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JOINT ASSIGNMENT OF MISSIONS AND MAINTENANCE OPERATIONS FOR A FLEET OF DETERIORATING VEHICLES

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This article presents a comparison between two genetic algorithm-based methods to schedule the missions and the maintenance operations for a fleet of deteriorating vehicles. The first one directly integrates the fleet dimension to schedule the activities while the second one starts by assigning the missions to each vehicle and then defines the vehicle schedules independently. The objective is to see if the fleet-based method enables to reduce the global maintenance costs for the fleet and if it is always the case.

Keywords: maintenance planning, mission scheduling, fleet management, stochastic deterioration

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1. Introduction

1.1. Context and background

To deliver satisfying transport solutions, the manufacturers of commercial heavy vehicles understood that it was necessary to increase the panel of services they could propose to their customers. The development of an efficient maintenance management system has become a key for success to ensure the vehicle availability for the missions to perform. Many haulers own fleets and need to manage their deliveries and the maintenance planning of their vehicles at the same time.

Then, the fleet dimension becomes essential to consider to optimize the customers productivity. The different missions have to be assigned to the vehicles based on the available information regarding the vehicles health state and the missions operational constraints.

1.2. State of the art

Asset management has become one of the new research hotspot but it is sometimes difficult to follow the advances in this area as researchers employ different terms to refer to their specific problem. Most of the time, the fleet are composed of identical assets. For instance, Feng et al. [1] developed a three-level decision structure for fleet maintenance with a fleet of aircrafts. Another form of fleet is a group of vehicles or machines that are not necessarily identical but share mutual technical features and work under similar conditions. Sriram and Haghani [2] considered a fleet of aircrafts as a pool from which any plane can be assigned to any origin-destination route. Then, the maintenance planning is scheduled considering different intervention levels.

Petchrompo and Parlikad [3] proposed in their review a classification and definition of multi-unit systems based on the existing literature about asset management. The classification is based on the diversity of assets and the intervention options. They also study the different dependencies for multi-unit systems, the different types of problem regarding fleet management and the solution methods.

1.3. Contribution

The objective of this work is to show the interest of using the fleet dimension to jointly schedule the missions and the maintenance operations to minimize the maintenance costs for the fleet. Indeed, the fleet capacity gives

flexibility to assign the missions to the vehicle having the most convenient health state.

This work compares two methods to jointly schedule the missions and the maintenance operations for a fleet. The first method directly uses the fact that we have a fleet of vehicles. There is no constraint regarding the possibility of each vehicle to perform each mission. The decision-making process tries to build the best schedule to minimize the maintenance costs for the fleet without having a too high risk of failure. The second method firstly assigns the missions to the vehicle. It adds a constraint on the final schedule obtained. Then, the joint schedule is independently defined for each vehicle.

The vehicle deterioration model, the effect of the missions on its evolution and the adapted maintenance strategy are defined. Then, the two scheduling methods are explained. Finally, a numerical example is led to compare both methods and analyse the interest of using the fleet dimension to define the optimized joint schedule.

2. Problem statement

A fleet of deteriorating vehicles has a finite set of missions to complete. The deterioration varies according to the missions severity and their operating conditions.

The objective is to define an optimized schedule integrating both the missions and the maintenance operations for the fleet. The equation 1 gives an example of the schedule π_1 for the vehicle 1. It is composed of three mission blocks. Each block is between square brackets and blocks are separated by maintenance operations. These operations are assumed to be perfect and restore the vehicle health state to an "as good as new" state.

$$\pi_1 = [10, 2][5][3, 8, 1] \quad (1)$$

The schedule optimization is based on the global maintenance costs for the fleet. Missions and maintenance operations are arranged to minimize the maintenance costs. The vehicles activities between two maintenance operations are maximized while considering the failure risks inside each mission block. The maintenance cost criterion is composed of two parts:

- The preventive maintenance costs associated to each preventive maintenance (PM) operation occurring at each block end. Each PM operation costs C_0 .

- The corrective maintenance costs associated with the probability to have a failure in each mission block. Each failure occurrence costs C_f .

3. Proposed approaches

This section explains the vehicle deterioration and maintenance models used to study the joint scheduling problem for a fleet of vehicles. Two static scheduling methods are described.

3.1. Deterioration model and operational environment

Each vehicle is characterized by a single global health indicator. The deterioration evolution is assumed gradual and depends on the usage conditions. The Gamma process has been favoured to model the deterioration evolution due to its ability to represent gradual deterioration phenomena for industrial systems [4]. It evolves in a varying environment because the missions have different usage severities. To capture these variations, the deterioration model is defined as a Gamma process with varying parameters.

