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Profit-based Optimisation of Rolling Stock Rotations: a case study from North America

Extended Abstract

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Abstract We address the optimisation of rolling stock rotations with maintenance constraints as a profit maximisation problem with fixed costs. We propose an approximate solution method that combines in a new way existing techniques. We report real revenue growths and cost savings obtained by VIA Rail Canada while using this solution method in practice, as well as optimiality gaps for small problem instances.

Keywords Rolling Stock · Rotation Planning · Profit · Optimisation

1 Introduction

The optimisation of rolling stock rotations (hereafter *rotations*) or circulations is usually regarded in the literature as a cost minimisation problem with the passenger demand being modelled as a hard or soft constraint (Fioole et al (2006), Borndörfer et al (2016)). This approach is not suitable for railway operators that run trains with reserved seats because in this context the maximisation of profit cannot be achieved just by minimising costs, it should also consider revenue. On the other hand, revenue management research (Hetrakul and Cirillo (2014), Hohberger (2020)) tends to ignore or oversimplify operational costs. Recently Grimm et al (2018) proposed a model for handling contingency scenarios that considers both cost and revenue but without considering maintenance constraints.

In order to overcome these limitations, we propose an hybrid approach for solving approximately the Maximum Profit Rolling Stock Rotation Planning (MPRSRP) problem with maintenance constraints assuming fixed ticket

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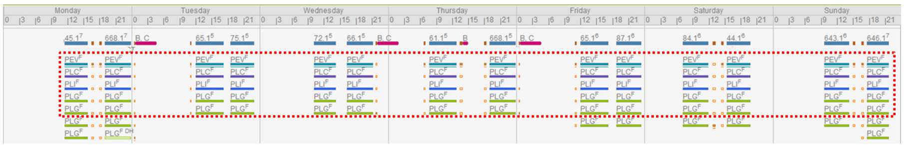

Fig. 1 Locomotive rotation showing the base composition where it belongs to (inside rectangle).

prices. We describe the approach and how it is successfully being used in practice by VIA Rail Canada (VIA) to plan their intercity locomotive-hauled operation along a corridor that connects Toronto, Montreal and Quebec City.

The MPRSRP problem can be stated in the following way: given a set of train trips each one with its own passenger demand (for business and economy), find, from scratch, for a standard week, the most profitable rotations that assign a vehicle composition (hereafter *composition*) to each trip that covers all or part of the demand and that satisfy all operational constraints, namely maintenance constraints and many others (see Borndörfer et al (2016)). The overall profit is equal to the revenue minus the operational cost, where revenue is derived from the expected tickets sold (obtained by matching demand with train capacity for economy and business class), and cost includes aspects like track occupation, fleet depreciation, maintenance and energy consumption and crew utilisation.

In the context of VIA every rotation must comply with the following maintenance constraints: a maintenance of type B (C) must be performed every week (two weeks), with the particularity that maintenance C includes B.

In the context of VIA the rotations comply also with a special requirement. The composition assigned to each trip has two parts: one, called the *base composition*, formed with vehicles that always circulate together as shown in Figure 1; and a second part formed with vehicles that don't have this restriction. The base composition is usually formed by a locomotive, a business and an economy carriage, but it can also include more economy carriages and a second locomotive in the rear.

2 Solution method

Since the problem cannot be solved exactly, due to the size of the VIA's problem instances, we propose an approximate solution method that is inspired on the concept of base composition described earlier.

The solution method solves the problem in two stages:

1. Produce rotations for the base composition,
2. Produce rotations for the extra carriages used to form compositions that are extensions of the base compositions obtained in the first stage.

The *first stage* is solved by an adapted version of the heuristic Abbink et al (2011), based on Lagrangian relaxation and column generation, which solves a minimum cost set covering problem with additional constraints where:

– set elements represent trips,
– sets represent rotations defined for specific composition types,
– cost represents loss (cost minus revenue) of rotations,
– additional constraints model fleet size restrictions for each vehicle type.

Apart from making this mapping, we also adapted the pricing procedure (which explores paths in a trip graph) to solve a resource constrained shortest path problem with a dynamic programming algorithm (Irnich and Desaulniers (2005)) where resources were set up properly to rule out paths in the trip graph that correspond to rotations violating maintenance or any other relevant constraint. We also made adjustments in the trip graph to accommodate the concept of rotation.

The *second stage* is solved with the approach described in Borndörfer et al (2016), which uses an hypergraph network model. In our case the hypergraph only contains hyperarcs related with the extra carriages that are used to enlarge the compositions obtained in the first stage. This reduces considerably the overall number of hyperarcs to a number that makes the problem tractable. In order to maximise profit this model favours (avoids) the assignment of extra carriages to trips with lack (excess) of seats.

Remark. Although the presented solution method was inspired in the concept of base composition, specific to VIA, it can be applied to any railway operator. It is just a matter of reducing the base composition to a single vehicle, e.g. a locomotive.

3 Computational results

The performance of our approach was benchmarked against human planners (an exact approach) for large (small) problem instances.

As a direct result of using our approach in production environment[1] VIA reported the following gains with respect to previous rotations (produced manually by human planners):

– C$10,000,000 of annual savings due to being able to operate all trips with one less composition,
– 3% to 5% increase in revenue,
– 3% to 4% increase in available seats per mile.

We also compared our solution method with an exact approach (i.e. the Borndörfer et al (2016) model with branch and bound). We tested both approaches with the problem instances from VIA characterised in Table 1. These instances specify a passenger demand for economy and business classes for each

[1] With the use of FLEET, a software product developed by SISCOG and used by VIA

Table 1 Characterisation of problem instances

Problem instance	# trips	# vehicle types	# composition types
P1	17	3	6
P2	36	10	113
P3	47	10	113
P4	69	10	113
P5	492	10	113

Table 2 Comparison with exact approach

1.1	100%	0%	Running time (s)	Profit	Gap (%)
P1	Approximate	2,109	10	162,976	0
	Exact	8,288	3	162,976	0
P2	Approximate	1,272	122	475,303	6.34
	Exact	153,989	42	505,472	0
P3	Approximate	5,072	423	690,821	1.09
	Exact	343,818	2,411	698,354	0
P4	Approximate	4,472	167	802,322	4.84
	Exact	701,549	8,145	841,173	0
P5	Approximate	583,079	5,173	6,145,189	-
	Exact	-	-	-	-

trip leg. These demands are average values computed over historical data for each particular trip leg and for each day of the week.

The results are presented in Table 2. As shown, our approach obtains solutions with optimality gaps from 0% to 6.34 for the small instances (P1 to P4). For the large instance (P5), the only one with practical interest for VIA, the exact approach runs out of memory during the creation of the model, which is the main reason why we developed an approximate method.

4 Conclusions

We addressed a fleet optimisation problem that is relevant for train operations with reserved seats. Because practical problem instances cannot be solved exactly we proposed an approximate solution method that combines existing techniques in a new way. By using this approach in production environment VIA Rail Canada obtained significant revenue growths and cost savings. We also reported optimiality gaps for small problem instances.

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