Research on Packaging Optimization in Customized Panel Furniture Enterprises

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Various information systems have been implemented in most of the customized panel furniture companies in China, resulting in increased production difficulty and informational isolation. Enterprises need to adopt more systematic, scientific, and information-based methods to guide the production on the shop floor. Packaging optimization is important because it promotes sustainable development in furniture enterprise. Through the examination of the packaging process in customized panel furniture companies, this study investigated the bottleneck problems of the packaging process, which are predominantly focused on the calculation of the optimal packaging scheme and the upgrade of information systems. After exploring the theories and methods to solve the existing bottleneck problems, the heuristic algorithm was applied to obtain the optimal packaging schemes and complete the upgrade of packaging process information system. Based on the intelligent packaging software in company A, the Taguchi method was applied to find the best optimization parameters, which was proven effective in comparison with the original packaging solution. The number of packaging was decreased by 3.0%, and the amount of packaging corrugated paper decreased by 12.4. The packaging efficiency represented by the total packaging time showed a significant improvement despite the unit packaging time having increased by 2.0%.

Keywords: Panel furniture enterprise; Packaging optimization; Heuristic algorithm; Informatization; Taguchi method; Stopwatch research method

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INTRODUCTION

With the development of information technology and the continuous reduction of the threshold of information systems, various types of information systems are gradually being adopted by furniture manufacturing enterprises (Ratnasingam *et al*. 2019; Xiong *et al*. 2020). Under the background of the development of "Internet+", "Industry 4.0" and "Made in China 2025", industrialization and informatization are gradually merging (Ray *et al*. 2017; Ratnasingam *et al*. 2020). However, this practice can lead to increased production difficulty, informational isolation, and process barriers (Yang *et al*. 2013). Packaging optimization can effectively promote the sustainable development of enterprises. Optimizing packaging can improve product quality, reduce the proportion of fillers, save packaging and transportation costs, reduce warehouse storage space, and reduce the number of times of transportation.

Packaging optimization can be carried out from the aspects of packaging material, packaging structure, packaging operation method, packaging algorithm, *etc*.

Guo *et al*. (2015) used an aqueous mixture of corn starch, straw fiber, and foaming agent to prepare a biomass cushion packaging material in a heated mould. The optimal forming parameters were obtained through experiments. After comparing with the mechanical performance of expanded polyethylene and expanded polystyrene, it was concluded that biomass cushion packaging materials can replace current packaging materials.

Pan *et al*. (2014) used ANSYS software to simulate the phone packaging box. By calculating the force distributions of the packaging box and optimizing the structure, the optimal buffer structure was obtained. After comparing the theoretical simulation results with the measured results, it was concluded that the simulation experiment has certain guiding significance.

In the furniture manufacturing industries, there are some risk factors in the packaging process that may lead to work-related diseases. Colim, *etc*. conducted investigations and evaluations from the perspective of ergonomics. It was concluded that the use of robot aids equipment can help reduce the probability of disease (Colim *et al.* 2020).

Chen *et al.* (2013) solved the problem that some small rectangles needed to be packed into a fixed rectangular object by developing a rectangular layer-packing algorithm (RLPA) combined with modified genetic algorithm (GA) or particle swarm optimization (PSO) algorithm. Through the experiments, the effectiveness of the improved algorithm was verified.

In this paper, the problems and solutions of the panel furniture companies were explored. The solutions were applied to Company A. The packaging optimization was accomplished by using intelligent packaging software, and the Taguchi method was applied to find the best optimization parameters. After verification and evaluation, it was concluded that Company A had successfully completed packaging optimization. Finally, the theory and method suitable for solving the bottleneck problems of packaging optimization in general panel furniture enterprises were summarized.

Problems

The packaging process is the last step in the production process of panel furniture, which is largely occupied with the packing of the finished panels in accordance with certain rules to ensure that the panels can be safely delivered to customers without damage. The packaging rules are the experience summarization of a company to guide the packaging workers in a simple operation. Lacking scientific and effective information to guide the operation, the packaging process usually depends on manual operation. The consequence is the inferior informatization level of the packaging process or even complete separation of the existing information system of the enterprise. The calculation of the optimal packaging scheme and the informatization upgrading of the packaging process have become the bottleneck of the packaging process in panel furniture companies (Nicola 2010; Schaefe *et al*. 2018).

Packaging scheme

Manual packaging is commonly used in most panel furniture enterprises. A small number of enterprises have stand-alone equipment such as paper cutters and sealing machines. Just a few enterprises have automatic packaging lines (Jin *et al*. 2016). The main business of panel furniture companies is customized services, resulting in different sizes of panel parts, so it is impossible to form a unified paradigm of packaging.

A packaging scheme refers to the overall scheme design to guide the packaging operation according to the size and type of the product. At present, most enterprises formulate corresponding packaging rules based on their product processing routes, panel size, panel name, panel type, and workers personal packaging experience, which makes the quality of packaging in aspects of quantity, weight, filling rate, *etc*. completely determined by the worker's operation and raising uncertainty (Denni *et al*. 2011).

The rule-based software has been adopted to automatically calculate the packaging scheme, so that the packaging workers can obtain subcontracting information automatically and perform the packaging operation according to the packaging scheme. More importantly, furniture enterprises can achieve effective guidance on packaging operations and greatly reduce their dependence on workers. Unfortunately, the proprietary software is far from operating at its proper capacity. For example, most companies can set only simple rules, such as maximum package weight, maximum package height, *etc*. The relatively simple packaging solution generated is hardly the optimal solution, not to mention reducing the number of packaging, packaging materials and fillers, and saving transportation costs (Popa *et al*. 2015).

Packaging Information

Packaging information is composed of subcontracting information, packaging weight, packaging height, number of panels in the package, and placement position of panels in the package. Such data are generated according to the packaging scheme formulated by the size, process route, product characteristics, production line layout, *etc*. At the moment, most companies only can handle basic packaging information about the number of panels in the package and the total weight of the package.

