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Research on Online Optimization of Continuous Casting Cutting based on Multi-objective Linear Programming Model

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Abstract

Aiming at the on-line optimization of continuous casting cutting. In this paper, firstly, the length of the billet after secondary cutting is within the target range of the user as the goal, the domino inverse thinking layout method is used to obtain the length of the residual value of the billet, and the treated part of the billet and the residual value are integrated into the residual value to complement, and the treated part of the billet and the residual value are evenly distributed to the remaining billet for splitting, so as to minimize the cutting loss. Secondly, the multi-objective linear programming mathematical model is established, and the cutting scheme is determined when the mold is abnormal by using the lookup table method. Finally, on this basis, the optimal mathematical model is established, the validity of the obtained data of the optimal billet length combination is tested, and the optimal cutting scheme satisfying the conditions is obtained. The results show that when the abnormal node data is the same and the target value and target range are different, the smaller the target value and target range are, the less residual value distributed to each section, the closer the final length of the billet is to the target value, and the smaller the cutting loss.

Keywords

Domino Layout; Multi-objective Linear Programming Model; Lookup Table Optimization.

1. Introduction

Continuous casting [1] refers to the production process of turning molten steel into billet, in which molten steel is poured continuously from the tundish into the mold and pulled down from the mold at a certain speed into the secondary cooling section. As the molten steel passes through the crystallizer, it forms a solid billet shell where it contacts the surface of the crystallizer. In the secondary cooling stage, the billet shell gradually thickens and eventually drums into a billet. Then, the billet is cut according to certain size requirements. Due to the casting process, the mold will appear abnormal. At this time, a section of billet located inside the mold needs to be scrapped and the cutting plan needs to be adjusted in time.

In this paper, by considering the process parameters of the cutting machine [2], in order to meet the process requirements and basic requirements of the cutting machine, through the multi-objective linear programming model to optimize the cutting technology, so that it can meet the requirements of users, the loss is minimized.

2. Materials and Methods

This paper used the 2021 national college students' mathematical contest in modeling contest D (https://developer.aliyun.com/article/1167896), data analysis and research.

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3. Model Establishment and Solution

3.1 Basic Model of Continuous Casting Cutting

In order to meet the basic requirements of the cutting machine itself, under normal operation conditions, this paper gives the specific optimal cutting scheme according to the content of "blank length, cutting scheme, cutting loss" and the list. Firstly, the definition of the optimal cutting scheme and related calculation formula are given, then the residual value of the billet is calculated according to the given length data, and the residual value is supplemented by spss software (the residual value of the processed billet is integrated into the residual value), split (the processed part of the billet and the residual value are evenly distributed to the remaining billet), and finally the second cutting is used. A cutting scheme that satisfies the minimum cutting loss and the length of the billet is within the target range of the user (9-10 meters).

3.1.1 Definition of Optimal Cutting Scheme and Relevant Calculation Formula

The optimal cutting scheme means that under the condition of meeting the basic requirements and normal requirements, under the same cutting loss, the cut billet should meet the user's target value or target range as far as possible. [3] According to the above definition, the corresponding calculation formula is given, namely:

The length that passes the first process is, the length that passes the second process is, the length that finally meets the user's goal is, the objective function is, and the scrap length is, then: a_i b_i c_i Z r_i .

$$Z = Min\sum_{i=1}^{n} r_i \tag{1}$$

$$s.t.\begin{cases} 4.8 \le a_i \le 12.6 \\ 8 \le b_i \le 11.6 \\ 9 \le c_i \le 10 \end{cases} \tag{2}$$

$$M = \frac{Z}{9.5} \tag{3}$$

$$r_i = w_i - 10 \tag{4}$$

3.1.2 Calculation of Cutting Loss in the Optimal Cutting Scheme

According to the above steps and operation, and with the help of SPSS software, the cutting loss is calculated, and the cutting scheme of rigid continuous casting is obtained. The specific results are shown in Table 1.

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Table 1. Summary of the final billet treatment scheme

Length of tailstock	Cut the length of the billet at one time	Leftover billet after cutting	Optimization method	The length of the billet after optimization	Scrap billet
13.7	8.9	4.8	Not processing	0	13.7
14.5	1 * 9.5	5	Make up	9.7	4.8
22.7	2 * 9.5	3.5	Finishing	2 * 10	2.7
31.6	3 * 9.5	3.5	Finishing	3 * 10	1.6
42.7	4 * 9.5	4.7	Replenishing	4 * 10	2.7
44.9	4 * 9.5	6.9	Topping up	4 * 10	4.9
52.5	5 * 9.5	5	Make up	5 * 10	2.5
62.7	6 * 9.5	5.7	Fill in	6 * 10	2.7
72	8 * 9	0	Do not process	8 * 9	0
80.9	8 * 9.5	4.9	Fill in	8 * 10	0.9
93.4	9 * 9.5	7.9	Add	* 9.5 + 3 * 6 to 9 + 9.4	0
109	11 * 9.5	4.5	Add	2 * 9.5 + 10 * 9	0

Note: 1. Finish: Add the cut residual value to the length of the first cut, so that all the final billet can pass the first and second processes, and finally meet the monthly standard range, to obtain the scrap steel is bad. 2. Add: Part of the length of the first cut billet is added to the residual billet, so that both of them are within the target range, so that no scrapped steel is damaged. 3. Unit: centimeter.

