CASPT 2018 Extended Abstract

Optimizing the Preventive-Maintenance Plan of a Public Transport Bus Fleet

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Abstract This extended abstract describes a system implemented in the city of Angers to optimize the maintenance plan of its public transport bus fleet. Important issues related to designing an effective maintenance plan are discussed, and an algorithm is presented to generate such a plan.

Keywords: Public transport · Transit bus maintenance · Optimization

1 Introduction

In a public transport company, buses usually have a life span of about 20 years and can cover more than one million kilometres before needing to be replaced. In this context, vehicle maintenance constitutes a critical area of activity, with a major impact on both operating costs and service quality. However, relatively few research papers have been published on models and algorithms that could help optimize the maintenance plan for public transport (see for instance Haghani and Shafahi (2002)). This extended abstract presents the main components of a new model and algorithm that have been successfully implemented for this purpose in the city of Angers in France. In Section 2, we present some of the issues that a transit company must consider in maintaining its buses. Section 3 briefly describes a model that aims at optimizing a maintenance plan subject to resource constraints. Section 4 proposes a heuristic solution approach for this model and Section 5 presents some results from a concrete implementation. Section 6 concludes with final remarks.

2 Maintenance issues in a public transport company

Maintenance tasks can be divided into two main categories: curative or preventive. Curative maintenance typically occurs to repair a bus when it becomes unfit for service, either because of an accident or an unexpected malfunction of some component. Preventive maintenance is normally performed on vehicles that are considered fit for service, but in need of some specific upkeep procedures (e.g. oil

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change). The goal of preventive maintenance is to decrease the probability of future failures and, consequently, curative-maintenance needs.

Several important issues have to be considered in implementing an efficient preventive-maintenance plan. For instance, the ideal frequency of each upkeep activity should be specified as a target that either depends on distance (e.g. replace alternator every 280 000 km) or time (e.g. clean radiator every 12 months). The target values must be defined appropriately so that the frequencies are sufficient to reduce the occurrences of curative activities (often measured as the number of kilometres between failures), but not so high as to lead to unnecessary extra costs. These targets are generally set according to guidelines provided by bus manufacturers, and adjusted over time by monitoring the reliability of the different components. Maintenance activities also require human and physical resources whose availability is limited and varies during the year. Most transit companies keep track of the maintenance activities performed on each vehicle by recording the date and odometer value of buses when they enter the maintenance workshop. After a bus is returned to provide service, its mileage is closely checked by dispatchers to make sure that it is redirected to the workshop when its next maintenance is due.

While this direct odometer-monitoring approach is theoretically sufficient to detect when vehicles are due for maintenance, in practice it produces several situations that can lead to inefficient results. For instance, several activities that require the same maintenance resources could be requested at the same time. If there is a shortage of these resources, some activities will have to be delayed (increasing the probability of failure) or pre-empted (increasing costs). Even if some flexibility is allowed in the targets, there will be periods in which several vehicles have to be withdrawn, which can lead to a shortage of vehicles for service. On top of that, some inspection activities are required by law. If they are not performed before the respective maintenance targets, the vehicle must be taken out of service until the inspection is completed. In order to ensure that the planned service can be provided to users when many vehicles are withdrawn for maintenance, transit companies typically keep a larger fleet than necessary. This entails extra capital costs, which can be avoided by using a plan that smooths the usage of maintenance resources over time. An optimized plan can eliminate days on which a large number of vehicles are scheduled to be maintained and lead to reducing the bus reserve.

3 Maintenance-plan model

An efficient preventive-maintenance plan should have two main minimizing objectives. The first is to minimize the difference between the actual timing of specific upkeep activities and their ideal target. This can be achieved by penalizing delays and advances that fall outside a tolerance interval defined for each maintenance activity. For instance, alternators ideally have to be replaced every 280 000 kilometres. However, if replacements are performed earlier, deviations of

20% are accepted, i.e. starting at 224 000 kilometres (tolerated extra costs). If replacements are performed later, deviations of at most 10% are accepted, i.e. up to 308 000 kilometres (tolerated extra risk of failure). The second main objective is to make sure that the number of withdrawn vehicles on any specific day of the maintenance plan does not exceed a specific target value. In practice, this goal can be achieved through a slack variable on a constraint that will guarantee that enough vehicles remain available to provide the service to users.

