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# Optimisation of the exploitation period of individual vehicles in freight transportation companies

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The individual vehicle replacement problem typical for freight transportation companies is discussed in the paper. Two characteristic features of such problem are that transportation companies utilise vehicles with intensity decreasing with an age of vehicles and that managers of such companies first of all take into account economical criteria when planning vehicle replacements. The paper presents a single criterion, nonlinear, deterministic and discrete mathematical model of such a problem that minimises a total exploitation and ownership costs calculated per kilometre. The exact solution procedure is proposed here. The problem is solved as a real life case study. As a result, an average, economically optimal 5-year exploitation period of vehicles has been determined.



## 1. Introduction

The replacement theory, that is a part of the maintenance theory, has grown up out of an industrial environment (Jardine, 1973; Jardine and Buzacott, 1985; Kelly and Harris, 1987; Spooner, 1989), where the optimal length of the operational life of production machinery or its components has been determined. An important part of the replacement theory is the capital replacement (Scarf, 1997), involving long-term, strategic decisions, including vehicle replacement planning.

Replacement is one of the two general ways of returning equipment, including capital equipment, to a "good" technical condition allowing for its utilisation. The second way is repairing (Jardine, 1973).

In general, there are two fundamental replacement strategies: replacement on failure and preventive replacement (Eilon et al., 1966). The first category of replacement strategies can be applied to the equipment that deteriorates with time of exploitation (e.g. almost all mechanisms), or not (e.g. electric or electronic parts), assuming that in both cases one can finally expect a failure. The second strategy can be applied when the following conditions are met (Jardine and Buzacott, 1985):

- the total costs associated with a failure replacement are greater than the total costs associated with a preventive replacement,
- the hazard rate $r(t)$ of the equipment is increasing with the time of utilisation.

In case of the preventive replacement strategy the general problem is how to determine the optimal time of the utilisation to replacement or the optimal cumulative usage of the equipment to replacement (Glasser, 1969).

Determining the optimal utilisation period of the equipment two common replacement policies can be applied: the age or the block replacement policy (Christer and Goodbody, 1980; Glasser, 1969; Nakagawa, 1984; Wang, 2002).

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In both cases a specified age/time/period to replacement $t_p$ has to assure a minimal replacement costs $C(t_p)$. The optimisation of the utilisation period of the equipment can be based on (Christer and Goodbody, 1980; Dohi et al., 2006; Jardine, 1973; Kelly and Harris, 1987): minimisation of the expected operational costs per time unit, maximisation of an operational profit per time unit or maximisation of an average productivity per time unit.

There are also many other replacement policies (Britten, 1971; Nakagawa, 1984; Wang, 2002), such as: replacement after $N$ failures, maintenances, repairs or shocks; an idle time policy; cost or repair limit policies and so on.

The vehicle replacement problem belongs to a group of preventive replacement strategies where an optimal utilisation period is determined as an age of a vehicle to replacement assuring minimisation of the expected vehicle operational costs per time unit.

One of the most popular replacement (preventive and age-based) policies is the policy balancing the exploitation (operational and maintenance) costs and the ownership costs – policy so called the minimal average costs during lifecycle (Britten, 1971; Jardine and Buzacott, 1985; Eilon et al., 1966). Some authors (Jardine and Buzacott, 1985) suggest that, aside from exploitation and ownership variable costs, the fixed costs should be taken into account too. But the fixed costs are treated as fixed in time, not as fixed in a comparison with the utilisation intensity/production scale. Treated in this way the fixed costs do not affect the length of the optimal time to replacement. On the other hand, the depreciation costs (that are fixed in a comparison with the utilisation intensity but not in time), taken into consideration significantly shorten the optimum economic operational life of the equipment (Eilon et al., 1966). The presented policy has been known since the time of World War II (Preinreich, 1940), and has many modifications. In general, it assumes that with time the exploitation costs should increase faster than the ownership costs decrease, giving the classic "bathtub" curve, where the minimum indicates the optimum economic operational life of the equipment. It is worthwhile noticing that in the case of a replacement of vehicles as well as other machines characterised by an utilisation intensity decreasing with time, such an assumption probably will fail in practice if the costs expressed per time period are taken into account (for example annual, monthly costs). This will happen due to the fact that the total utilisation costs per time period decrease with time similarly to the utilisation intensity. Spooner states outright: "Cost analysis suggests that vehicle maintenance costs should increase faster than depreciation, giving the classic bathtub curve ... But, this is rarely the case" (Spooner, 1989).

The aforementioned replacement policies and methods represent only a small part of all attempts that have been done to solve the equipment replacement problem in general (Nakagawa, 1984; Ritchken and Wilson, 1990), and the vehicle replacement problem in particular (Britten, 1971; Eilon et al., 1966).

Even though the vehicle replacement policy has a crucial impact on different effectiveness parameters of transportation companies and belongs to an important class of the fleet strategic management problems that have been extensively considered in the literature during last 40 years (Dejax and Crainic, 1987), there are many difficulties when applying the existing methods to the area of road, freight transportation. Such difficulties arise from the following features of the existing replacement methods:

– dedicated to a simple (e.g. electronic parts, bearings) or more complex (gear boxes, starters, alternators) elements, but not to the complete vehicles,
– dedicated to the production lines and other manufacturing equipment operated in more stable environment than vehicles' operational conditions, affected by the way the vehicles are utilised, the loads carried, the type of journeys, the climate, and the random stresses inducted from road surfaces,
– focused on a given group (type) of vehicles instead of a single vehicle,
– assuming a constant utilisation rate of the equipment during its operational life.

It is important to notice that applying the existing replacement methods to a real life vehicle replacement problem, even one of the mentioned above drawbacks makes such application difficult. Unfortunately, the existing methods have at least one of these drawbacks. For example, Eilon et al. (1966), consider particular vehicles, but assume constant utilisation of them, whereas Simms et al. (1984), relax the assumption of the constant utilisation, but constrain an age to replacement giving lower bound which equals 15 years (probably to avoid too many replacements). Similarly, Suzuki and Pautsch constrain an age to replacement giving the upper bound of 5 years and concluding that "... vehicles of age 6 or beyond may not be suitable for business operations" (Suzuki and Pautsch, 2005), that contradicts Simms's, Lamarre's, Jardine's and Boudreau's assumption.

The significant part of the capital replacement methods takes into account budget constraints (Simms et al., 1984), which are important when replacement policy is defined for a fleet of vehicles but not particular vehicles. However, such constraints usually result in the replacement of the limited group of the oldest vehicles only. Even though Simms, Lamarre, Jardine and Boudreau conclude that "One would expect that the older buses would be replaced first and younger buses kept. For many reasons this is not the case", all the replaced buses have been older than 15 years. Budget constraint leads Suzuki and Pautsch to the statement that "Carriers having newer vehicles should use shorter replacement cycles and purchase newer vehicles at replacement than carriers having older vehicles", which can be justified from the budget point of view only.

Because of the listed above drawbacks of the existing replacement methods, a direct application of them to the vehicles exploited by freight transportation companies is difficult, if not impossible. It induced the author to make some efforts, presented in the paper, to adapt one of the existing methods to the conditions of the freight transportation companies and to take into account a decreasing utilisation intensity of vehicles exploited by such companies.