If the number of the exchanged vehicles is 5 the utilization ratio decreases by 4.5%.

ACKNOWLEDGEMENTS

CONCLUSIONS

The FS/FC decisions concerning types and number of vehicles in a fleet, as well as MoB decision problem, belong to the group of the strategic fleet management problems. These decisions as any other strategic ones concern relatively long-term planning and effects they cause are postponed in time. It means that to asses if the FS/FC decisions made were correct or wrong is possible after a relatively long time (half a year to one year or even more). Moreover, such decisions are usually crucial and their results that are noticeable outside a company have an economical character (e.g. investments). That is the cause why it is very important to make this type of decisions not only intuitively, but first of all based on comprehensive and correct analysis. The presented in this paper analysis, on the one hand, is consistent with a widespread opinion that the number of vehicle types in a fleet should be limited (the lower, the better). It the other words it means that the versatility/ interchangeability of vehicles is very important. On the other hand, the analysis proves that even small changes in a fleet size/ fleet composition can result in an important changes of the fleet effectiveness (measured for example by the utilization ratio).

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STRATEGICZNE ZARZĄDZANIE TABOREM SAMOCHODOWYM - PROBLEM KOMPOZYCJI

STRESZCZENIE. **Wstęp:** Floty pojazdów stanowią podstawowy środek produkcji w transporcie. Prawidłowe zarządzanie nimi jest zatem kluczowe dla wszystkich firm realizujących przewozy. Niniejszy artykuł jest drugim z serii trzech, jakie autor chce poświęcić tematyce strategicznego zarządzania taborem samochodowym.
Metody: W artykule omówiono sposoby kształtowania flot samochodowych przedsiębiorstw. To znaczy ustalenia liczby (problem liczebności - FS) i rodzajów pojazdów (problem kompozycji - FC) we flocie. Istota obu problemów leży w równoważeniu podaży i popytu na przewozy z uwzględnieniem różnych rodzajów popytu, jakie trzeba zaspokoić, oraz różnych rodzajów pojazdów, jakie mogą znaleźć się we flocie wraz z wzajemną zastępowalnością owych pojazdów przy zaspokajaniu poszczególnych rodzajów popytu. W artykule zaproponowano autorską, matematyczną metodę (model optymalizacyjny) pozwalającą na prowadzenie analiz typu FS/FC.
Rezultaty: W artykule zaprezentowano zastosowanie opracowanej metody na rzeczywistym przykładzie problemu decyzyjnego w warunkach polskich oraz uzyskane rezultaty. Rezultaty te pokazały, że istnieje pewne, najlepsze (optymalne) dopasowanie struktury floty do potrzeb przewozowych. Rozwiązanie pozwalające na wykorzystanie taboru w stopniu istotnie wyższym (10-15%), niż w przypadku innych, w tym losowych, rozwiązań. A zmiana owego optymalnego rozwiązania, nawet w niewielkim stopniu, powoduje pogorszenie wykorzystania taboru o kilka procent.
Wnioski: Prezentowana w pracy analiza jest z jednej strony zgodna popularną opinią, iż ilość typów samochodów we flocie powinna być ograniczona. Oznacza to, że uniwersalność i możliwość zmian w liczbie samochodów ma bardzo duże znaczenie. Z drugiej strony, prezentowana analiza potwierdza stwierdzenie, że nawet małe zmiany w wielkości floty i jej składzie mogą powodować istotne zmiany efektywności całej floty (mierzone na przykład, jako procent użytkowania).

Słowa kluczowe: zarządzanie, optymalizacja, flota, transport, liczebność, kompozycja.

STRATEGISCHES FAHRZEUGFLOTTENMANAGEMENT - DAS PROBLEM DER FLOTTENZUSAMMENSETZUNG

ZUSAMMENFASSUNG. Einleitung: Fahrzeugflotten und Fuhrparks stellen das Rückgrat der Verkehrsproduktion dar. Ein angemessenes Flottenmanagement ist für alle Gesellschaften und Firmen mit Transportaufgaben von großem Belang. Der vorliegende Artikel ist der zweite von dreien, die der Autor dem strategischen Fahrzeugflottenmanagement widmet.
Methoden: Dieser Artikel beschreibt Möglichkeiten für Unternehmen ihre Fahrzeugflotte zusammenzusetzen. Dies beinhaltet sowohl die Beantwortung der Frage nach der Flottengröße (the fleet sizing problem - FS) und der Zusammensetzung der Fahrzeugflotte (the fleet composition problem - FC). Der Kern beider Probleme liegt dabei darin, Angebot und Nachfrage nach Transportdienstleistungen so auszubalancieren, dass der Typ der Fahrzeugnachfrage auf Basis verschiedener Fahrzeugtypen einer Flotten bedient werden kann. Verschiedene Fahrzeugtypen können dabei substituierend eingesetzt werden. Im vorliegenden Artikel wird dabei ein ursprünglich mathematisches Modell (Optimierungsmethode) zur FS/FC-Analyse vorgestellt.
Ergebnisse: Es werden die Umsetzung und Ergebnisse einer Anwendung der vorgestellten Optimierungsmethode im Rahmen eines Feldversuchs in Polen präsentiert. Die Lösung zeigt, dass es eine optimale Flottengröße und -zusammensetzung gibt um die Transportnachfrage eines Unternehmens zu bedienen. Die Verwendung einer optimalen Flottengröße und -zusammensetzung erlaubt eine spürbar höhere (10- 15%) Auslastung der Fahrzeugflotte im Vergleich zu anderen, auch zufällig gewählten, Strategien zur Flottenzusammensetzung. Weiterhin kann gezeigt werden, dass bereits kleine Veränderungen in der FS/FC-Struktur zu merklichen (mehrere Prozent) Auslastungsveränderungen der Gesamtflotte führen.
Fazit: Einerseits, die präsentierte Analyse stimmt mit der öffentliche Meinung, die die Anzahl der Arten von Autos in der Flotte begrenzt werden sollte. Dies bedeutet, dass die Universalität und die Möglichkeit von Veränderungen in der Anzahl von Fahrzeugen von große Bedeutung ist. Andererseits bestätigt diese Analyse die Feststellung, dass auch kleine Änderungen in der Größe der Flotte und der Zusammensetzung können wesentliche Veränderungen in der Effizienz der gesamten Flotten verursachen.

Codewörter: Management, Optimierung, Fahrzeugflotten, Transport, Verkehr, Flottenersatz.

Adam Redmer
Division of Transport Systems
Institute of Machines and Motor Vehicles
Faculty of Machines and Transportation
Poznan University of Technology
3 Piotrowo street, 60-965 Poznan, **Poland**
phone: +48 61 665 21 29
e-mail: adam.redmer@put.poznan.pl