There are also several constraints that have to be satisfied in order to obtain a valid maintenance plan. Each upkeep activity consumes some resources, whether physical (e.g. lift station) or human (e.g. one or more specialized employees). Linear constraints must then be included to verify that the overall maintenance capacity is not exceeded at any time. Several constraints also have to be added to take into account the number of kilometres that are planned for each specific vehicle between consecutive visits to the maintenance workshop, and the total number of kilometres that have to be performed by the entire fleet on each specific day. These constraints ensure that sets of vehicles of specific types (e.g. standard, articulated) will cover the overall service load that was planned for them. More detailed constraints also have to be added to validate practical issues such as precedence relations between some maintenance activities, or bounds on the number of transfers between garages for activities that require specialized equipment that may not be available in all maintenance workshops.

The maintenance-plan problem can be formulated as an integer linear problem in which binary decision variables correspond to sequences of maintenance assignments for a given vehicle over the considered time horizon (which can span several years). These sequences specify the planned maintenance dates for each vehicle, as well as the total number of kilometres that should be performed between two consecutive visits to the maintenance workshop.

4 Optimization algorithm

The problem described in the preceding section gives rise to a very large number of variables for real-life problems, which makes them difficult to solve with a mathematical programming approach. It is however possible to generate very good maintenance plans using a heuristic algorithm (hereafter called PlanMaint) that first constructs an initial unfeasible solution in which all maintenance activities are scheduled at their ideal target. This initial solution can then be progressively turned into feasibility by using an iterative process that adjusts the mileage targets of vehicles in order to eliminate the distance surpluses and shortages that are associated with the volume of service to be covered for each day. In the presence of multiple depots, the algorithm may schedule some maintenance activities that will occur in a different depot than the one to which the vehicle belongs (i.e. where it usually spends the night). In this case, some “bridge blocks” that allow transferring vehicles between depots must be provided by the vehicle-scheduling department. PlanMaint must then validate that the number of available bridge blocks is not exceeded in the produced solution. Similarly, the algorithm must ensure that the number of withdrawn vehicles of each type for any given day does not go beyond the limits defined by the operational needs.

The final result from the PlanMaint algorithm consists of target numbers of kilometres between consecutive maintenances for each vehicle in the fleet. These target values must then be communicated to another optimization algorithm (hereafter called PlanBus) which in turn assigns vehicles to the anonymous blocks from the vehicle schedule. The PlanBus algorithm must be applied on a daily basis to account for variations in the actual distance covered by vehicles, which can fluctuate because of possible disruptions in the operations. When the cumulative distance covered by a bus deviates too much from its target, the daily optimization will aim at redressing the situation by assigning longer blocks to vehicles for which the odometer indicates a lag versus the planned target. Because of unforeseen events such as disruptions or route deviations, the PlanMaint algorithm is regularly rerun (i.e. every week or month) to provide an updated plan adjusted to the most recent data.

5 Results

The algorithms PlanMaint and PlanBus have been implemented in the city of Angers in France and have been used to optimize the maintenance plan since September 2015. As can be seen in Figure 1, the average deviation between the actual distance measured on the odometer and the ideal target value for maintenance decreased rapidly after the implementation and has now stabilized.

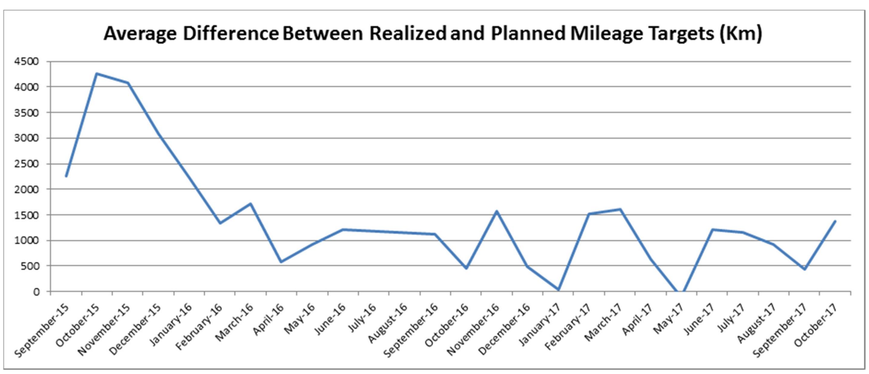

Fig. 1 Average deviation from maintenance targets (km)

