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Dynamic Programming and Design of Continuous Casting Cutting based on Graph Theory

Ni Ruan, Gangming Sun*

School of mathematics and information science, Guangxi Institute of Education, Nanning 530023, China

Abstract

The optimization technology of continuous casting cutting is the key to improve the utilization rate of billet. Based on the traditional optimized cutting model and graph theory thought, the dynamic programming model of continuous casting cutting was established according to different trail billet lengths in stop pouring stage, which met different user requirements, with the least billet loss. Matlab software was used to optimize the solution, and the algorithm was simple and intuitive, which has certain guiding significance for the formulation of multi-flow single fixed length and multi-flow multi-fixed length continuous casting cutting scheme.

Keywords

Continuous Caster; Trail Billet Cut; Mould Anomaly; Graph Theory Thought; Dynamic Programming.

1. Introduction

Continuous casting is a production process in which molten steel is converted into billets. Today, with the rapid development of continuous casting cutting technology, people have realized that application of advanced NC cutting and nesting optimization technology is not only the key to ensure the cutting quality of products, but also the key to improve the utilization rate of billets. More and more attention has been paid to the optimization technology of steel cutting. Among them, the trail billet will be produced when the continuous casting stops pouring. If the trail billet is too long and excessive, the yield of billet will be reduced; in addition, in the process of pouring steel, the mold will also produce scrapped billets abnormally, so it is necessary to adjust the cutting scheme immediately. In this paper, combined with the data of Problem D of the 2021 Contemporary Undergraduate Mathematical Contest in Modeling [1], the research on cutting optimization of continuous casting is particularly important. under the background of advocating "resource-saving society".

Graph theory thought as a very mature theory, the author uses vertices to represent logical blocks, and the directed edges between vertices represent the dependencies of logical blocks. Using the relationship presented by directed graphs, dynamic programming and design can be well carried out.

2. Traditional Cutting Optimization

The cutting optimization model aims to monitor the billet cutting operation, change the cutting scheme in real time according to the optimization process, and get the products with target length and target quantity, so as to minimize the scrap of billet. However, the traditional cutting optimization mostly focuses on the conventional production problems such as single-flow single-length, single-flow multi-length, multi-flow single-length and multi-flow multi-length, etc., and the research on the trail billet cutting in the stop-pouring stage and the cutting scheme according to the mould anomaly

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is less involved [2-5].

Currently, there are two main types of cutting optimization technologies [6]: First of all, single-machine single-flow optimal cutting for single or multiple slab length is commonly used in slab continuous casting. Large slab casters imported from China all contain similar technology, but its recursive calculation workload is large, and the actual scrap billet quantity is not well considered, which has certain limitations. Secondly, aiming at multi-machine and multi-flow optimized cutting with a certain length, it is commonly used in imported square billet and round billet casters. There are two popular calculation methods for this kind of technology at present: (1) The algorithm of stopping casting flow sequentially by estimating the remaining time of casting flow. This method is accurate in calculation, but its disadvantage is that it needs to collect the casting speed from the basic stage. If the casting speed fluctuates abnormally, the calculation model will also be affected. (2) The calculation method of judging whether the amount of steel in ladle is a fixed-length multiple, this method has a small amount of calculation, the ladle weight value to be collected will not fluctuate greatly, and it is relatively easy to control. However, the cast billet is not considered in the calculation model, but there are many problems due to its optimization logic, so this method is only suitable for less than four-strand continuous caster [7].

3. Problem Raising

In the process of continuous casting cutting, it is assumed that certain requirements are met: (1) The length of cut billet must be between 4.8 and 12.6m, otherwise it cannot be transported away and hinders production. The acceptable billet length in the next working procedure is 8.0-11.6m. If it is not within this range, the billet can be transported away for secondary off-line cutting, but the cut part is scrapped, resulting in losses. (2) The length of billet should meet the target value as far as possible, and the length within the target range is also acceptable when cutting normally according to the user's requirements. (3) The time for cutting a billet is 3min, and after cutting, the time for returning to the working starting point is 1min. The length of billet from the center of mold to the starting point of cutting machine is 60.0m, and the speed of continuous casting billet is 1.0 m/min. When the mold is abnormal, the length of the scrapped section is 0.8m. (4) The length loss of billet caused by the cutting machine in the cutting process can be ignored.

