The Optimization Research of EMU Second-grade Maintenance Plan Based on Simulate Anneal Arithmetic

Qing Sun^{1, a} Xian Zhang^{1, b} Hong-Yan Yang^{1, c} Lei Chen^{1, d}

¹ School of Traffic and Transportation, Beijing Jiaotong University, China

^a15125782@bjtu.edu.cn, ^b15125809@bjtu.edu.cn, ^c15120901@bjtu.edu.cn,
^d11114231@bjtu.edu.cn

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Abstract. As for the optimization of EMU second-grade maintenance plan, the author has made a model out of the target function which is the minimization of total mileage wasted within scheduled duration and managed to get solutions out of simulate anneal arithmetic. Finally, taking the Beijing-Tianjin inter-city bullet train for an example, the author has used the model constructed and the simulate anneal arithmetic to perform the optimization trial of the EMU maintenance. At last, the author has verified that when Reserved trains are used under non-fixed mode, routing plan is accomplished and the application efficiency is enhanced at the same time.

Introduction.

The application process for the EMU in our country at present mainly involves two stages. First make the EMU application routing plan based on the train graph. The daily operation of EMU and maintenance is in the charge of EMU based on workflow and the application plan of the station is to allocate well-conditioned EMU for the routing.

This paper has referred to some of the research fruits obtained by scholars at home and abroad and has analyzed the factors affecting the making of EMU maintenance plan under EMU non-fixed section application model in order to decrease the EMU quantity in use as well as to mitigate maintenance cost, then a model is built and a solution is obtained for the integrated application plan and maintenance plan.

Problem Description.

Among the investment made in the infrastructures of passenger-dedicated railway system, the cost for EMU purchasing and maintenance has taken up a relatively large scale, therefore the quality of EMU maintenance plan directly affecting the operational benefits of the railway system. The making of EMU maintenance plan is in consideration of the EMU maintenance constraints (normally being the maintenance above second-grade) for over 1 day (1 day included) of maintenance work. An advance maintenance between 1 day to 3 days is arranged for EMU having an maintenance cycle of second-grade or higher (referred to as to-be-checked EMU) according to the operational status (accumulated operational mileage and time of the EMU) at present, in the meanwhile, the routing of the EMU is adjusted, ultimately the process of application plan for each EMU within maintenance plan cycle is generated.

In actual production process, when the train operation diagram is determined, optimization needs to be done for routing plan as well as maintenance plan due to the limitations of maintenance capacity of the EMU based on workflow and the quantity of the spare car. In this paper, on the basis of known routing schedule, the author has thought about the maintenance plan optimization and the decrease of workload in EMU based on workflow.

As for simplex EMU as well as its routing, the basic characteristics of the EMU maintenance plan can be described as follows:

Known conditions. (1) Routing Information of the EMU: the starting point and finishing point of routing, starting time and finishing time, total operating hours and operating mileage. (2) Information of the EMU Application Station: affiliated or connected station, duration of the maintenance work at

each grade, maintenance capacity, quantity of spare cars.(3)Information of the EMU: Accumulated operating mileage and operating hours, whether it is to-be-checked EMU or not.(4)EMU Repair Class: EMU Maintenance Cycle at each Grade(mileage and duration).

Constraint Conditions. (1) Cycle Operation Constraint: two adjacent crossed sections in the charge of the same EMU, the finishing point of the former routing should be the starting point of the latter one.(2)System Constraint of the EMU Maintenance: when choosing continuous EMU, maintenance constraint should be taken into account and the EMU in charge of transportation should be one that was examined and one that will never reach maintenance mileage before completion.(3)Capacity of EMU based on workflow Constraint: The quantity of EMU being maintained in each EMU based on workflow shall not exceed its maintenance capacity and the EMU taking each EMU based on workflow for sojourn shall not exceed the prescribed quantity.(4) The EMU quantity for use of the EMU Maintenance plan shall exactly be the sum of the quantity in routing and the quantity of spare cars.

Building Optimization Model.

The Definition of Parameter.

Making planned day within planned duration set $D=\{d \mid d = 0,1,2,\dots,N_D\}$, in which d is the number of planned day, N_D is concrete days within planned duration; EMU set is $E = \{e \mid e = 1,2,\dots\}$ in which e is the number of EMU; the Application Routing set in the charge of the EMU based on workflow $R = \{r \mid r = 1,2,\dots,N_R\}$ in which r is the number of application routing; N_R is the quantity of the application routing; l_r is the operating mileage of the application routing r ; the maintenance work package set is $P = \{p \mid p = 1,2,\dots\}$ in which p is the number of maintenance work package;

l_{ep} represents the accumulated running mileage from the finishing of maintenance work package p by EMU e to restarting the maintenance work package p ; T_{lp} represents the running mileage prescribed by maintenance work package p ; the maintenance task taken by the EMU based on workflow each planned day is N_C ; v_{dr} represents the transportation task taken by the EMU based on workflow within planned day d for application routing r ; v_{dp} represents the maintenance task under work package p within planned day d .