As missions are grouped into blocks, the operational environment changes inside the same block. To evaluate the failure probability of a block, an equivalent Gamma process is estimated for each block based on the missions deterioration parameters and their durations.

3.2. Maintenance model and decision criterion

The adopted maintenance model is a deterioration-threshold failure maintenance model. It is applied to schedule at best maintenance operations to avoid failures. Thanks to the deterioration model, the remaining useful life of the vehicles can be estimated to make a decision whether the health state is enough to dispatch them on other missions or if a maintenance operation is needed.

A decision criterion is defined to manage the decision-making process. The criterion C (Eq.2) estimates the global maintenance costs for the fleet, composed of N_v vehicles. Each vehicle has a joint schedule π_v composed of $N_b(v)$ blocks. It considers only one failure by block.

$$C = \sum_{v=1}^{N_v} \left(\sum_{k=1}^{N_b(v)} \left(C_0 + C_f \mathbb{P}_f(k, v) \right) \right) \quad (2)$$

3.3. Fleet and 1VS1 algorithms

To schedule missions and maintenance operations for the vehicle fleet, a genetic algorithm is defined. The individuals are defined as block of missions separated by preventive maintenance operations for each vehicle. Eq.3 defines an individual for a two-vehicle fleet and with 12 missions to schedule.

$$Indiv = \left\{ \text{VI 1 : [4, 6][2, 12][5]} \quad || \quad \text{VI 2 : [1, 10, 3][11, 7][9, 8]} \right\} \quad (3)$$

The genetic algorithm optimizes the fleet maintenance costs by assigning the missions to the vehicles and building the blocks to avoid failures and to respect the maximum admissible failure probability for the blocks P_{max} .

The 1VS1 algorithm adds a constraint on the way to schedule the missions. The first stage is to assign the missions to the vehicles. Then, each vehicle is independently considered and a genetic algorithm schedules its activities to minimize its maintenance cost. The global fleet maintenance costs correspond to the sum of the vehicles maintenance costs.

The genetic algorithm used for the 1VS1 method is the one developed in a previous paper [5] while the one for the fleet is an adaptation of the same algorithm by integrating the fleet dimension.

4. Application example

A static scheduling problem is considered. A fleet of two vehicles has to perform 12 missions. The objective is to compare the maintenance costs obtained for the fleet and the 1VS1 methods to see the interest of integrating the fleet dimension when scheduling missions and maintenance operations. Table 1 defines the missions. All vehicles have the same configuration and are supposed identical. They can be deployed on all missions.

To compare the scheduling methods, a process is established. In a first stage, the missions are randomly assigned to each vehicle so that the vehicles may not have the same number of missions to perform. Then, each vehicle schedule is computed (1VS1 method). At the same time, the schedules are defined while considering the fleet dimension (Fleet method). The vehicles schedules for the fleet method are always the same while the schedules for the 1VS1 method changes according to the random assignment stage. Each random selection and distribution of missions among the vehicles is called a scenario. For each scenario, Monte Carlo simulations enables to simulate the fleet schedule and the 1VS1 schedule. 1000 simulations or scenarii are generated to have different random assignments of missions and they enable to reach the algorithm convergence (global maintenance cost convergence).

Table 1. Definition of the 12 missions parameters

Mission	Duration	Shape parameter α	Scale parameter β	Failure probability P_f
1	3	4.17	0.25	0.0021
2	6	4.08	0.35	0.026
3	9	1.62	0.27	0.0034
4	4	5.45	0.33	0.016
5	3	5.61	0.29	0.0056
6	4	4.81	0.31	0.0094
7	3	0.667	0.01	4.99×10^{-4}
8	3	0.0067	0.01	0.0045
9	6	0.213	0.08	6.88×10^{-4}
10	2	0.36	0.06	0.0011
11	2	0.16	0.04	0.0022
12	5	0.036	0.03	0.0032

4.1. Maintenance costs analysis

The objective of this part is to analyse the benefit of using the fleet dimension regarding the global maintenance costs for the fleet.

The schedules definition are constrained by the maximum admissible failure probability for the mission blocks P_{max} . Simulations are then made for different values of P_{max} . Moreover, the 1VS1 method has one more constrain as the missions are randomly distributed among the fleet vehicles.

