обеспечить поддержание допустимого уровня риска при эксплуатации объектов инфраструктуры и подвижного состава, а также для оценки уровня тяжести последствий транспортных происшествий при маневровой работе.

Развитие данного направления исследования рисков способствует принятию верных управленческих решений, учитывающих неопределенность условий работы железных дорог, возможность наступления определенных событий или обстоятельств в будущем, а также их влияние на достижение функциональной безопасности объектов инфраструктуры и подвижного состава.

Список литературы

1 ГОСТ Р 54505-2011. Безопасность функциональная. Управление рисками на железнодорожном транспорте. – Введ. 2011-11-23. – М. : Стандартинформ, 2012. – 34 с.

2 **Филатов, Е. А.** Обоснование технической совместимости горловин железнодорожных станций и подвижного состава / Е. А. Филатов // Транспортные системы и технологии перевозок : сб. науч. тр. Днепров. нац. ун-та ж.-д. трансп. им. акад. В. Лазаряна. – Днепр : ДНУЖТ, 2020. – Вып. 19. – С. 25–36.

3 **Филатов, Е. А.** Безопасность взаимодействия путевой инфраструктуры железнодорожных станций и подвижного состава // Интеллектуальные транспортные системы : материалы II Междунар. науч.-практ. конф. (25 мая 2023 г.). – М. : Перо, 2023. – С. 644–654.

4 ГОСТ Р МЭК 62502-2014. Менеджмент риска. Анализ дерева событий. – Введ. 2014-10-24. – М. : Стандартинформ, 2015. – 30 с.

RESEARCH ON TRAIN MARSHALING AND STOPPING OPTIMIZATION OF INTERCITY RAILWAY CONSIDERING PASSENGER TRAVEL COST AND TRAIN OPERATING COST

HE HONG

Guangzhou Railway Polytechnic, China，

Belarusian State Transport University，Republic of Belarus

Optimize the operation plan of intercity railway trains considering marshaling and stopping schemes

The travel distance of intercity railway passenger flow is mostly between 30–100 km, and the intercity railway passenger flow is highly cyclical, which is mainly manifested in the time distribution of weekly and daily cycles. The cycle of natural days is reflected in the peak passenger flow from 7:00 to 9:00 in the morning and 17:00–19:00 in the evening. The weekly basis is reflected in the peak passenger flow from Friday to Monday of the week, especially the Friday night peak and Monday morning peak, while the peak passenger flow on Saturday and Sunday mainly comes from travel, family visits, etc. The passenger flow characteristics of intercity railway integrate the passenger flow characteristics of traditional railway and urban rail transit. In the early stage of the opening of intercity railway lines, due to the passenger flow in the cultivation period and the low passenger flow, it was difficult to match the existing single-group, single-stop train operation scheme with the current passenger flow, resulting in low passenger load factor and waste of train capacity. The operation of large-interval trains will increase the waiting time of passengers, resulting in increased travel costs for passengers. Based on this, starting from the train operating cost and passenger travel cost, this paper takes the train operation scheme in a certain direction in the early stage of intercity railway opening as the research object, and optimizes the train operation scheme from the aspects of train formation and stop scheme, as shown in Figure 1.

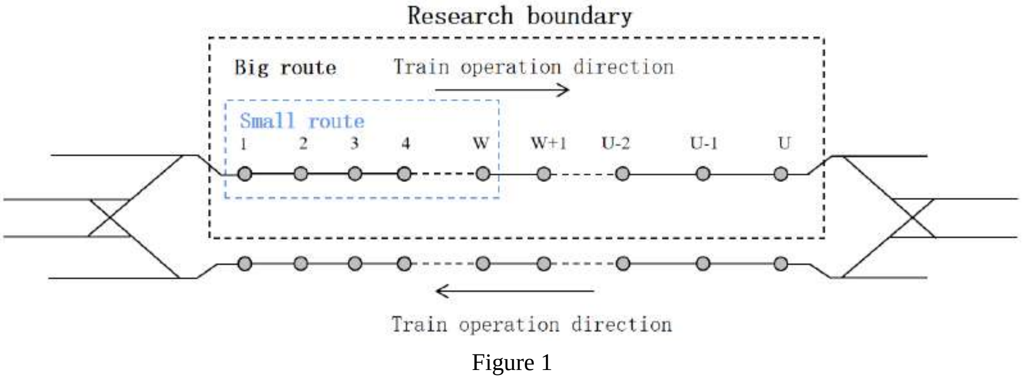

Figure 1

Define the model parameters as follows.

1 Collection variables.

Define station collection $\boldsymbol{U}$ = {u|1,2 …, U}=$\boldsymbol{W}$ + $\boldsymbol{B}$, while $\boldsymbol{W}$ ={w|1,2 …, W}refers to stations which small route pass through, B ={b|1,2…, B}refers to stations form station collection U which except the station collection W.