With the continuous introduction and updating of automatic packaging equipment such as manipulators, paper cutters, box sealing machines, *etc*., more packaging information is required. It is necessary to know the size of the package, the location of the panels in the package, and the weight of the package in advance. Therefore, to achieve the guidance of the packaging operation effectively, enterprises must first formulate a reasonable and easy-to-maintain packaging scheme, which is capable of breaking the informational isolation and enabling the packaging information to integrate with the entire information system (Liu and Li 2015).

The bottleneck of the packaging process is the calculation of the optimal packaging scheme and the informatization upgrading of the packaging process. There are relatively few studies on the optimal packaging of panel furniture companies, and the packaging methods with complete information source and concise packaging instructions on the production site are relatively insufficient. To thoroughly solve the bottleneck problem of the packaging process, the optimization of packaging must be conducted from the very beginning by refining the optimal packaging scheme and upgrading the information of the packaging process.

Optimal Packaging Solution

The calculation of the optimal packaging scheme is a typical NP-hard problem. Because the NP-hard problem is very complex and has great application value, it has become the focus of research in today's academia. Constructive heuristic algorithm is a commonly used method to solve the packing problem. This section will study the algorithm of the optimal packaging scheme based on the constructive heuristic algorithm (Nguyen and Kim 2013).

Constructive heuristic algorithm

A constructive heuristic algorithm is a constructed algorithm based on manual loading experience. The algorithm is highly targeted, so the calculation efficiency of the algorithm is very high. The quality of the algorithm depends on the design of the loading strategy. The person who designs the algorithm must be very familiar with the problem to be solved. Through constructive heuristic algorithms, it is often possible to obtain a more reasonable loading scheme than manual loading. However, if the loading strategy is unreasonably obtained, the results may not be satisfactory. Therefore, in the actual construction of the packaging algorithm, it is necessary to continuously optimize the loading strategy based on experience (Yang 2016; Feng *et al*. 2005).

George and Robinson (2015) introduced the concept of "layers" in the packing problem, that is, loading one layer at a time along one side of the loading box during the packing process. When loading in each layer, it is loaded according to the rules established in advance, and the three-dimensional packing is converted into two-dimensional packing through the layer loading method, which effectively reduces the packing complexity (Alvelos *et al*. 2009). Because the thickness of the parts of the panel furniture is mostly uniform, when designing the algorithm, the concept of layers can be introduced to reduce the complexity of the algorithm.

Algorithm design

The design of the algorithm must be carried out on the basis of satisfying the constraints of packing (Mayer *et al*. 2020). The following constraints should be met during the packing of the panel:

- Order constraint, during the packing process, the single order should be used as the dimension for packing.
- Panel type constraints, different types of panels should be packed according to different packing rules according to the actual situation of the enterprise itself.
- The size of the bottom layer is constrained. The lowest panel in the box must be a single panel, and it should be the largest panel in a single package.
- The direction in which the panels are placed is constrained. When the items are placed, their sides should be parallel to the packaging box.
- The weight of the loading box is constrained, where the total weight of the panels in the loading box cannot exceed the maximum load set by the loading box.
- The height of the panels in the loading box is restricted, where the total height of the panels in the loading box cannot exceed the height limit.

An excellent loading strategy can greatly increase the calculation efficiency of the algorithm, which makes it easier to obtain a better loading scheme (Wang 2019). For the packing of panel furniture, the following loading strategies are summarized:

- Sort the panels by the weight, where the heavier panel will be placed first. The weight of the panel is proportional to the volume, and the heavier one is also larger, which is suitable for being placed at the bottom. If the smaller panel is placed underneath, it is not conducive to stabilizing the center of gravity of the package, nor to the managing reasonably of fragmented space.
- Place the panel in the order first at a corner of the loading box space. According to the Cartesian three-dimensional coordinate system, load the starting angle to select the coordinate origin.
- Take the largest bottom panel in the package as the reference panel, find the ratio of the panel to be loaded and the reference panel, sort these ratios, and then find the

panels with the ratio of 1.0 or close to 1.0 to combine them. If the new panel meets the loading constraints, keep the new panel for subsequent loading, otherwise discard it. In this way, small-sized panels can be spliced at the same level, reducing the number of packages.

● When selecting panels for loading, try to avoid the occurrence of fragmentary space after loading, and select panels that make the remaining space neat for loading.

● When placing the panel, there are two placement methods, namely, the long side of the panel is placed parallel to the long side of the loading box and the long side of the panel is placed parallel to the short side of the loading box.

● When the initial remaining space is quite large, the division of the remaining space cannot be avoided by loading another panel, so try to choose a larger panel for loading.

Panel packing steps

The workflow of packing the panels based on structural heuristic algorithm is shown in Fig. 1. This workflow is a processing process that is applicable to one order and one rule. Other orders and rule processing processes can refer to this workflow.