As can be seen from Table 1, when the length of the billet is 72 meters, the length of the cut billet is all 9 meters, which is optimized without processing. When the length of the billet is 93.4 m and 109 m, the measure of splitting (added in the table) is used for optimization, and the loss of the billet is 0.

3.2 Adjustment of Continuous Casting Cutting Model Considering Crystallization Anomaly

In the case of abnormal crystallizer, in order to meet the needs of target users and ensure the minimum cutting loss, based on the initial cutting plan, adjusted cutting plan, cutting loss, etc., the specific optimal cutting plan at these moments is listed. Firstly, starting from the data of the abnormal time nodes of the crystallizer provided, using the known abnormal time nodes of the crystallizer, through the relevant calculation formula, the optimal cutting scheme of each section including scrap section with the minimum cutting loss and meeting the user's target range is given. Secondly, the MATLAB software is used to input the corresponding solving commands. Finally, the obtained results can be validated by SPSS mentioned in question 1 to ensure the authenticity, feasibility and rationality of the results.

3.2.1 Definition of Scrap Section and Relevant Formulas to Satisfy the Minimum Cutting Loss and User Target Range

Scrap section refers to a section of billet that is located inside the mold and needs to be scrapped when an anomaly occurs in the mold. According to the above definition and analysis, the corresponding calculation methods are given as follows:

$$\frac{X-H-0.8}{9.5}=N......M \tag{5}$$

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$$\frac{M}{0.5} = K \ldots\ldots\ S \tag{6}$$

3.2.2 Calculation of Cutting Loss when Mold is Abnormal

When processing the data, it is necessary to first determine whether to cut off or only give the position mark. Secondly, if this section is to be cut off, a mathematical model should be established to optimize the billet in front of this position according to the optimal length combination, so as to form a new cutting scheme. [4][5] Based on the above analysis, the following conclusions can be drawn:

(1) When N=K, the billet is completely completed without loss;

(2) when N>K, under the condition of K 10m billets, if there is S, it is (n-k)*9.5m billet; If there is no S, the salvage value makes up a section of steel billet, which is 1*(9.5+S) m+(N-K-1)*9.5m billet;

(3) If N<K,(Y-H-0.8)/N is the length of smoothly entering the two processes.

After processing according to the above steps, the optimal cutting side is obtained when the abnormal time node occurs in the mold. The specific results are shown in Table 2.

Table 2. Summary of exception time processing schemes

Crystallizer abnormal time	Initial cutting scheme	Optimized cutting scheme	Cutting loss
0	9.5 * N	(9.5 + 0.8 + 9.5 * N	0.8
45.6	(9.5 + 0.8 + 9.5 * N	(112 + 0.8 + 11.2 * 3	5.6
98.6	(11.2+0.8) +11.2*3	10.44 * 4 + 1124	3
131.5	10.44 * 5	(112 + 0.8) + 10 * 2	2.9
190.8	(11.2+0.8) +10*2	10 * 3 * 3 + 9.5	2.3
233.3	10 * 3 * 3 + 9.5	10.425 + 0.8) + 10.425.3	2.5
266	(10 + 0.8) + 10.425 * 3	10.63 (10.63 + 0.8) + 2	2.7
270.7	(10.63 + 0.8 + 10.63 * 2	(10.63 + 0.8 + 5.5 + 10.63 * 2	5.5
327.9	(10.63 + 0.8 + 10.63 * 2	9.5 * 4 + 9.4	3.2
		Total cutting losses	28.5

Note :1.N Complete billet divided by the number of strips after the user's target value 9.5. 2.(11.2+0.8)+11.2*3 means that there is a section of 11.2+0.8 where 0.8 is the scrap section and there are three sections of 11.2.

According to the above data analysis, when the abnormal node is 131.5m, the initial cutting scheme has no loss, but with the continuous occurrence of abnormal nodes, the cutting scheme is finally adjusted to 2*10m+1*12m, and the cutting loss of this section is 2.9m. After the appearance of the first scrap section, the interval time of the next scrap section is continuously shortened with the cutting of the billet, scrap increases and quality decreases. Therefore, it can be seen that cutting the good billet into normal billet as much as possible (user target) not only meets the production plan, but also reduces the waste of molten steel, which plays a vital role in continuous casting cutting.