Using the fleet dimension enables to reduce the maintenance costs C_m but these gains vary according to the value of P_{max} . The maximum gains on the maintenance costs earned when using the fleet dimension represent 6.45% (Table 2) and are obtained when $P_{max} = 0.1$.

Table 2. Maintenance costs results when comparing the two methods

P_{max}	Savings with fleet method	Method	C_m convergence	Cases when the method wins
0.1	6.45%	Fleet	7254	100%
		1VS1	7722	0%
0.2	2.53%	Fleet	7275	83.4%
		1VS1	7459	16.6%
0.3	2.41%	Fleet	7276	86%
		1VS1	7451	14%

Figure 1 represents the repartition of the maintenance costs difference between the fleet and 1VS1 methods for each value of P_{max} . The maintenance costs for each method are computed for each scenario. It is the average value of the maintenance costs on the 1000 simulations for each scenario. When $P_{max} = 0.1$, the fleet method always wins with respect to

the 1VS1 method. For the two other values, the fleet method wins in about 85% of the cases.

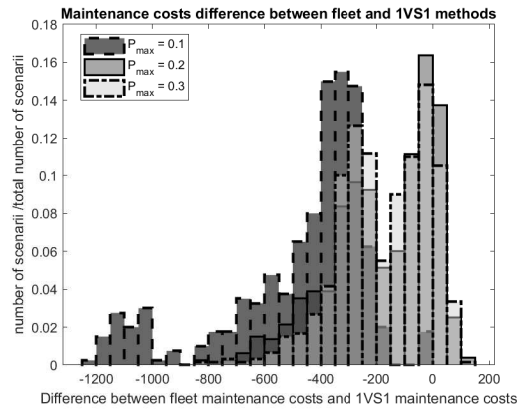


Figure 1. Distribution of the maintenance costs difference between the two methods

4.2. Study of extreme cases

The schedules difference between the fleet and the 1VS1 methods comes from the random mission assignment to each vehicle for the 1VS1 method and the value of P_{max} . Indeed, when P_{max} is higher, the constraint on the way to build mission blocks is relaxed so missions grouping becomes easier for the 1VS1 method despite the random mission assignment.

Different observations can be made. When all the missions have the same characteristics (duration, deterioration properties), using the fleet dimension to schedule the fleet activities is not necessary. Then, the gain from one random mission assignment to another can vary a lot (Table 3).

When $P_{max} = 0.2$, many schedules obtained with the 1VS1 method are composed of 6 blocks like the schedule obtained with the fleet method. Some can have smaller maintenance costs than the ones for the fleet methods (3). In these cases, the blocks are less filled with missions than when using the fleet method. So when deterioration trajectories are generated, if a mission, belonging to a very filled block of the fleet schedule has a huge impact on the deterioration, it is more likely to have a failure. The fleet method takes the maximum risk to define the schedule to tend towards P_{max} .

Table 3. Comparison of the gains between fleet and 1VS1 schedules examples

P_{max}	Method	Schedule	Number of blocks	Gain/loss with fleet method
0.1	Fleet	[1, 7][2, 8][4, 12] [6, 11][5, 10][3, 9]	6	
	1VS1	[7, 10, 12] [8, 5][4][11, 3][2][6][1, 9]	7	4.93%
		[4][3][7] [9, 8, 10, 12, 11][5][2][6][1]	8	14.83%
		[5, 10][1, 7] [11, 6][2, 8][9, 3][12, 4]	6	0%
0.2	Fleet	[4][3, 7][2] [11, 6][1, 12, 8, 10][9, 5]	6	
	1VS1	[7, 10][4] [3, 9][6][2][11, 1, 8][5, 12]	7	6%
		[4][1] [9, 7, 10, 11, 8, 12][3][2][6][5]	7	4.28%
		[8, 11, 6][4] [10, 3, 12][7, 1][2][5, 9]	6	-1.29%

5. Conclusion

This comparison shows the interest of integrating the fleet dimension when scheduling both the missions and the maintenance operations for a fleet of vehicles. In most cases, the fleet method reduces the fleet maintenance costs but on some specific cases the global maintenance costs can be slightly higher than with the 1VS1 method because of the maximum admissible failure risk defined by P_{max} . The gain offered by the fleet method exists but may seem not so significant because it is a static case. Considering different vehicle configurations could highlight the interest of using the fleet dimension as the same mission would have a different deterioration impact according to the vehicle configuration. Nonetheless, the fleet dimension interest will surely appear when considering a dynamic case with available monitoring information to update the initial schedule.

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