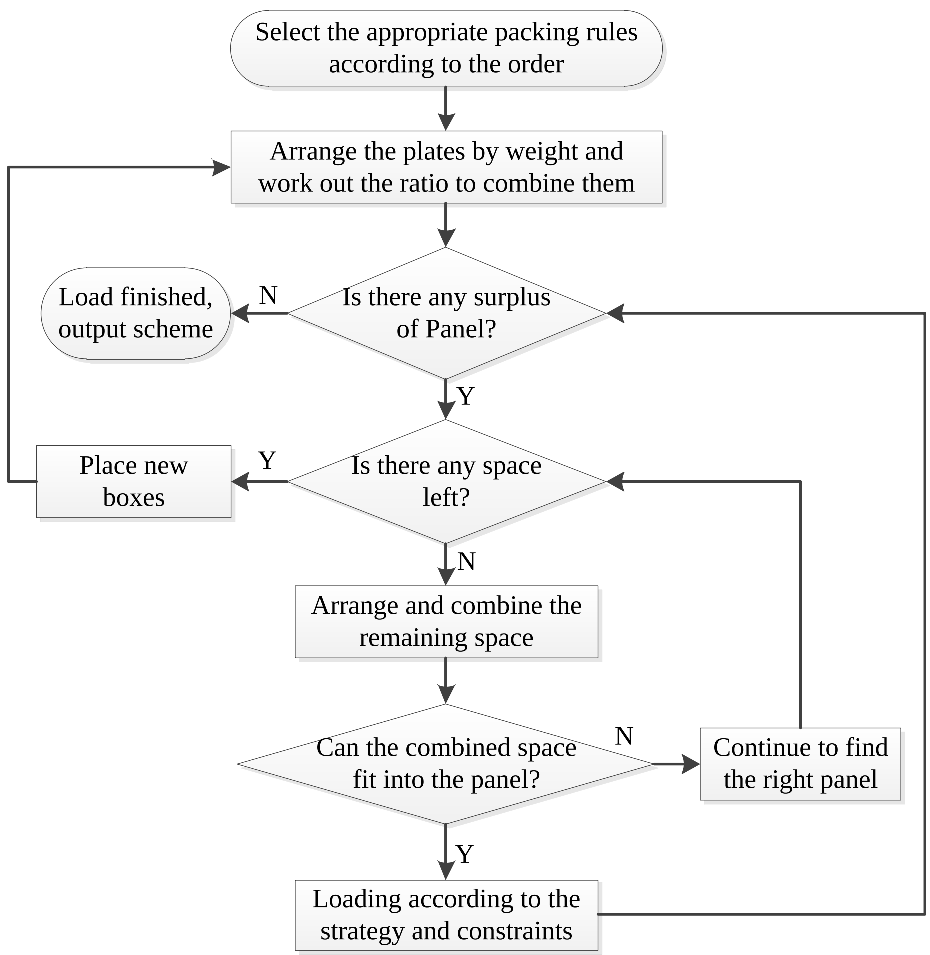

Fig. 1. Constructive heuristic algorithm flowchart

The constraints and strategies of heuristic algorithm are constructed based on manual packing experience, which can solve the problem of the onboard packing of furniture and optimize the results of panel packing to a certain extent. But this algorithm has certain disadvantages. The algorithm is designed under the assumption that the thickness of the panel is consistent, and it is only suitable for packaging schemes with the same thickness. Moreover, the area utilization rate is not considered in the constraints, which may result in a low area utilization rate of a certain layer. In the loading strategies, the panels were combined and loaded according to the ratio, but the specific lower limit of the ratio was not given, which needs to be determined according to the specific situation. The calculation of the optimal packaging scheme focuses on improving the cubic utilization rate of packaging, reducing the use of packaging materials and fillers, and thereby reducing the packaging and transportation costs of products, which is of great significance to the rapid development of furniture industry.

Informatization Upgrading Solution

The bottleneck problem in the informatization upgrading of the packaging process lies in the disconnectedness between the packaging information calculated by the packaging scheme and the production equipment, which results in over depending on the experience of the packers.

The calculation of packaging schemes is closely bound up with the upgrade of information technology. The scientific packaging scheme depends on the source of information, and the perfect information system is the guarantee for the implementation of the optimal packaging scheme. In order to achieve the informatization upgrading, the calculated packaging information needs to be able to connect with the existing information system of the enterprise, where the data can be transmitted through Web Service or intermediate database. The packaging information, with more details in packaging size, filler size, and weight for manual packaging, can be transmitted to the automatic sorting line and automatic packaging line. Only by implementing the informatization upgrading is it possible to better achieve the packaging optimization in panel furniture enterprises.

EXPERIMENTAL

Company A mainly engaged in customized panel furniture production. The optimization and upgrading of the packaging process of company A were conducted with an aim to improve the competitiveness and achieve sustainable development of enterprises. Due to the imperfect informatization in its packaging process, only simple subcontracting information was applied to guide the sorting operation. The bottleneck problem of its packaging optimization lay in the inability to automatically calculate the packaging schemes based on existing process routes and packaging rules, bringing the automatic packaging lines cannot obtain packaging information.

Company A designed new packaging rules based on the existing process routes, and issued the rule amendments by upgrading the company's existing order splitting software - Easym, which can automatically calculate the packaging schemes. However, the packaging schemes of Company A can only subcontract according to the name of the panels on the basis of limiting the weight of the packages and the number of the panels. Unreasonable packaging such as super high and overweight often occurred. Moreover, the packaging information could not be automatically transmitted to the automatic packaging equipment, and it needed to be uploaded manually by personnel.

To resolve the issue, the intelligent packaging software-IPACK software was introduced to company A. The software not only can calculate different schemes according to the existing process routes and packaging rules of the enterprise, and automatically check whether the packaging is reasonable, but also it can be seamlessly connected with the existing information system of the enterprise, which can provide data sources for automatic packaging equipment and provide accurate packaging guidance for on-site production (Bambura *et al*. 2020).

IPACK Software

IPACK software is a kind of intelligent packaging software tailored to the panel furniture industry, which was developed by Guangzhou Liansi Software Technology Co., Ltd. The software can access the existing bill of materials of the furniture enterprise, pre-calculate the packaging scheme of the panel according to the predefined packaging rules, and automatically generate the packing list. More importantly, the IPACK can be connected to the enterprise's ERP system, MES system, automatic sorting line and automatic packaging line.