Problem 1: Assuming that the user target value is 9.5 m and the target range is 9.0-10.0 m, the cutting optimization scheme is worked out for the following trail billet lengths: 109.0, 93.4, 80.9, 72.0, 62.7, 52.5, 44.9, 42.7, 31.6, 22.7, 14.5 and 13.7 (unit: m).

Problem 2: According to the abnormal moments of mold: 0.0, 45.6, 98.6, 131.5, 190.8, 233.3, 266.0, 270.7 and 327.9 (unit: min), (1) when the billet is scrapped for the first time, the cutting scheme of this billet is given; (2) after a new scrapped section appears, give the cutting scheme of the new section billet and the adjustment scheme of the current section billet cutting, or declare that no adjustment will be made. The user target values are 9.5m, 8.5m and 11.1m, and the target ranges are 9.0-10.0m, 8.0-9.0m and 10.6-11.6m, respectively.

4. Establishment of Cutting Optimization Model

4.1 Solution to Problem 1

Because the length of trail billet is related to the amount of residual steel in tundish and other factors when continuous casting stops pouring, we assume that the target range is divided with a step size of 0.1 m. After the first cutting, it does not meet the current target range of users, but the length meets the use of the second cutting, so we start to calculate the loss. Therefore, first of all, according to the user's target requirements and the process requirements of continuous casting cutting line, it is judged whether the existing cutting scheme is optimal. If the loss is large, some staff will modify the scheme until the optimized scheme determines that the generating program executes the cutting task, as shown in Fig.1.

In the cutting scheme, the author uses the tree structure in directed graph D to express the dependency

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relationship between logical blocks. Vertex in the graph represents logical blocks, and Edge between two points represents the dependency relationship between logical blocks. Assuming that any vertex v in Figure D is selected as the initial starting point, then every adjacent vertex w of v is searched from v in turn until all vertices in the figure that have paths with the initial starting point v have been visited, and the final cutting scheme is obtained, as shown in Fig. 2.

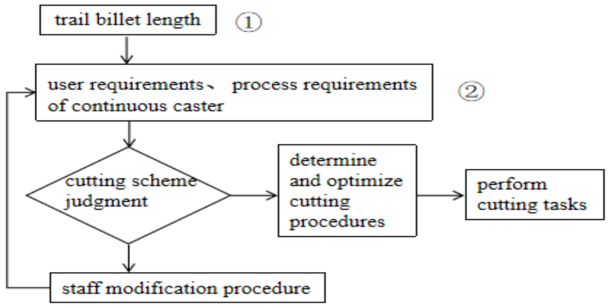

Figure 1. Design model of trail billet cutting process

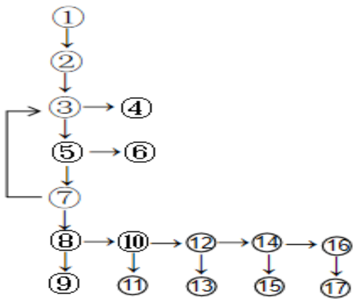

Figure 2. Tree structure of trail billet optimization cutting scheme

Therefore, according to the problem 1, the cutting scheme is discussed in three situations:

Situation 1: When the cutting length is $x_i < 4.8\,\text{m}$ ③, the loss $f(x_i)$ hinders the production, namely the current cutting length does not meet the basic requirement of 4.8-12.6m, and this scheme is not allowed to appear ④.

Situation 2: When the cutting length is $x_i = 4.8\,\text{m}$ ⑤, there is a loss $f(4.8) = 4.8$, namely the current cutting length is 4.8m, and the cutting loss is recorded as 4.8m ⑥.

Situation 3: When the cutting length is $4.8 < x_i \le 12.6\,\text{m}$, ⑦, the target range is 9.0-10.0m because the target value of users is 9.5m, which meets the current cutting consideration range, the following 5 sub-cases are obtained:

(1) When the cutting length $4.8 < x_i < 9.0\,\text{m}$ ⑧, the loss amount $f(x_i) = x_i$,namely the cutting length does not meet the user's target value and is not in the target range, so the cutting loss amount is recorded as $x_i\,\text{m}$ ⑨.

(2) When the cutting length is $9.0 \le x_i < 9.5\,\text{m}$⑩, the loss amount is $f(x_i) = 0$, namely the cutting length does not meet the user's target value and meets the user's target range of 9.0-10.0m, so the cutting loss amount is recorded as 0m. ⑪.

(3) When the cutting length is $x_i = 9.5\,\text{m}$ ⑫, the loss amount $f(x_i) = 0$, namely the cutting length meets the user's target value and target range, so the cutting loss amount is recorded as 0m ⑬, and the billet of 9.5m is cut once.

