INTERCITY SHORT-DISTANCE RAILWAY'S PASSENGER FLOW DYNAMIC ALLOCATION

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Summary: *This paper builds a passenger flow dynamic allocation and a multi-objective programming model for the optimal dynamic allocation intercity railway passenger train operating scheme. The model is solved by MATLAB to determine the optimal passenger train operating scheme. The paper gets the optimal train operating scheme of the Guangqing intercity railway as the example to examine the models.*

Keyword: *Multi-objective programming model, optimal passenger train operating scheme, Guangqing intercity railway, passenger flow dynamic allocation.*

I. INTRODUCTION

In China, the railway system is monopolized by the China Railways Corporation, which sometimes may result to the railway system supply couldn't meet passengers demand. Especially, in some big and medium cities, the intercity railway system has been overloaded and insufficient to meet passengers demand. The most important considerations of intercity railway passengers are price, travel time, comfort, travel conditions and reliability (*Claessens.M.T, Vandijk.N.M, Zwaneveld.P.J. ,1998)*. This paper presents a passenger flow dynamic allocation and a multi-objective programming model. Then, a detailed presentation is defined to calculate the models. Moreover, the to-be-built GuangQing intercity railway system is used to show how the model works and to examine the model's effectiveness. Specific conclusions on train operating scheme for GuangQing intercity railway are drawn and discussed.

II. THE NECESSITY OF OPTIMIZED TRAIN OPERATING SCHEME BASED ON PASSENGER FLOW DYNAMIC ALLOCATION

For the sake of improving intercity trains' competitiveness, it is important to optimize the passenger train operating scheme, is an extreme important part for the optimal passenger train operation plan (*Goossens.J, Hoesel.S.T, Kroon.L., 2006)*.On the purpose of presenting the mutual impaction between train operating scheme and passenger flow volume, in addition synthetically optimizing them. The optimal train operating scheme based on passenger flow dynamic allocation is discussed in this paper (*Zhou X., Zhong M., 2005)*. So, the integrated intercity railway transportation scheme can be attained to meet passengers demand.

III. THE PASSENGER FLOW DYNAMIC ALLOCATION OPTIMIZATION MODELS

3. 1. The passenger flow dynamic allocation model

First of all, this paper assumes that all intercity train passengers would choose the rank of train according to their own economic condition, which generates an original passenger flow volume matrix. The intercity train passengers will transfer among different ranks of trains through adjusting train operating scheme. Then, a new matrix, which would have feedback to the operating scheme, would be generated. In this circulation process, new matrixes and their corresponding operating scheme are constantly generated *(Sheffi Y., Powell W.B. ,1982)*. In the end, an operating scheme would be generated to satisfy the stable passenger allocation status. This circulation process meets the high requirement of intercity train service and the high need of intercity train passengers.

On an intercity rail line $\Omega = \{S, E\}$. S is a set of n stations from start station to end station, $S = \{s_i \;\; i = 1, 2, \cdots, n\}$. s_i is station i. E is a set of n - 1 sections between two neighboring stations, $E = \{e_i \;\; i = 1, 2, \cdots, n-1\}$. e_i is section between s_i and s_{i+1}. $T = \{X, Y, Z\}$ is a set of three stop-schedules between station s_1 and s_n. X is the operating scheme which takes the least time and need to be paid most. Z is the operating scheme which takes the most time and need to be paid least. And Y is the medium rank train operating scheme. $P = (p_{ij})_{n \times n}$ is the intercity train original passenger flow volume matrix between station s_i and s_j. p_{ij} is the original passenger flow volume between station s_i and s_j. $\overline{P} = (\overline{p}_{ij})_{n \times n}$ is the real passenger flow volume matrix between station s_i and s_j. $\overline{p}_{ij}$ is the passenger flow volume transferring among different stop-schedule.

Assume the high consumption level passengers prior to the X stop-schedule, the passengers of medium consumption level prior to the Y stop-schedule and the low consumption level passengers prior to the Z stop-schedule. If high consumption level passengers p_{ij}^X travel from s_i to s_j, but trains following the stop-schedule X don't stop at station s_i or s_j, then p_{ij}^X will transfer to p_{ij}^Y. If trains following the stop-schedule Y don't stop at station s_i or s_j, then p_{ij}^Y will transfer to p_{ij}^Z. Trains following the stop-schedule Z stop at every stations, $r_{ij}^Z = s_i^Z \times s_j^Z = 1$. According to the current situation, trains following lower stop-schedule stop at every higher stop-schedule stopping stations. The transfer formulation of different consumption level passenger flow volume between station s_i and s_j as follow.