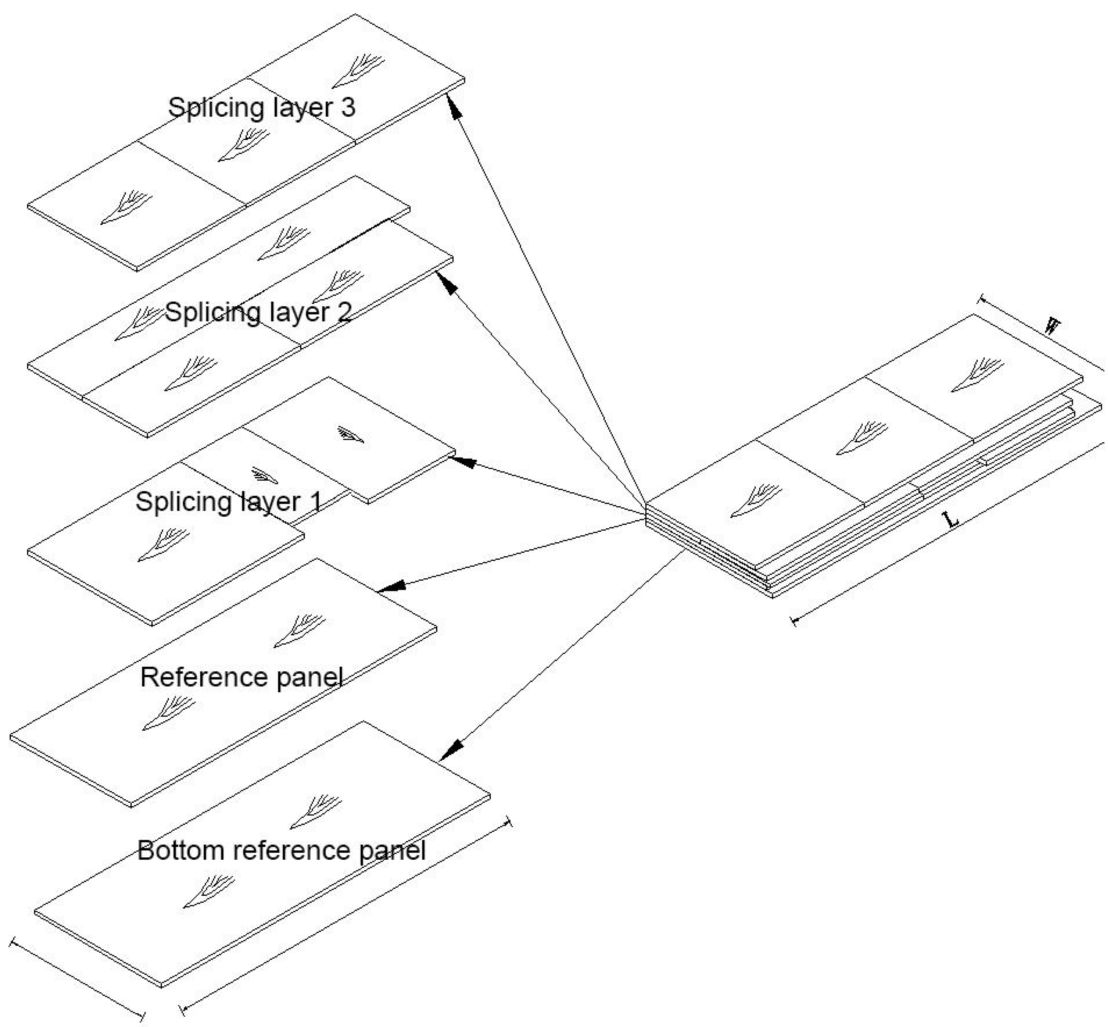

Fig. 2. Splicing diagram

Based on the constructive heuristic algorithm, a packaging scheme, entitled cabinet panel splicing rule, was generated by IPACK software. The principle of cabinet panel splicing is to find qualified panels according to the packing process based on the loading strategy based on the constraints. The next step is to find a larger panel among these panels as the bottom reference panel. Then one uses the layer-by-layer stacking of panels to form the package and finally find the best solution through software calculation (Fig. 2). The splicing rules can be configured in aspects of packaging, load-bearing layer, splicing layer, top layer and merge (Table 1).

Table 1. Main Points of Splicing Rules

Grouping	Main points of splicing rules
Packing	Packaging parameters control the maximum weight, maximum height and maximum number of layers of a single package
Load-bearing layer	The load-bearing layer is one or two layers at the bottom, which can be configured by the minimum height. The load-bearing layer must be a single piece, which serves as a backing panel for load-bearing support. Allow stitching in the width direction
Splicing layer	The splicing layer is the middle layer. The splicing layer can set the maximum number of layers and the maximum percentage of gaps, and can also set the maximum overflow
Top layer	The top layer can be set with the maximum percentage of gaps, and can also choose whether to allow different thickness of panels to be packed
Merge	Merge can set the maximum package weight, maximum height, maximum number of layers, the maximum number of splicing layers, the maximum percentage of gaps in the splicing layer and the maximum percentage of gaps in the top layer

The setting value of each parameter in the parameter setting can be further refined. The conditions for merging are controlled by merge rules. Depending on the weight of the package or the number of panels, the method of merging can be chosen, and limit the maximum package weight and other parameters by the merging function in the parameter settings to ensure that its total weight is within the control range (Figs. 3 and 4).