Making all the feasible solution for EMU e within planned duration D feasible path set F^e , element f_i^e in F^e being one feasible path orderly formed by several transportation task v_{dr} and maintenance task v_{dp} , and this feasible path meets each constrain condition.

Decision Variable is as follows:

$$x_{edr} = \begin{cases} 1 & \text{the application routing } r \text{ within planned day } d \text{ for EMU } e \\ 0 & \text{Otherwise} \end{cases}$$

$$y_{edp} = \begin{cases} 1 & \text{when EMU are performing the maintenance of work package } p \\ 0 & \text{Otherwise} \end{cases}$$

$$z_{f_i^e} = \begin{cases} 1 & \text{when EMU } e \text{ implementing feasible path} \\ 0 & \text{Otherwise} \end{cases}$$

The construction of Model.

Taking the wasted mileage z within planned duration as goal, the model for integration of EMU application plan and maintenance plan is as follows:

$$\min Z = \sum_{e \in E} \sum_{d \in D} \sum_{p \in P} y_{edp} (T_{lp} - l_{ep}) \quad (1)$$

$$s.t. \sum_{e \in E} \sum_{p \in P} y_{edp} \leq N_C \quad \forall d \in D \quad (2)$$

$$\sum_{r \in R} x_{edr} \leq 1 \quad \forall d \in D, e \in E \quad (3)$$

$$\sum_{e \in E} z_{f_i^e} x_{edr} = 1 \quad \forall d \in D, r \in R \quad (4)$$

$$x_{edr}, y_{edp}, z_{f_i^e} \in \{0,1\} \quad \forall e \in E, \forall r \in R, \forall p \in P \quad (5)$$

In the above-mentioned functions, the first one is the target function showing the minimization of total mileage wasted by all the EMU within planned duration; the second one the maintenance capacity constraint in the EMU based on workflow, that is to say, the quantity being maintained everyday shall not exceed the maintenance capacity possible; the third one means the path constraint of the EMU which guarantees that a feasible path is chosen for each bullet train, that is, every EMU has the application plan of routing and maintaining; the fifth one being the 0-1 variable constraint.

Model Solving Strategy Based on Simulate Anneal Arithmetic.

According to the maxim of Metropolis, the probability of a particle reaching the state of equilibrium at temperature T is $e^{-\Delta E / (kT)}$, in the equation E being the internal energy at temperature T , ΔE being its variable quantity and k being the constant of Boltzmann. Using solid annealing to simulate combinatorial optimization, followed by simulating E as the value of target function f , followed by making T the control parameter t , then we have here the simulate anneal arithmetic which starts from the initial solution i and the initial control parameter t , followed by the repetition of “generating a new solution $\rightarrow$ computing difference with the target function $\rightarrow$ accept or deny” accompanied by a gradual decrease in the value of t , and the final solution is approximately the best solution we could possibly get. The whole process is a heuristic random searching one based on the iterative solution of Monte Carlo's. The annealing process is under control of the cooling schedule including the initial value t of the control parameter as well as its attenuation factor Δt , the iterative time L of the corresponding t value and the cessation condition S .

Starting with some comparatively high initial temperature, simulate anneal algorithm searches randomly for the best solution overall to target function in the solution space according to the properties of probabilistic leap, in other words, to jump out of the best solution locally so as to get to the best solution globally.

Example Analysis.

Taking the Beijing-Tianjin inter-city EMU CRH3C from Beijing Southern EMU based on workflow as the research background, the author has known empirically that twenty bullet trains out of the total only take the transportation mission from Beijing to Tianjin and are given the actual application plan and maintenance plan for the first week in June, 2013. Through data organization and analysis, the author has obtained mileage data of each routing as well as the maintenance constraint of CRH3C EMU. Due to the fact that the workload of the bullet train station is supposed to be mitigated in this paper, the author has made the value of one, which means the EMU based on workflow can provide workers to repair at most one set of EMU.

CRH3C EMU takes the transportation mission from Beijing to Tianjin. Because the first-grade maintenance is allowed to work within Beijing Southern Bullet Train Station and only basic servicing work can be provided in Tianjin, it has to be made certain that the EMU has to return to Beijing Southern Station to do the first-grade maintenance within two days under the application plan. For CRH3C EMU two-level maintenance, four work package can be divided therein: In I2 work package, maintenance mileage includes thirty thousand Kilometers which takes about a day to do the maintenance; in M1 work package, maintenance mileage includes one hundred thousand kilometers; in M2 work package, maintenance mileage includes four hundred thousand kilometers; in M3 work

package, maintenance mileage includes eight hundred thousand kilometers. According to an empirical research, the maintenance frequency for M1 work package is normally two months while the maintenance interval for M2 and M3 work package is normally beyond two months, so in the example only I2 work package is taken as the maintenance constraint.

