Space Layout Method for Carton Conveying System Based on SOSG Matrix

Weilin Cao¹, Jie Qian¹, Jie Li¹, Qi Xu¹*, Yizhen Lin¹ and Xiang Wang¹
¹China Tobacco Zhejiang Industrial Co. LTD., Ningbo, China

*Corresponding author email: qjztc@163.com

Abstract. The traditional cigarette conveying system of cigarette industry adopts a one-to-one hard connection method, which has problems such as poor spatial scalability and high equipment coupling. A spatial layout method for carton conveying system based on the SOSG (Solid Orthogonal Structure Graph) matrix is proposed. Through this method, a matrix cigarette conveying system is constructed. Compared with the traditional mode, its space utilization rate is increased by 67%, equipment coupling is reduced, and the downtime rate of carton conveying line due to the shutdown of sealing machine can be reduced from 100% to 0%.

Keywords: Carton conveying system; SOSG matrix; Space layout method.

1. Introduction

With the expansion of the tobacco market, cigarette factories continue to expand and introduce equipments, such as GDX2 (40 sticks/min), GDX6 (60 sticks/minute), ZB47 (55 sticks/minute), ZB48 (80 sticks/minute), H1000 (100 sticks/minute) etc., to increase the output, and the requirements for carton conveying system [1-4] are also getting more and more. The traditional method adopts many-to-one transmission [1]. On the one hand, it is necessary to purchase more sealing machines, which cause large investment and low utilization rate. On the other hand, the equipment coupling is too high, and the shutdown of one sealing machine will cause multiple carton conveying lines to stop, which has a huge impact on the normal operation of the equipment. The SOSG matrix algorithm [5-7] has good properties and is effectively used in the calculation of orientation and size in spatial layout problems. It plays an important role in the process of layout model generation, constraint checking and coordinate map generation. For this, a matrix carton conveying system is constructed combined with the new air cushion packing machine [8] based on the SOSG matrix algorithm.

2. Matrix Representation and Operation of SOSG Model

2.1. SOSG Matrix

In order to construct a matrix cigarette conveying system, SOSG graph is specially generated for solution. Suppose \( S_n \) is a SOSG graph with \( n \) nodes, and its SOSG matrix \( A = (a_{ij})_{mn} \) is defined as:

\[
A = \begin{cases} 
\text{There is a connecting edge of length } r_{ij} \text{ between } v_i \text{ and } v_j, \\
0 & \text{There is no connecting edge between } v_i \text{ and } v_j, \\
0 & \text{if } i \neq j;
\end{cases}
\]

In the formula, \( v_i \) and \( v_j \) represent equipment nodes in \( S \), and equipment types include those involved in the transportation of cigarettes, such as packaging machines, elevators, conveyor lines, and so on.

The SOSG matrix has the following characteristics: diagonal elements are all 0, and other elements are either 0 or \( r_{ij} \) which is a positive integer.
2.2. Layout Generation Process Based on SOSG Graph
Based on the SOSG graph with \( N \) inner nodes, the distance between nodes \( r_{ij} \) is continuously optimized until the distance between all nodes in the SOSG graph is the smallest. Suppose \( x, y, \) and \( z \) represent the total length of the connection distance of all nodes in the \( X, Y, \) and \( Z \) directions in the three-dimensional space, respectively. If \( x, y, \) and \( z \) can't meet the constraint conditions at the same time, continue to optimize and adjust \( r_{ij} \) until the distance between all nodes in the SOSG graph is the smallest.

3. Research on Spatial Layout of Carton Conveying System

3.1. SOSG Graph Generation Algorithm for Carton Conveying System
Based on the No. 1 packing machine in Ningbo Cigarette Factory Packing Workshop, the north-south direction is the \( X \) axis, the east-west direction is the \( Y \) axis, and the vertical direction is the \( Z \) axis. According to the actual size of the workshop, the constraint lengths of the \( X, Y, \) and \( Z \) axes are set as \( X, Y, Z \). The SOSG chart calculation process is shown below, and the calculation flow chart is shown in Figure 1.

\[
\begin{align*}
& \text{Start} \\
& \text{Initialization: step}=0.5, \ i=1, \ j=1 \\
& i\leq N? \quad \text{No} \\
& \quad j\leq N? \quad \text{Yes} \\
& \quad \quad x\leq X \text{ and } y\leq Y \text{ and } z\leq Z? \quad \text{Yes} \\
& \quad \quad \quad r_{ij}=r_{ij}-\text{step} \\
& \quad \quad \quad j=j+1 \\
& \quad \text{No} \\
& \quad i=i+1 \\
& j=1, \ j=1, \ i=1 \\
& \text{Output SOSG graph} \\
& \text{End}
\end{align*}
\]