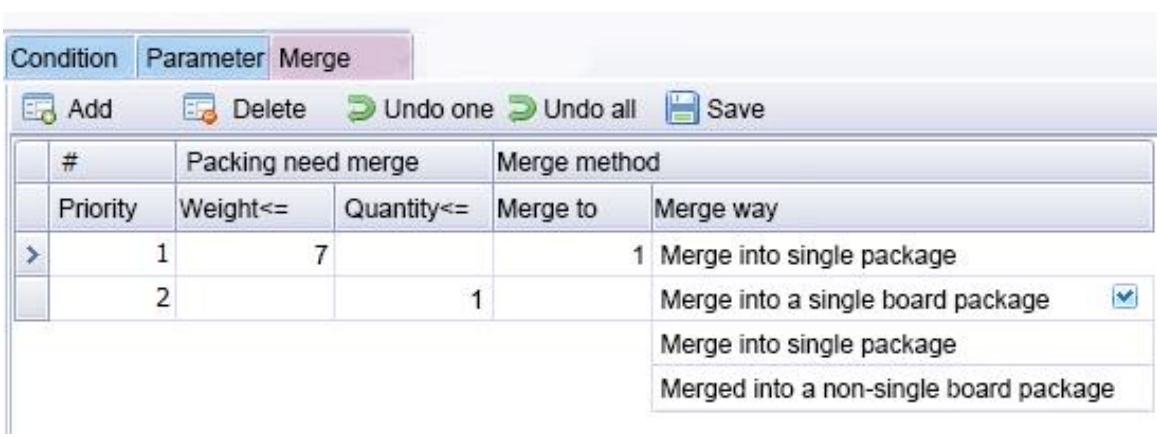

Fig. 3. Parameter setting of merge rules

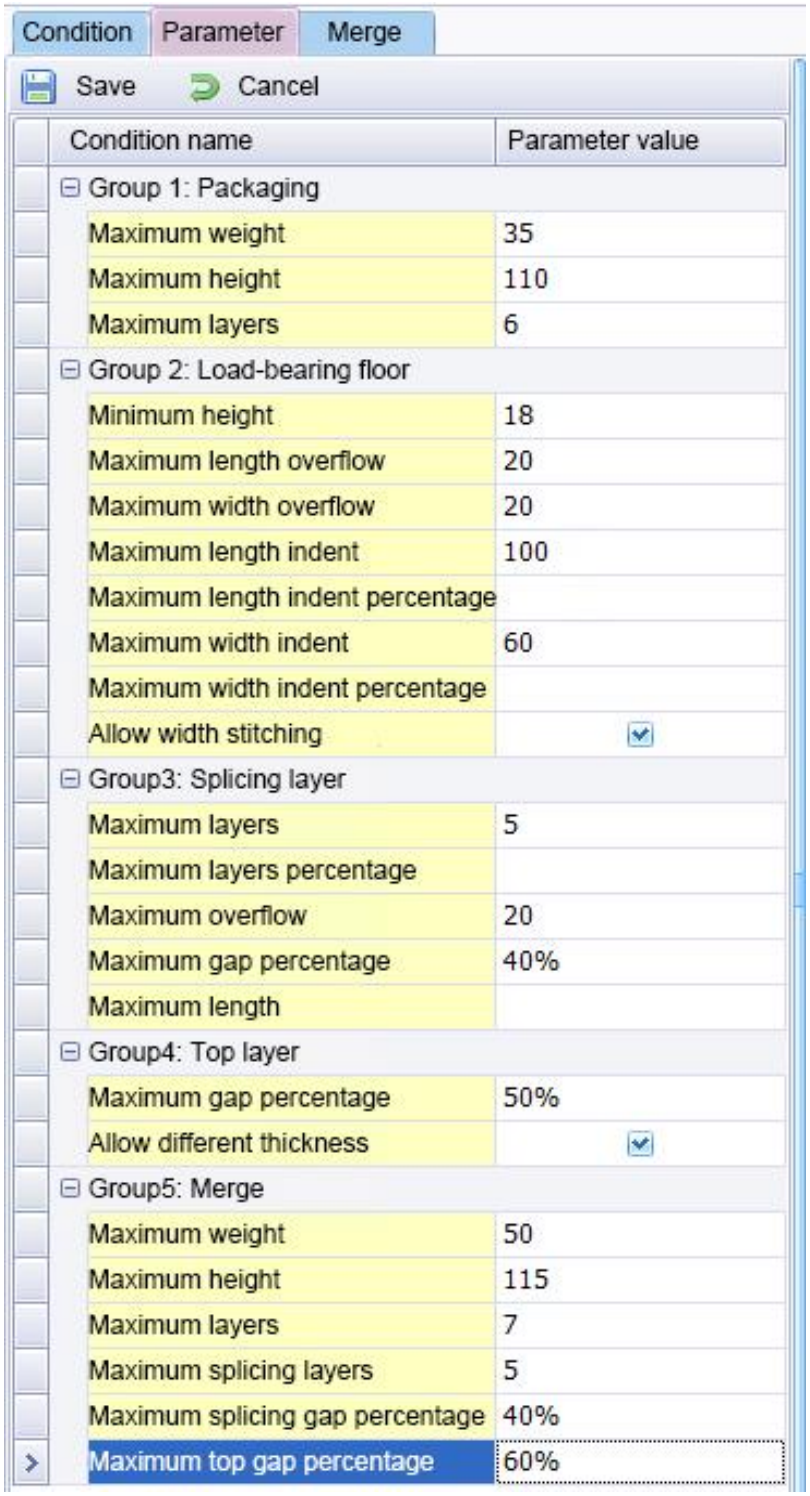

Fig. 4. Parameter setting of splicing rules

Another commonly used rule in IPACK software is mixed package. The principle of the mixed package rule for cabinet panels is to find the panels that meet the conditions in the packing list through the condition setting, which the parameters can be determined by the maximum weight of the single package, the maximum number of the single package, the maximum length difference, and the maximum width difference. The mixed package of panels and parts can also be combined through the merger rules to meet the qualified packaging.

Optimization Scheme

The panel splicing and mixed package in IPACK software are the two main packaging rules adopted in company A's packaging optimization. Panel splicing rules are mainly used for cabinet body panel splicing, which uses the three conditions of weight, height and number of layers to limit. Panel mixed packaging is mainly used for small pieces, strips and backboard packaging. After the calculation is completed, the software will automatically generate the completed packaging schemes and transfer the data to the enterprise's MES system through the SQL database, which realizes the connection with the enterprise's existing information system.