(4) When the cutting length is $9.5 < x_i \le 10.0\,\text{m}$⑭, the loss amount $f(x_i) = 0$, namely the cutting

length does not meet the user's target value and meets the user's target range 9.0-10.0m, so the cutting loss amount is recorded as 0m ⑮.

(5) When the cutting length $10.0 < x_i \le 12.6$ m⑯, the loss amount $f(x_i) = x_i - 10.0$, namely the cutting length does not meet the user's target value and is not in the target range, but meets the maximum allowable billet transportation value, so the cutting loss amount is $f(x_i) = x_i - 10.0$ m ⑰.

According to the above analysis, a dynamic programming model with the minimum loss as the objective function is established and solved by matlab program:

$$\min \ z = W - \sum_{\substack{i=1,2,\cdots n \\ j=1,2,\cdots \infty}} m_j x_i$$

$$s.t.\begin{cases} 1.m_j \ge 0; \\ 2.x_i = A, \quad f(x_i) = A; \\ 3.A < x_i \le B; \\ (1)A < x_i < l_{\min}, \quad f(x_i) = x_i; \\ (2)l_{\min} \le x_i < TL, \quad f(x_i) = 0; \\ (3)x_i = TL, \quad f(x_i) = 0; \\ (4)TL < x_i \le L_{\max}, \quad f(x_i) = 0; \\ (5)l_{\max} < x_i \le B, \quad f(x_i) = x_i - L_{\max}. \end{cases}$$

Where, z -Billet loss; W -Trail billet length; m_j -Meet the corresponding number of cutting elements in the cutting range; x_i - Meet the cutting length within the target cutting range of the user; A -Minimum allowable cutting length of billet for caster; B -Maximum allowable cutting length of billet for caster; $l_{\min}$ -The lower limit of the user target; $l_{\max}$ -User Goal Upper Limit; TL -User target value.

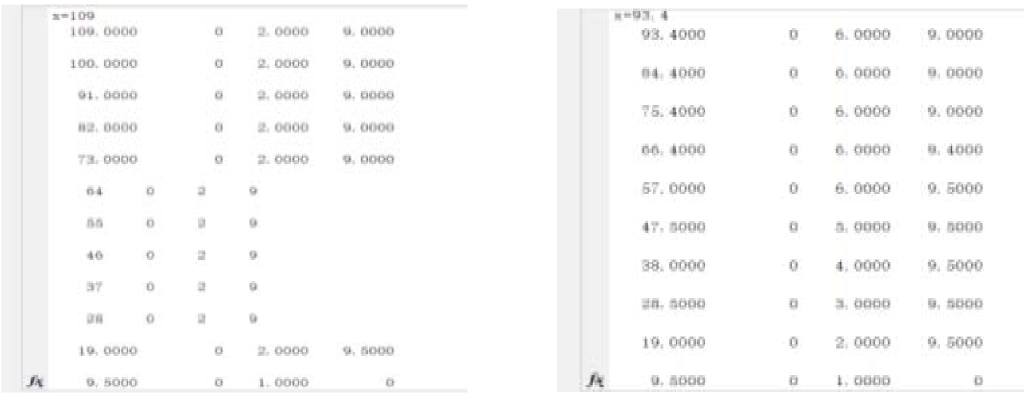

Figure 3. Running results of cutting program with trail billet length of 109m and 93.4m

The cutting operation methods of other trail billet lengths are similar, and the solution results of problem 1 are shown in Table 1.

Table 1. Summary of Cutting Optimization Schemes for Trail Billet

trail billet/m	109.0	93.4	80.9	72.0	62.7	52.5	44.9	42.7	31.6	22.7	14.5	13.7
cutting scheme	9.5m 2pcs、9m 10pcs	9.5m 6pcs、9m 3pcs、9.4m 1pcs	10m 5pcs、10.2m 2pcs、10.5m 1pcs	9m 8pcs	10m 1pcs、10.2m 4pcs、11.9m 1pcs	10m 1pcs、10.2m 3pcs、11.9m 1pcs	10m 1pcs、10.2m 1pcs、12.2m 1pcs、12.5m 1pcs	10m 2pcs、10.2m 1pcs、12.5m 1pcs	10m 1pcs、10.2m 1pcs、14.1m 1pcs	10.2m 1pcs、12.5m 1pcs	4.8m 1pcs、9.7m 1pcs	4.8m 1pcs、8.9m 1pcs
cutting loss/m	0.0	0.0	0.9	0.0	2.7	2.5	4.9	2.7	1.6	2.7	4.8	13.7