As is described in Guernalec (2016), an important goal of the project was also to smooth out the number of vehicles that are withdrawn for preventive maintenance and eventually reduce the size of the reserve fleet. Figure 2 displays for each date the number of vehicles in service (in blue) and the number of vehicles assigned to preventive upkeep activities (in red). The green area on top corresponds to the remaining vehicles that are kept in reserve or undergoing curative maintenance. Monitoring these values can help devise a more efficient maintenance plan. For instance, more upkeep activities may be scheduled when the service level is reduced during the holiday summer season (if the human and material resources are available).

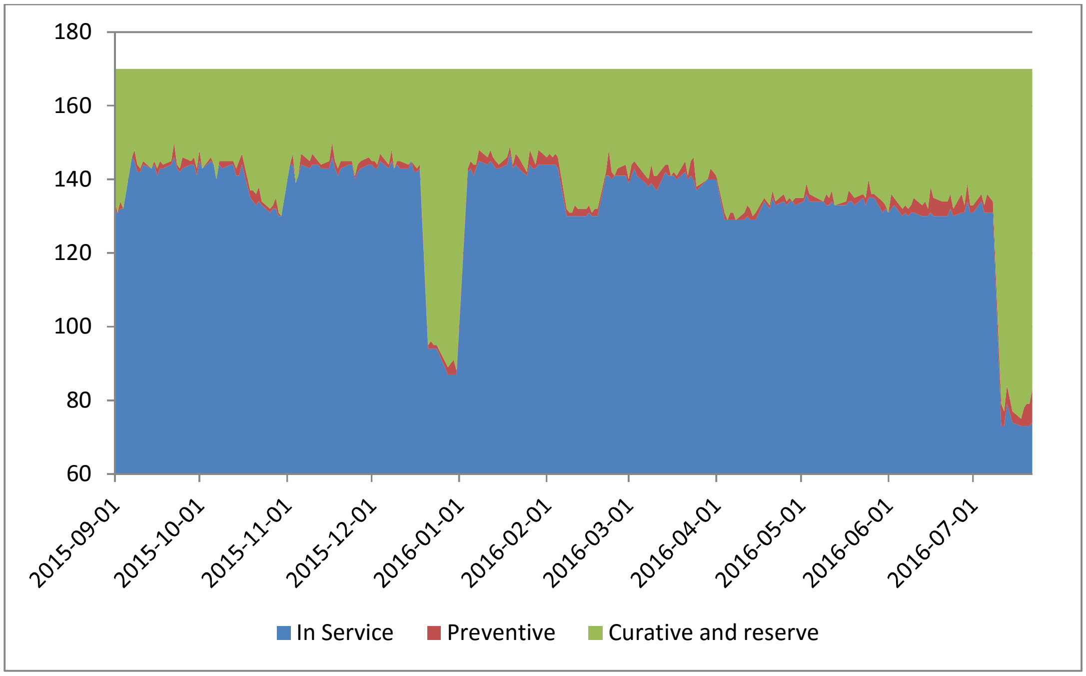

Fig. 2 Number of vehicles assigned to service or preventive maintenance

6 Conclusion

The maintenance plan of a transit company has a major impact on the reliability of operations and the fleet size needed to deliver service. When ideal mileage targets are provided between consecutive maintenance activities, it is possible to generate an optimized plan that minimizes the deviations from these targets and smooths out the consumption of material and human resources over the planning horizon. This allows reducing the risk of failure and the number of vehicles that have to be kept in reserve. Such a system has been implemented in the city of Angers in France since September 2015.

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