By introducing IPACK software and restricting the use of packaging rules, company A solved the problem of non-automated calculation in the packaging solution. At the same time, the informatization upgrading in company A is realized by connecting the IPACK software to the existing database of the enterprise, which can transmit data to the equipment and guide the work of the workers at the production site.

Best Optimization Parameters

The reduction in the number of packages directly means the reduction of logistics costs, while the increase in the volume ratio directly means the reduction of the fillers in the packages. These two points have a greater impact on the economic benefits of enterprises in the packaging process (Zhang 2011). The goal of this optimization experiment is to achieve the least number of packages after optimization and the highest volume ratio of the panels in the package.

Because the weight and height of packaging are restricted in company A, the number and volume ratio of packaging are mainly affected by the four variables as the maximum percentage of the splicing layer gap, the maximum percentage of the top layer gap, the maximum percentage of the merged splicing layer gap, and the maximum percentage of the merged top layer gap.

Because the change of the quantity and volume ratio of packaging is affected by the above four variables. Furthermore, each variable is independent of each other. The multifactorial optimization makes the traditional exhaustion method no longer adequate for solving the solution, so the Taguchi orthogonal experiment method will be applied to find the optimal parameters (Chauhan *et al*. 2018).

Taguchi orthogonal experiment

The Taguchi orthogonal experiment method can effectively solve the problem of an inordinate number of samples and reduce the time to find a solution greatly, which can achieve the similar effects as the exhaustive method (Manigandan *et al*. 2020). The first step of the Taguchi orthogonal experiment method is to select the control factor and the level of the control factor. Therefore, the maximum percentage of the splicing layer gap, the maximum percentage of the top layer gap, the maximum percentage of the merged splicing layer gap and the maximum percentage of the merged top layer gap are named A, B, C, and D, respectively. Combined with the technician’s experience of Liansi software and the requirements of company A, the level value of each control factor is formulated (Table 2).

Table 2. Values of Each Control Factor Level

Control Factor	A	B	C	D
Level 1	30	50	40	60
Level 2	40	60	50	70
Level 3	50	70	60	80

The second step is to establish the Taguchi method orthogonal test table. The selecting of the correct orthogonal table and establishing the corresponding parameter combination are the key to the success of the Taguchi method. According to the number of control factors and the number of levels of control factors in this optimization experiment, the L_9 (3^4) orthogonal table can be selected, and nine sets of orthogonal data can be obtained as shown in Table 3.

Table 3. Orthogonal Data

No.	A	B	C	D
1	30	50	40	60
2	30	60	50	70
3	30	70	60	80
4	40	50	50	80
5	40	60	60	60
6	40	70	40	70
7	50	50	60	70
8	50	60	40	80
9	50	70	50	60

A total of 1000 cases were randomly selected from the above 9 sets of data for experimental calculations, and the average package quantity and average volume ratio were obtained (Table 4).

Table 4. Calculation Result

No.	Average Package Quantity	Average Floor Area Ratio
1	10.214	92.216
2	10.360	91.462
3	10.314	91.256
4	10.358	91.357
5	10.290	91.239
6	10.244	91.004
7	10.264	90.981
8	10.172	90.940
9	10.140	90.559
Mean	10.262	91.224

In order to count the impact of different levels of each factor on the number of packages and volume ratio, the average value X_{ij} of the quality characteristics of each factor at this level needs to be solved. The formula is shown in Eq. 1,

$$X_{ij} = \frac{S_{ij}}{N_{ij}} \tag{1}$$

where N_{ij} represents the number of experiments with the control factor i at level j, and S_{ij} is the sum of the quality characteristic values of the N_{ij} experiments with the control factor. The value of X_{ij} can be calculated from the above formula, and the results are shown in Table 5.

Table 5. The Average Values of Quality Characteristic of Each Control Factors

Control Factor	Level	Value	Average Package Quantity	Average Floor Area Ratio
A	1	30	10.296	91.645
	2	40	10.297	91.200
	3	50	10.192	90.827
B	1	50	10.279	91.518
	2	60	10.274	91.214
	3	70	10.233	90.940
C	1	40	10.210	91.387
	2	50	10.286	91.126
	3	60	10.289	91.159
D	1	60	10.215	91.338
	2	70	10.289	91.149
	3	80	10.281	91.184

The changes in average package quantity and average volume ratio with different values of control factors are shown in Figs. 5 and 6.

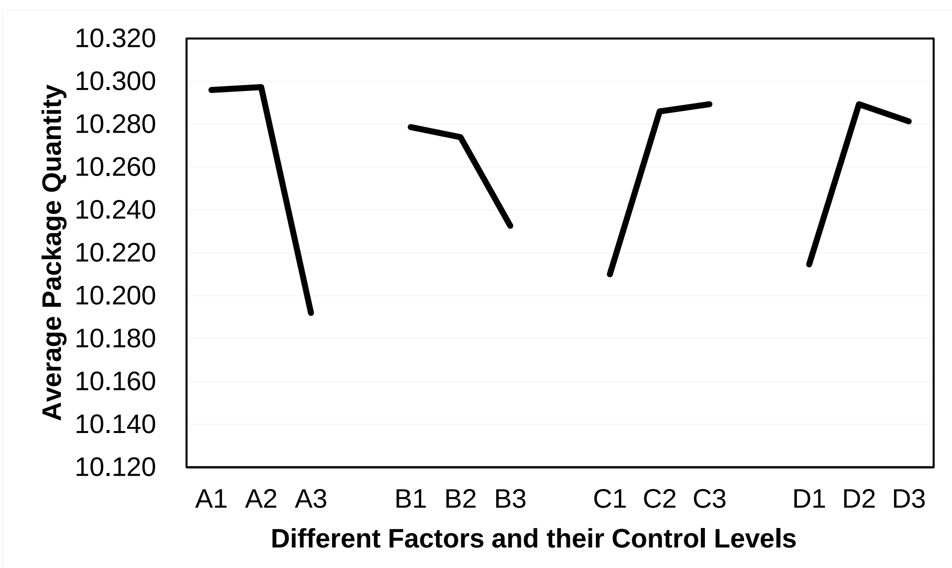

Fig. 5. Trend chart of the influence of changes in control factors on the average package quantity