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4.2 Solution to Problem 2

According to the conditions given by the problem, the cut billet cannot contain scrapped sections when entering the next working procedure. When the scrapped section of the billet appears, the billet attached with the scrapped section is cut off by a cutting gun first, and then the remaining billet meets the length required by the next working procedure by offline secondary cutting; Other billets entering the next process must also meet the length requirements of the next process. After a new scrapped section appears, the cutting scheme of the new section of the cutting gun gives priority to cutting according to the cutting scheme of the first section. When cutting the scrapped billet, there may be a part between the scrapped section and the scrapped section that does not reach 4.8 ~ 12.6m. At this time, it can be considered to select left or right to make the scrapped section just cut to the end of the scrapped section when cutting.

Considering the user target value of 9.5m, the target range is 9.0-10.0m. When the crystallizer appears abnormal scrap section at 0.0 time, the cutting gun just returns to the working starting point of the continuous casting machine after cutting, and the scrap section is 0.8m. Now, the billet is optimized for cutting accordingly.

(1) When the scrap section of billet appears for the first time, the length of billet in this section is 60.8m. At this time, if the second abnormality of mold in 45.6min is not considered, cutting can be carried out according to the model of problem 1. The result is 10m 6pcs, and the cutting loss is 0.8m, that is, the first scrap section of 0.8m contained in the 60.8m long billet can be put into the next billet for cutting optimization.

(2) When the billet is scrapped for the second time (The abnormal time of mould is 45.6min), see Figure 4 for the billet length.

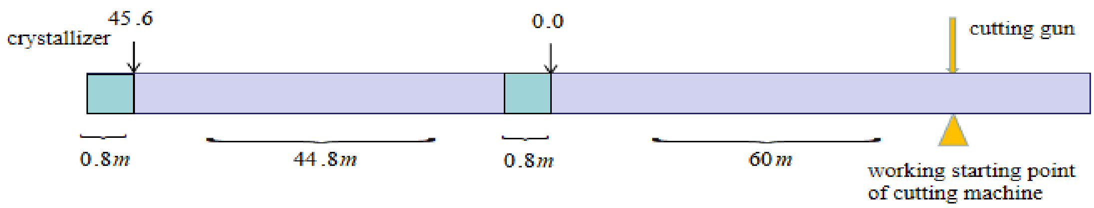

Figure 4. Schematic diagram of scrapped section of billet

At this time, the cutting gun is waiting at the working starting point of the continuous casting cutting machine, And the first section of billet 60.8m has not been cut, Therefore, the current billet cutting scheme is divided into initial scheme and adjusted scheme, if we still insist on cutting the first 0.8 m scrapped section into the second billet at this time, it can be seen from the adjusted cutting scheme (as shown in Table 2) that 4.8m 1pcs and 5.6m 1pcs are cut, and the cutting loss is large, so we can consider not adjusting the current cutting scheme. The cutting length of the new billet is 45.6m, including the scrapped section of 0.8m that appeared for the first time. The cutting scheme is shown in Table 2.

Table 2. Cutting scheme for billet length 60.8 m and 45.6m

billet length	cutting scheme	
	initial	after adjustment
60.8m	10m 4pcs	10m 4pcs 9.6m 1pcs 4.8m 1pcs 5.6m 1pcs
cutting loss/m	0	10.4

billet length	cutting scheme
45.6m	9.5m 1pcs 10m 3pcs 6.1m 1pcs
cutting loss/m	6.1

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According to the user target value of 9.5m, the target range is 9.0-10.0m, The total length of billet is calculated at 0.0, 45.6, 98.6, 131.5, 190.8, 233.3, 266.0, 270.7 and 327.9min when the mould of this continuous casting cutting machine is abnormal. In order to meet the user's requirements and the billet loss is the least, the results displayed by matlab program (see Figure 5) show that the length of billet of continuous casting cutting gun is 5.6, 15.6, 25.6, 35.6, 48.1, 58.1, 68.1, 78.1, 88.1, 98.1, 109.4, 119.4, 129.4, 141.6, 151.6, 161.5, 171.3, 181.1, 193.3, 203.3, 213.3, 223.3, 235.5, 245.5, 255.5 respectively, 265.5, 271.2, 281.4, 291.1, 300.2, 309.3, 318.4, 3285, 337.7, 347.2, 356.7, 366.2, 375.7, 385.2, 394.7, 404.2, 413.7, 423.2 (unit: m) as cutting points. Similarly, when the user target values are 8.5m and 11.1m, and the target ranges are 8.0-9.0m and 10.6-11.6m respectively, the results are summarized in Table 3.