$$\begin{cases} \overline{p_{ij}^X} = r_{ij}^X \times p_{ij}^X \\ \overline{p_{ij}^Y} = r_{ij}^Y \left[p_{ij}^Y + (1-\varepsilon_1)\left(1-r_{ij}^X\right) p_{ij}^X \right] \\ \overline{p_{ij}^Z} = r_{ij}^Z \left[p_{ij}^Z + \left(1-r_{ij}^Y\right)\left((1-\varepsilon_2) p_{ij}^X + (1-\varepsilon_3) p_{ij}^Y\right) \right] \end{cases}$$

ε_1, ε_2, ε_3 indicates respectively the churn rate when higher rank trains not running, which is determined by time sensitivity of different consumption level passengers *(Vansteenwegen P., Van Oudheusden D., 2007)*.

$s_i = 0$ indicates a train following stop-schedule T wouldn't stop at station i and $s_i = 1$ indicates a train following stop-schedule T would stop at station i. $r_{ij} = s_i \cdot s_j$, only when $(s_i = 1) \bigcup (s_j = 1)$, $r_{ij} = 1$.

The assumption of the dynamic allocation model

(1) The intercity train system is closed. There is no consideration about the competition with other transportation.

(2) The same rank trains run at the same speed, capacity and stop at the same stations.

(3) The intercity railway is straight line structure.

3.2 The optimization model

(1) Maximum total operating profit of railway bureau

$$C_p = \sum_{k \in T} \sum_{i=1}^{n} \sum_{j=i}^{n} d_{ij} p \overline{p_{ij}^k}$$

C_p is the total ticket profit of intercity railway, which is the sum of passenger flow volume of different travel distance times ticket price (*Goossens J, Hoesel S T, Kroon L. ,2004).* d_{ij} and $\overline{p_{ij}^k}$ respectively indicates the distance and ticket rate between station i and station j. p is the ticket rate.

$$C_c = \sum_{k \in T} f^k \left(\sum_{i=1}^{n} s_i^k c_s^k + d_{1n} c_o^k \right)$$

c_s^k 、 c_o^k 、 d_{1n} indicates respectively stopping cost ,operation cost and total distance of k rank train.

So, the max operation profit C is

Maximum $C = C_P - C_c$

(2) Minimize passenger's total travel expenditure

The travel time loss depends on the distance between station i and station j, total operation speed. The total operation speed is relevant to the rank of train. So, the total travel time loss of k rank train is

$$\text{Min } T = \sum_{K \in T} \sum_{i=1}^{n} \sum_{j=i}^{n} \frac{d_{ij}}{v^K} \overline{p_{ij}^K}$$

v^K indicates the average operation speed of k rank train.

(3) Maximum the needs of original passenger flow volume

$$\min E_{OD} = \sum_{K \hat{I} T} \sqrt{\sum_{i=1}^{n-1} \sum_{j=i}^{n} (\overline{p_{ij}^K} - p_{ij}^K)^2}$$

In China, most of intercity rail lines have enormous abundant capacity, so, we don't consider the constraints of model.

IV. INSTANCE ANALYSIS

Set $\varepsilon_1 = 0.4$, $\varepsilon_2 = 0.5$, $\varepsilon_3 = 0.3$. This paper uses MATLAB to calculate the optimization model and gets the optimal train operating scheme of the Guangqing intercity railway.

Basic parameter of the optimization model

Rank of train	X	Y	Z
Capacity (person)	**586**	**938**	**1520**
Highest Speed (km/h)	**200**	**160**	**160**
Cost per km (yuan/km)	**70**	**65**	**55**
TicketRate $yuan/person \cdot km$	**0.5**	**0.4**	**0.32**
Total stopping time (min)	**0**	**1**	**4**

We get the stop-schedules as follows.

The stop-schedule table of each rank train

	Qingyuan	Longtang	Yinzhan	Shiling	Shipo	Guangzhou north
X	40	0	0	0	0	40
Y	32	0	0	0	32	32
Z	48	48	48	48	48	48

V. SUMMARY

This paper discusses about optimizing operating scheme of intercity passenger trains, which need to build a dynamic allocation model and a mutil-objective programming model for maximum total operating profit of railway bureau, minimize passenger's total travel expenditure and maximum the needs of original passenger flow volume. The model can be solved using MATLAB to generate a best compromise train operating scheme. This paper uses passenger flow volume of the Guangqing intercity railway as the case to verify the effectiveness of the dynamic allocation and optimization model.

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