Define train marshalling type collection $\boldsymbol{K}$ ={k|1,2, …, K}, train collection $\boldsymbol{R}$ = {r|1,2, …, R}refers to the number of the train in the operating scheme, while R refers to the sum of trains

2 Decision variables.

fk refers to the number of the trains in type k;

$a_{k,u}^{r}$ indicates whether train r with formation type k stops at station u, which is 0,1 variable。

3 Constant parameter:

g_k refers to the number of vehicles of the train in type k;

C_l refers to the cost of per kilometer of per vehicle operation;

C_s refers tj the cost of per time of per vehicle stopping;

C_p refers to the average time value of passengers;

L refers to the total mileage of the intercity railway line, L_1 refers to the total mileage of small route, L_2; refers to L minus L_1.

C refers to vehicle capacity.

In order to facilitate the model establishment of the research problem, this paper makes the following assumptions.

1 Assuming that the studied intercity railway line is straight and the train runs separately up and down, this paper only optimizes the direction of the line with a large passenger flow, and does not consider the problem of train continuation.

2 This article does not consider cross-line passenger flow, only local passenger flow.

3 Suppose a passenger chooses to take a train that stops at both the beginning and end of their trip,they does not transfer.

4 The arrival pattern of passengers is known, and the principle of first-come-first-served service is obeyed.

5 Suppose the train does not cross the line.

6 Suppose the operational organization model operates on large and small route.

Optimization model of large and small marshalling train operation scheme in stop mode

Based on the characteristics of passenger flow in the initial stage of intercity railway, this paper constructs an optimization model for large and small marshalling trains in multi-stop mode from the perspective of optimizing enterprise operating costs and passenger travel costs, aiming at minimizing train operating costs and passenger travel costs, and comprehensively considering the constraints such as the number of trains, train full load rate, OD service frequency, and number of stops

1 Objective function of enterprise operating cost

From the perspective of train operation, train operating costs mainly include train operating costs and train stop costs, of which operating costs include the train's electricity and other energy consumption costs, line usage costs, and train operating costs are related to the kilometers traveled by the vehicle and the operating costs per kilometer of the vehicle; The cost of train stops refers to the cost incurred by the train in the process of stopping at the station, which is related to the number of train stops and the cost of each stop, etc., and the objective function of enterprise operating costs is as follows:

$$\min Z_1 = \sum_{r=1}^{f_1} g_1 (L_1 + \varepsilon_r \cdot L_2) C_l + \sum_{k=1}^{K-1} \sum_{r=f_k}^{f_k+f_{k+1}} g_{k+1} (L_1 + \varepsilon_r L_2) C_l + $$
$$+ \sum_{r=1}^{f_1} \left[g_1 (\sum_{u=1}^{W} a_{1,u}^{r} + \varepsilon_r \sum_{u=W+1}^{U} a_{1,u}^{r}) C_s \right] + \sum_{k=1}^{K-1} \sum_{r=f_k}^{f_k+f_{k+1}} \left[g_{k+1} (\sum_{u=1}^{W} a_{k,u}^{r} + \varepsilon_r \sum_{u=W+1}^{U} a_{k,u}^{r}) C_s \right] \quad (1)$$

In formula 1, variable ε_r is a 0,1 variable which represent the train r runs in large route or small route, when its value equal to 1, then it refers to the train r runs in large route,otherwise it runs in small route.

Variable $a_{k,u}^{r}$ is a 0,1 variable which represent the train *r* stops at station *u* or not, when its value equal to 1, then it refers to the train *r* stops at station *u*, otherwise it does not stop at station *u*.

2 Objective function of passenger travel cost.

The cost of passenger travel is related to the number of passengers, the average time value of passengers, and the time of travel, of which the boarding time includes the time in and out of the station, waiting time, and the time on the train, considering that different groups have no effect on the passengers entry and exit and on-board time, and different stopping schemes have little impact on the passengers' time on the train, therefore, this paper only considers the waiting time, which is half of the travel interval. The average time value of passengers is taken from the average hourly wage of locals, and the objective function of the minimum passenger travel cost is constructed as follows:

$$\min Z_2 = \sum_{i=1}^{U-1} \sum_{j=i+1}^{U} q_{i.j} C_p \frac{1}{2} \frac{60}{\sum_{k=1}^{K} f_k}. \quad (2)$$

In formula 2, variable $q_{i,j}$ refers to the passenger flow from station i to station j.

The constraints of the model mainly include the number of running trains, train full load rate, OD service frequency, stop constraint, integer value constraint of variable and 0,1 variable constraint.

1 Constrains of the number of running trains.

Considering the operating costs of the enterprise and meeting the number of trains of large and small formations during peak hours, set upper and lower limits on the number of trains in any one period:

$$\sum_{k=1}^{k} f_k \le f_{\max}, f_k \ge f_{\min}. \quad (3)$$

In formula 3, $f_{\max}$ refers to the maximum running trains of the operation period, $f_{\min}$ refers to the minimum trains of all the train marshaling type.

2 Constrains of train full load rate.

According to the OD passenger flow demand, the cross-section passenger flow is obtained, and then the cross-section full load rate is obtained. Considering the train capacity, it is necessary to constrain the upper limit of the section full load rate and the lower limit of the average section full load rate:

$$\eta_d = \frac{\sum_{i=1}^{d} \sum_{j=d+1}^{U} q_{i,j}}{\sum_{k=1}^{K} f_k g_k C} \le \eta_{\max}, \frac{\sum_{d=1}^{U} \eta_d}{N-1} \ge \eta_{\min}. \quad (4)$$

In formula 4, η_d refers to the cross-section full load rate of the section *d*; *C*: Refers to the train capacity.