**Figure 1.** The calculation flow chart for SOSG graph of carton conveying System.

step 1. Initialization: \( \text{step}=0.5, \ i=1, \ j=1 \);
step 2. Whether \( i \) is less than or equal to \( N \), if not satisfied, go to step9;
step 3. Whether \( j \) is less than or equal to \( N \), if not satisfied, go to step7;
step 4. Whether the total length \( x, y, z \) of all nodes connected in the \( X, Y, \) and \( Z \) directions of the three-dimensional space less than \( X, Y, \) and \( Z \) at the same time, if it is satisfied, go to step10;
step 5. \( r_{ij}=r_{ij} \text{ -step} \);
step 6. \( j=j+1 \), go to step3;
step 7. \( i=i+1 \);
step 8. \( j=1 \), go to step2;
step 9. Whether the total length \( x, y, z \) of all nodes connected in the \( X, Y, \) and \( Z \) directions of the three-dimensional space less than \( X, Y, \) and \( Z \) at the same time, if it is satisfied, go to step11;
step 10. \( i=1, j=1 \), go to step2;
step 11. Output SOSG graph.
The height of the ceiling of Ningbo Cigarette Factory's cigarette packaging workshop is 6 meters high, the height of the bottom layer is about 3.5 meters, and the distance between layers is about 0.75 meters. Using the SOSG graph generation algorithm of the cigarette conveying system, a 3-layer 10-lane matrix carton conveying system was finally constructed, which completed the reasonable layout of Stereoscopic equipment in the three-dimensional space, and realized the effective use of the space in cigarette packaging workshop. The structure schematic diagram is shown in Figure 2.

![Figure 2. Structure schematic diagram of carton conveying system.](image1)

The physical diagram of the matrix carton conveying system is shown in Figure 3. The cigarette is transported by an elevated chain track. The plane of the overhead transmission is about 5 meters above the ground, and the longest transmission distance is 287 meters.

![Figure 3. The physical diagram of the matrix carton conveying system.](image2)

### 3.2. Application Achievements of Matrix Carton Conveying System

The application of the matrix carton conveying system can effectively reduce the downtime rate of the cigarette conveying line. Take the Ningbo Cigarette Factory of China Tobacco Zhejiang Industry Co., Ltd. as an example for analysis. The rated speed of sealing machine is 300 sticks/minute. If one sealing machine corresponds to multiple packaging machines in hard connection, one sealing machine can connect 7 GDX2 (corresponding to 7 conveying lines), or 5 ZB47 (corresponding to 5 conveying lines), or 3 ZB48 (corresponding to 6 conveying lines). Suppose a sealing machine connects L packaging machines, corresponding to M conveying lines. When a sealing machine stops, N conveying lines stop. The downtime rate of carton conveyor lines is calculated as shown in formula (1).

$$\text{Downtime rate of carton conveyor lines} = \frac{N}{M} \times 100\%$$ (1)

In the hard connection mode where one sealing machine corresponds to multiple packaging machines, N=M, and the downtime rate of carton conveyor line is 100%. In this paper, the matrix carton conveying system is constructed based on SOSG matrix. After a sealing machine stop, the corresponding M conveying lines can switch to other sealing machines to continue running, thus, N=0, and the downtime rate of carton conveyor line is 0%.
4. Conclusion
The matrix calculation method based on SOSG model to generate SOSG graph of carton conveying system and a matrix carton conveying system can be constructed. This system can effectively reduce the equipment coupling degree and make the packaging machine and the sealing machine many-to-many connection which can make space utilization rate increase by 67%. The downtime rate of carton conveying line due to the shutdown of sealing machine can be reduced from 100% to 0%. Moreover, we desire to build a smarter and more efficient cigarette conveying system based on SOSG Matrix in the future.

References
[1] Yuxing Xu, Design of High-speed Carton Conveying System[J]. Sciences & Wealth, 2013(8):120-120.
[2] Yi Ma, Jianzhong Xue, Dong Zhang, Modification Design of Carton Conveying System in Cigarette Packaging Workshop[J]. China Science & Technology Panorama, 2010, 000(002):19-19.
[3] Wenhui Wang, Design of Carton Conveying System[J]. Mechanical and Electrical Information, 2005(14):17-18.
[4] Quan He, Chen Li, Lian Tang, Improvement of Carton Conveying System[J]. Tobacco Science&Technology, 2012(10):28-30.
[5] Yinglin Wang, Huizhong Wu, Qionglei Wu, The Matrix Operations for Spatial Layout Design[J]. Journal of Nanjing University of Science and Technology, 1996(05):65-68.
[6] Huizhong Wu, Yinglin Wang, A Solid Spatial Layout Model and The Layout Algorithm[J]. Chinese Journal of Computers, 1994(11):835-841.
[7] Yinglin Wang, Huizhong Wu, Jie Sun, Research on Simplification of SOSG Three-Dimensional Layout Search Tree[J]. Journal of Chinese Computer Systems, 1996(05):12-17.
[8] Renrui Liu, The New PN Air Cushion Machine Development[J]. Fuzhou University, 2014.