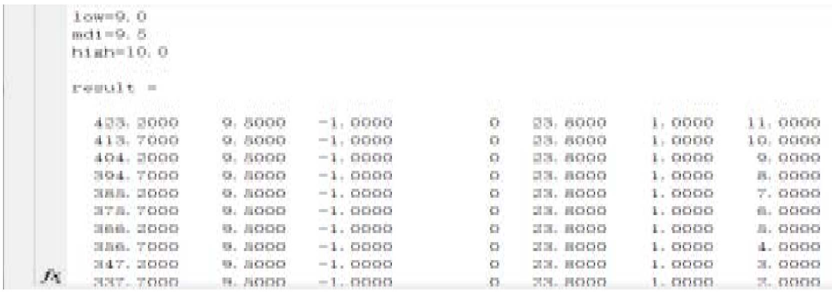

Figure 5. Cutting program running results when the mold is abnormal and the user target is 9.5m

Table 3. Optimized billet cutting scheme when mold is abnormal

	user target value of 9.5m, the target range is 9.0-10.0m	user target value of 8.5m, the target range is 8.0-9.0m	user target value of 11.1m, the target range is 10.6-11.6m
cutting scheme	9.5m 9pcs、9.1m 3pcs、9.2m 1pcs、9.7m 1pcs、9.8m 2pcs、9.9m 1pcs、10m 17pcs、10.1m 1pcs、10.2m 1pcs、11.3m 1pcs 、12.2m 3pcs、12.5m 1pcs、5.6m 1pcs、5.7m 1pcs	8.5m 12pcs、8m 5pcs、8.1m 3pcs、8.2m 3pcs 、8.3m 7pcs、8.7m 6pcs、8.8m 2pcs、9m 8pcs、9.2m 1pcs、9.4m 1pcs、9.5m 1pcs、9.8m 1pcs、5.1m 1pcs、4.9m 1pcs、	11.1m 10pcs、11.2m 1pcs、11.3m 1pcs、11.5m 4pcs、11.6m 8pcs、11.7m 3pcs、11.8m 1pcs、11.9m 1pcs、12.2m 2pcs、12.3m 1pcs、4.8m 2pcs、4.9m 2pcs、5.9m 1pcs、6.9m 1pcs、7.1m 1pcs、10.7m 1pcs、10.9m 1pcs
cutting loss/m	23.8	24	43.7

5. Conclusion

In this paper, based on the traditional cutting optimization model, combined with the idea of graph theory thought, according to the different trail billet length in the stop casting stage, or the analysis of the situation when the mold is abnormal, the dynamic programming model of continuous casting cutting which meets different user requirements and has the least billet loss is established, and the optimization solution is carried out by matlab software. The optimization problem of cutting length controlled by computer in continuous casting production process is solved, and the billet yield is improved. The algorithm has certain reference significance for the formulation of cutting scheme of multi-flow single-length and multi-flow multi-length continuous casting.

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References

[1] Information on http://www.mcm.edu.cn/.

[2] X.B. Wang, X.M. Zhou, L. Liu. Research on cutting length optimization (CLO)system. Mechanical Engineering & Automation, (2007)No.5,p. 4-6.

[3] P.R. Zheng, Continuous steel casting process and equipment. Beijing: Metallurgical Industry Press, 1991.

[4] D.M. Zhang, J.X. Dong, H. Tian. Computer control and optimization for cut length of continuous casting. Science & Technology of Baotou Steel (Group) Corporation, Vol.27(2001)No.3,p.56-58.

[5] D. Sun, H.Z. Qian, C.G. Qiu, H. Liao, P. Zhao. Research on cutting optimization control model of Shuangliu slab caster. Mining and Metallurgy, Vol.24(2015) ,p. 206-209.

[6] L.G. Sun, J.Q. Zhang. Study on the length optimization model for multi-strand bloom casting. Continuous Casting, Vol.3(2008), p.5-8.

[7] W.C. Pang, S.L. Chen. Optimizing Cut-length of Trail Billet Module Design. Research Studies On Foundry Equipment, (2005)No.2,p.14-16.