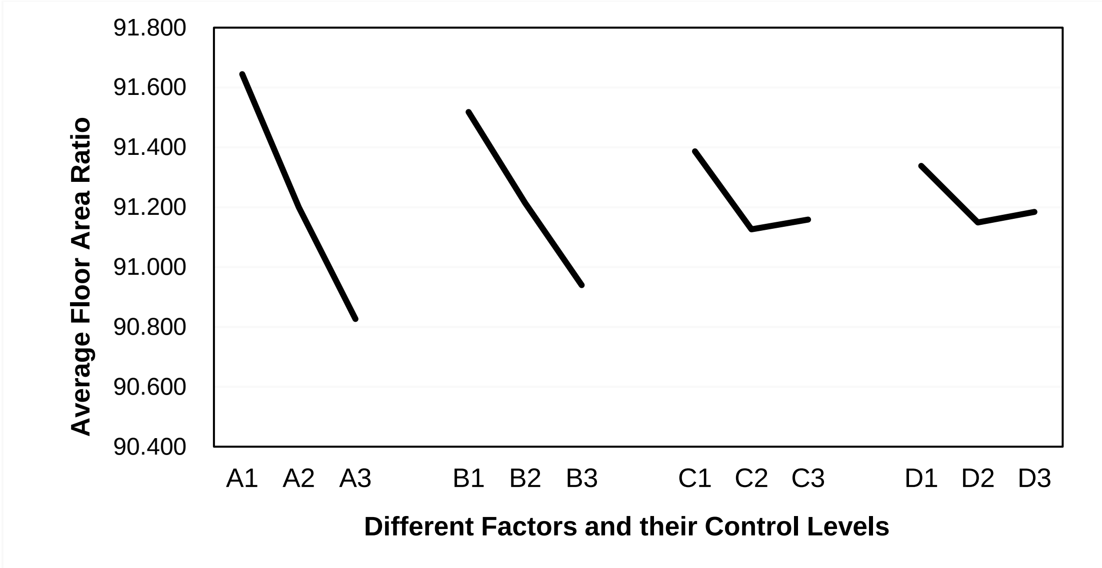

Fig. 6. Trend chart of the influence of the change in control factors on the average volume ratio

To measure the difference between the average package quantity and the average volume ratio when the value of the control factor changes, the specific gravity will be calculated by the variance calculation shown in Eq. 2,

$$SS = \sum_{j=1}^{3} (m_i(S_i)\text{-}m(S)) \qquad (2)$$

where j represents the control factor level number. $m_i(S_j)$ is the j-th level quality characteristic value of the control factor i. $m(S)$ is the average value of the quality characteristics of the control factor i. From the above formula, the influence proportion and percentage of different control factors on the average package quantity and average volume ratio can be obtained as shown in the Table 6.

Table 6. Ratio of the Influence of Each Control Factor on Quality Characteristics

Control Factor	Average Package Quantity		Average Floor Area Ratio	
	SS	Percentage	SS	Percentage
A	10.956×10^{-3}	45.725%	0.312×10^{-2}	59.541%
B	1.923×10^{-3}	8.026%	25.108×10^{-2}	29.714%
C	6.040×10^{-3}	25.209%	60.499×10^{-2}	7.159%
D	5.041×10^{-3}	21.041%	30.291×10^{-2}	3.585%

Determine the best parameters

Because this optimization experiment is affected by multiple variables and multiple levels, the importance of each level should be comprehensively considered before the selection of factor level. At the same time, the performance of the performance index should be weighed against the large and small characteristics (Vijay *et al*. 2018).

By comparing the effect of the average package quantity and the average volume ratio and combining the analysis of the charts and tables, the following conclusions can be drawn:

A has a greater influence on the average volume ratio, and when A takes level 1, its average volume ratio is the highest, so level 1 can be determined by A.

B has a greater influence on the average volume ratio, and when B takes level 1, its average volume ratio is the highest, so level 1 can be determined by B.

C has a greater impact on the average number of packages, and when C takes level 1, the number of packages is the smallest, so level 1 can be determined by C.

D has a greater impact on the average number of packages, and when D takes level 1, the number of packages is the smallest, so level 1 can be determined by D.

Therefore, the final optimized parameter combination is A1, B1, C1, and D1.

After the introduction of IPACK software in company A, the optimal optimization parameters of the packaging rules were basically determined through the Taguchi method. The optimal packaging scheme was obtained and the upgrade of the packaging process information was realized. The obtained optimization solution solved the bottleneck problem of enterprise packaging optimization, but the effect of the optimization and whether it will adversely affect the company's production capacity still needs further investigation.

RESULTS AND DISCUSSION

IPACK software was applied in Company A to complete the packaging optimization. To explore whether the optimization had a positive impact on the company's production capacity, the effect of packaging optimization was evaluated by comparing both the number of packages and the packaging efficiency before and after optimization.

Packaging Quantity

The authors randomly selected 10,000 orders and compared the number of packages before and after optimization. Through data analysis, it was found that, on the basis of solving the existing packaging problems in company A, the overall packaging quantity was reduced by 2.96% (Table 7).