On the basis of first-grade maintenance restraint and actual situation, EMU needs to go back to Beijing Southern Bullet Train Station for first-grade maintenance within two work days (Tianjin Station is not capable of maintaining). Therefore, the routing information is as Table 1 :

Table 1: Routing in use

Name of the Routing	Duration of the Routing/d	Mileage of the Routing/km
r1	2	3840
r2	2	3920
r3	2	4080
r4	2	3760
r5	2	2920
r6	2	3280

At present, Beijing Southern EMU based on workflow has more than twenty sets of CRH3C EMU and the routing quantity for everyday is six (according to real data obtained in Beijing Southern Bullet Train Station). Eighteen sets of EMU have been chosen, meaning the EMU quantity in use is mitigated directly, to accomplish the routing mission arranged by the railway station. Inputting the mileage constraint for the I2 maintenance work package of the EMU ($T_{lp} = 30000\text{km}$); the accumulated running mileage l_{ep} from the accomplishment of I2 work under maintenance work package by eighteen sets of EMU; the most second-grade maintenance task taken by EMU based on workflow being $N_C = 1$; because routing is done within two days and the plan acquired needs to be specific to everyday, the six routing is numbered according to date. (see Table 2).

Table 2: Routing Date named in Different Groups

Name of the Routing	Day One	Day Two
r1	0	6
r2	1	7
r3	2	8
r4	3	9
r5	4	10
r6	5	11

Initialization. Set the original temperature T_0 twenty, the step size of the temperature decline one, terminal temperature T_{end} zero, the iterative time under the same temperature L one hundred. Using simulate anneal arithmetic and letting the temperature drop constantly until T is below T_{end} or the target function value is not altered after continuous iteration, the best solution will be generated finally by the program.

Taking the minimization of total wasted mileage as goal and using simulate anneal arithmetic, with the decline of temperature and the combination of probabilistic leap, the best solution is gotten out as iteration time adds up. It is listed below in Table 3.

Table 3: Results Comparison between Computational Establishment and Manual Establishment

	Manual Establishment	Computational Establishment
Total Maintenance Time	Over Ten Times	8
Total Mileage Wasted	5000	608
EMU Quantity Required	20	18

From the computational outcome, it is known that total best solution maintenance time after a series of iteration is eight and total mileage wasted is 608km. When EMU application quantity is decreased, the workload of EMU based on workflow is decreased as well and the corresponding EMU maintenance plan and application plan is made. Using the model and arithmetic given in this paper, EMU is used less and maintenance work is performed less when same same amount of transportation task is accomplished.

With the increase of iterative times, the variation process of the target function value is as Figure 1. Abscissas stands for iterative times and ordinate stands for total mileage wasted. Finally, the best plan shows in Table 4.

Figure 1: The Variation Process of the Target Function

Conclusion

On one hand, the application efficiency of the EMU based on workflow for single type of EMU is increased and the maintenance work of the EMU is mitigated using the optimization model of the EMU second-grade maintenance plan in this paper. On the other, this model has created the optimized application plan and maintenance plan in non-fixed road sections, which has the turnover of EMU optimized and the EMU in use lessened.

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Form 4:Ultimate Optimization Results

EMU	d1	d2	d3	d4	d5	d6	d7	d8	d9	d10	d11	d12	d13	d14	d15
e1	r1	r5		R.	R.	R.	S.E.	R.	r2		r4		r2		r2
e2	r2	r3		R.	R.	R.	r6		S.E.	r2		r4		r6	
e3	r3	r4		r6		r1		r1		r3		S.E.	r6		r4
e4	r4	R.	r2		R.	r2		r6		r1		R.	r3		R.
e5	r5	R.	r5		r6		r2		R.	r5		r5		S.E.	r5
e6	r6	r6		r1		r4		r2		R.	r6		R.	R.	r1
e7	R.	r2		r4		r3		r4		r6		r3		r4	
e8	r5		r1		R.	r6		r5		S.E.	r3		r4		r6
e9	r6		R.	R.	R.	R.	R.	R.	R.	R.	R.	R.	R.	R.	R.
e10	r2		R.	R.	R.	R.	R.	R.	R.	R.	R.	R.	R.	R.	R.
e11	R.	R.	R.	r5		S.E.	r1		r1		r2		r1		r3
e12	R.	R.	r6		r5		r3		r6		S.E.	r2		r3	
e13	r1		R.	r3		r5		R.	R.	R.	R.	R.	R.	r2	
e14	R.	r1		R.	r1		R.	R.	r3		R.	r6		R.	R.
e15	r3		r3		r3		r5		r5		r5		S.E.	r1	
e16	R.	R.	R.	R.	r2		r4		r4		r1		r5		R.
e17	r4		r4		r4		R.	r3		r4		r1		r5	
e18	R.	R.	R.	r2		R.	R.	R.	R.	R.	R.	R.	R.	R.	R.

Note: "R." means Reserved vehicle, "S.E." shows the meaning of Second Examination.