3 Constraints of OD service frequency.

In order to meet the demand of passenger travel,considering the change of train stopping plan will change the passenger waiting time of different station,set the constrains of OD service frequency, the serving trains of every OD can not smaller than the minimum:

$$\sum_{r=1}^{f_1} a_{1,i}^{r} a_{1,j}^{r} + \sum_{k=1}^{K-1} \sum_{r=f_k}^{f_k+f_{k+1}} a_{k,i}^{r} a_{k,j}^{r} \ge \frac{q_{i,j}}{\min(q^i, q^j)}. \quad (5)$$

In formula 5 *qi* refers to the passenger flow that station *i* absorbs; q^j refers to the passenger flow that station *j* absorbs.

4 Constrains of train stopping.

The train operation route is divided into two types: large route and small route, and the stop mode is divided into three types: stops at large station, stops at every station and stops at optional station. According to the stopping needs of different stations on different route, the specific stopping constraints of trains are as follows: small route trains can choose three types of stops: stops at every station, stops at the terminal station, and stops 1 station in the middle; large route trains can choose three options: stops at every station, stops at large station and choose 2 middle station stops. The specific train stop constraints are shown in Table 1.

Table 1

Station number		1	2	3	...	*W*	*W*+1	...	*U*
Small route train	Stop at terminal station	1	0	0	0	1	0	0	0
	Stop at terminal station and 1 middle station	1	1			1	0	0	0
	Stop at every station	1	1	1	1	1	0	0	0
Large route train	Stop at large station	1	0	0	0	1	0	0	1
	Stop at terminal station and 2 middle station	1	1			1	1		1
	Stop at every station	1	1	1	1	1	1	1	1

5 Integer constraints:

$$f_k \in Z^+, \;\; g_k \in Z^+. \tag{6}$$

Conclusion

Starting from the problem that the passenger flow of intercity railway is small in the early stage of operation but still needs to ensure a high service level, and the contradiction between passenger travel cost and enterprise operating cost, a multi-objective optimization model is established to obtain the optimization conclusion of the train operation scheme that balances passenger service level and operating cost. Through case analysis, maintaining the average logarithm of 8 marshaling trains and 4 marshaling trains has a significant optimization effect on the reduction of passenger travel costs. In addition to 8 marshaling trains, a small number of 4 marshaling trains is the best choice to balance the cost of passenger travel and the operating cost of enterprises.

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ИНДУСТРИЯ 4.0 И ПЕРЕВОЗКА ОТХОДОВ

М. П. ЦВИЛЬ
Белорусский государственный экономический университет, г. Минск

Увеличение объема образующихся твердых коммунальных отходов во всём мире (ежегодно около 2,01 млрд тонн с увеличением до 3,40 млрд тонн к 2050) и усугубление проблемы загрязнения окружающей среды, свидетельствует, помимо прочего, о частичной неэффективности сложившейся системы по обращению с отходами и призывает к поиску новых стратегий для улучшения экосистемы, например, использованию искусственного интеллекта.

В настоящей статье пойдет речь о применении технологий индустрии 4.0 для оптимизации логистических процессов при обращении с отходами.

Система логистики и транспортировки отходов является важным звеном, объединяющим источник образования отходов и их дальнейшую переработку. Однако существующие системы логистики и транспортировки отходов имеют ряд недостатков. Во-первых, затраты, связанные с логистикой и транспортировкой отходов, непомерно высоки, особенно на этапе сбора. Так, сегодня большинство систем по сбору отходов осуществляются вручную и часто неэффективно. Согласно проведенным исследованиям на сбор отходов приходится примерно 70–80 % от общего объема затрат на обращение с отходами. Более того, в результате неэффективного планирования образуются заторы на маршрутах, увеличивается объем потребления топлива для организации сбора. Всё это вносит свой вклад в увеличение объема выбросов парниковых газов в атмосферу до 50 %. [4] Во-вторых, человеческий фактор является своего рода кадровым ограничением и влечет за собой недоработки в планах сбора отходов и подборе транспортных средств. Поэтому для решения подобного рода проблем были разработаны и внедрены решения на основе искусственного интеллекта для оптимизации процессов логистики и транспортировки отходов.

Преимуществами технологий индустрии 4.0 являются максимизация прибыли, сокращение инвестиционных и операционных расходов, преобразование отходов во вторичные материальные ресурсы, преодоление некоторых операционных сложностей, которые невозможны без передовых технологий, увеличение скорости операций по управлению отходами, повышение имиджа компании, внедрение и популяризация экологических ценностей, оптимизации соотношения цены и качества. Согласно проведенным исследованиям, использование искусственного интеллекта в логистике отходов помогает снизить дистанцию транспортировки до 36,8 %, сэкономить на затратах до 13,35 % и сократить временные потери до 28,22 % [1].