3.3 Change the Restriction Conditions to Further Adjust the Basic Model of Continuous Casting Cutting

On the basis of the previous crystal abnormal adjustment, the user's target value and target range are changed. Based on the initial cutting scheme, the adjusted cutting scheme, the cutting loss and other

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contents, the specific optimal cutting scheme of the mold abnormal time node is listed. Therefore, starting from the data of the abnormal time nodes of the crystallizer provided, using the known abnormal time node data, combined with the relevant calculation formula, the optimal cutting scheme with the minimum cutting loss of the billet including scrap section and meeting the user's target range is given.

3.3.1 When the User's Target Value is 8.5m and the Target Range is 8-9m, the Relevant Calculation Process is Given

$$\frac{X-H-0.8}{Q}=N......M \tag{7}$$

$$\frac{M}{0.5}=K\ ......\ S \tag{8}$$

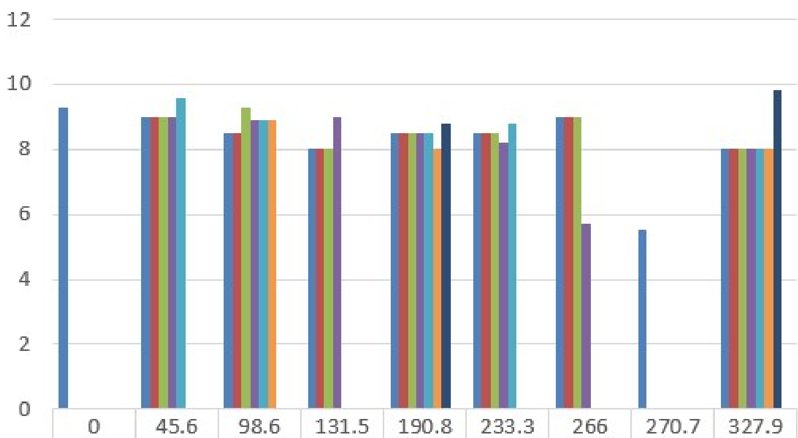
When processing the data, the judgment criteria should be based on: whether to cut off or only to give the position mark; secondly, if this section is to be cut off, the billet in front of this position should be optimized according to the mathematical model set up in question 2, so as to form a new cutting scheme. Based on the above analysis, the following calculation methods are given:

(1) When N=K, the billet is completely completed without loss;

(2) when N>K, under the condition of K billets of 10m, if there is S, the billet of 1*(9 +S) m+(n-K-1)*9m will be replenished; If there is no S, then it is (N-K)*8.5m billet;

(3) If N<K,(X-M-0.8)/N is the length of the billet entering the process (not reaching the user range).

After the above processing, Excel is used to map and analyze the data exported by Mathmtica software, so as to feel the change of cutting scheme more directly. The specific results are shown in Figure 1.



	0	45.6	98.6	131.5	190.8	233.3	266	270.7	327.9
The first section	9.3	9	8.5	8	8.5	8.5	9	5.5	8
The second section		9	8.5	8	8.5	8.5	9		8
The third section		9	9.3	8	8.5	8.5	9		8
The fourth section		9	8.9	9	8.5	8.2	5.7		8
The fifth section		9.6	8.9		8.5	8.8			8
The sixth section			8.9		8				8
The seventh section					8.8				9.8
The eighth section									

Figure 1. User target value 8.5m when mold is abnormal

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3.3.2 Calculation Process when the User Target Value is 11.1m and the Target Range is 10.6~11.6m (ibid.)

$$\frac{X-H-0.8}{Q}=N......M \tag{9}$$

$$\frac{M}{0.5}=K\ ......\ S \tag{10}$$

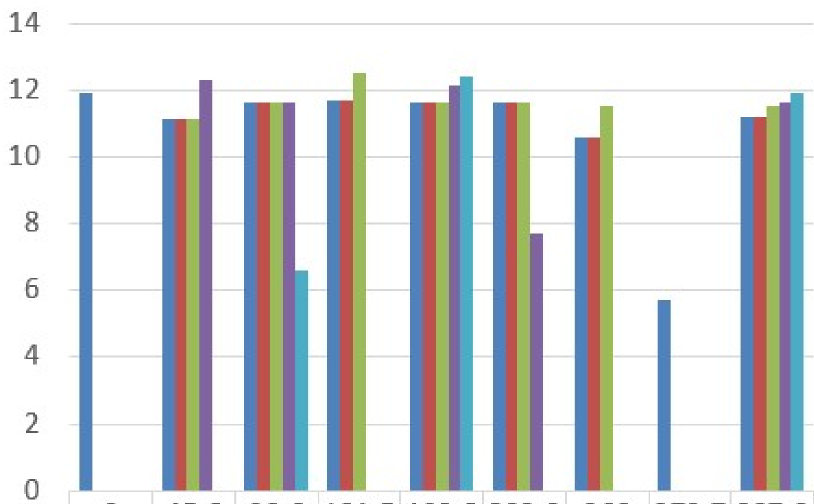
When the data is processed, judge whether to cut off or only give the position mark. If this segment is to be cut off, the billet in front of this position is optimized according to the optimal length combination according to the multi-objective linear programming model, [6][7] so as to form a new cutting scheme. Based on the above analysis, the following calculation methods are given:

(1) When N=K, the billet is completely completed without loss;

(2) when N>K, in the condition of the billet of 11.6*K, if there is S, the billet of 1*(11.6+S) m+(n-k-1)*11.6m will be replenished; If there is no S, then it is (N-K)*10.6m billet;

(3) If N<K,(X-M-0.8)/N is the length of the billet entering the process (not reaching the user range).

After the above processing, the data derived from Mathmtica software is used for graph analysis, so that the change of cutting scheme can be felt more directly. The specific results are shown in Figure 2.



	0	45.6	98.6	131.5	190.8	233.3	266	270.7	327.9
The first section	11.9	11.1	11.6	11.7	11.6	11.6	10.6	5.7	11.2
The second section		11.1	11.6	11.7	11.6	11.6	10.6		11.2
The third section		11.1	11.6	12.5	11.6	11.6	11.5		11.5
The fourth section		12.3	11.6		12.1	7.7			11.6
The fifth section			6.6		12.4				11.9

Figure 2. User target value 11.1m when mold is abnormal

After solving and processing the above data, the optimal cutting scheme is given under the comparison of multiple parties. See Table 3 for details.

Table 3. Summary table of cutting schemes with user target values of 8.5m and 11.1m

The target value is 8.5			
Knot abnormal time	Initial cutting scheme	Optimized cutting scheme	Cutting loss
0	8.5 * N	(0.8 + 8.5 + 8.5 * N	0.8
45.6		9*4+(8.8+08) +8.5*N	0.8
98.6		8.5 * 2 + (8.5 + 0.8 + 8.9 + 8.5 * 3 * N	0.8
131.5		3 * (8.1 + 0.8 + 8.5 * 8 + N	0.8
190.8		8.5 * 5 + (8) + 0.8 + 8.5 * 8 + N	0.8
233.3		3 + 8.2 + 8.5 * (8) + 0.8 + 8.5 * N	0.8
266		9 * 3 + (4.9 + 0.8 + 8.5 * N	5.7
270.7		(0.8 + 3.9 + 0.8 + 8.5 * N	5.5
327.9		6 * 8 + + 8.5 * (8.4 + 08) N	0.8
Total			16.8
The target value is 11.1			
The knot is abnormal	Initial cutting scheme	Optimized cutting scheme	Cutting loss
0	11.1 * N	(11.1 + 0.8 + 11.1 N	0.8
45.6		3 + 11.1 * 11.1 (11.5 + 0.8) + N	0.8
98.6		4 + 11.6 * 11.1 (5.8 + 0.8) + N	6.6
1315		11.7 * 2 + 11.1 (11.7 + 0.8) + N	11
		3 + 12.1 + 11.6 * (11.6 + 0.8 + 11.1 N	13
233.3		3 + 11.6 * 11.1 (6.9 + 0.8) + N	7.7
266		106 * 2 + 11.1 (10.7 + 0.8) + N	0.9
270.7		(0.8 + 3.9 + 0.8 + 11.1 N	5.5
327.9		* 2 + 11.5 + 11.6 + 11.1 + 11.1 (11.1 + 0.8) N	0.8
Total			25.5

According to the above processing measures for abnormal nodes of crystallizer [6] and the optimal cutting scheme given, when the abnormal node data are the same and the target value and target range are different, the smaller the target value and target range, the less residual value distributed to each section, the closer the final billet length is to the target value, and the smaller the cutting loss. Thus, it can be shown that when the user's target value and target range are closer to the length of the billet that can pass the two processes smoothly, the cutting loss is minimum, and it is easier to meet the user's target, so as to reduce the production cost and increase the company's income.

4. Conclusion

When the user's target value is 8.5m and the target range is 8~9m, the cutting loss is less than that when the user's target value is 11.1m and the target range is 10.6~11.6m. In other words, when the user's target value and the target range are closer to the length of the billet that can pass the two processes smoothly, the cutting loss is minimum, thus reducing the production cost and increasing the company's income.

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