Table 7. Ratio of the Influence of Each Control Factor on Quality Characteristics

Quantity of order	Number of panels	Original packaging quantity	Packaging quantity after optimization	Packaging quantity reduction percentage
10,000	462,325	104,364	101,278	2.96%

Table 8. Operation Unit Division Situation Table

Unit	Operating unit name
1	Take the panel from the tray to the operating table
2	Organize the panels on the operating table according to the packaging plan
3	Fill the foam and place the corner protector
4	Tape packing
5	Take the packaging from the operating table to the tray

Packaging Time

The comparison of packaging time was measured using the stopwatch time research method (Sembiring and Kusumawaty 2018). The worker's packaging time was divided into five operating units, which is shown in Table 8. Based on experience and work cycle table (Table 9), the number of observations was determined to be 20.

Table 9. Work Cycle Table

Operating cycle (min)	0.1	0.5	0.75	1.0	2.0	5.0	10.0	20.0	40.0
Number of observations	200	60	40	30	20	15	10	8	5

Table 10. Determination of Packaging Time before Optimization

NO.	Unit 1(s)	Unit 2(s)	Unit 3(s)	Unit 4(s)	Unit 5(s)
1	36.422	35.274	36.750	100.812	4.521
2	29.539	25.741	66.233	114.763	5.501
3	31.970	23.955	78.783	100.966	6.714
4	15.944	36.366	119.369	94.906	4.392
5	9.641	71.281	90.988	106.745	4.785
6	4.936	11.314	92.770	115.580	2.567
7	4.742	42.350	75.146	79.542	2.341
8	31.420	51.602	73.044	128.559	2.927
9	46.193	27.398	60.870	79.635	2.655
10	8.123	19.397	80.672	72.989	4.038
11	4.390	13.234	97.598	69.343	2.673
12	32.089	40.277	106.889	106.043	4.773
13	20.085	32.435	90.407	69.342	4.363
14	21.275	45.698	86.704	84.619	4.984
15	75.751	76.056	86.527	106.160	3.595
16	7.125	14.643	61.808	36.379	2.808
17	7.609	20.297	81.997	60.433	2.786
18	4.137	9.941	115.106	74.809	1.998
19	7.729	23.116	76.155	76.555	3.354
20	7.265	39.827	66.473	96.699	3.325
$\bar{X}$	20.319	33.010	82.214	88.744	3.755
σ	17.493	17.416	19.012	21.132	1.168
UCL	72.799	85.259	139.251	152.138	7.258
LCL	-32.160	-19.239	25.178	25.349	0.252
Outliers	No	No	No	No	No

In the time measurement, a continuous test method was used. A Casio stopwatch was used to observe the five units of the packaging before and after optimization 20 times, and the actual operating time was obtained. The triple standard deviation method was applied to find and remove outliers. For the calculation of outliers, the average x and standard deviation σ of each operating unit were calculated as shown in Eqs. 3 and 4.

$$\overline{X} = \frac{\sum_{i=1}^{n} Xi}{n} \tag{3}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(Xi - \overline{X})^2}{n}} \tag{4}$$

The upper limit of deviation UCL= $\overline{X}$+3σ, and the lower limit of deviation LCL= $\overline{X}$-3σ, those that are not in this area are outliers and should be eliminated. There were no abnormal values before and after packaging optimization (Tables 10 and 11).

The average total packaging time per package before optimization was 228.0 s, and the average total packaging time per package after optimization was 232.5 s. Single package packaging time is increased by 4.5 s, which means an increasing rate of 1.97% for packaging time after optimization.

Table 11. Determination of Packaging Time after Optimization

NO.	Unit 1(s)	Unit 2(s)	Unit 3(s)	Unit 4(s)	Unit 5(s)
1	4.134	47.516	108.144	56.691	2.873
2	3.631	29.353	112.245	77.703	4.987
3	20.005	21.522	87.013	60.124	4.015
4	21.737	20.306	123.174	70.480	6.321
5	5.195	14.326	139.126	81.098	5.808
6	13.943	25.414	100.907	71.948	3.527
7	3.122	36.988	140.298	84.689	3.279
8	16.992	25.291	160.176	76.547	3.019
9	5.345	48.745	125.417	116.895	3.173
10	7.309	16.629	67.369	94.732	3.173
11	30.553	26.158	56.980	81.978	3.820
12	39.269	19.448	125.395	126.139	4.727
13	7.648	32.476	61.535	93.407	3.832
14	28.780	15.331	106.372	106.402	4.677
15	11.410	12.210	209.472	80.945	3.237
16	11.634	27.851	40.689	98.624	5.900
17	24.684	7.000	48.412	106.784	4.015
18	21.831	5.437	69.700	90.265	3.615
19	6.935	24.774	74.094	95.497	6.368
20	22.850	25.835	47.522	101.572	4.018
$\overline{X}$	15.350	24.131	100.202	88.626	4.219
σ	10.189	11.175	41.364	17.478	1.096
UCL	45.916	57.654	224.294	141.061	7.506
LCL	-15.215	-9.393	-23.890	36.191	0.932
Outliers	No	No	No	No	No

Packaging Production

The packaging production data of 2 months before and after optimization were randomly selected, and the average number of panels packed per person per day was counted (Tables 12). Through chart comparison (Fig. 7), it is easy to find that production efficiency has been improved, and the optimization effect is obvious.

Table 12. Average Number of Panels Packed per Person per Day

Day	September 2019	October 2019	September 2020	October 2020
D1	552.3	492.0	663.7	566.9
D2	584.4	526.6	622.1	600.6
D3	567.1	551.1	645.9	602.1
D4	552.1	552.6	661.3	603.7
D5	544.2	557.3	660.7	655.8
D6	511.2	521.3	651.3	613.4
D7	555.5	557.4	671.5	570.0
D8	519.6	499.0	608.6	592.4
D9	559.0	513.6	661.6	539.0
D10	494.7	442.4	617.4	613.0
D11	546.8	489.1	581.0	549.5
D12	494.9	494.0	630.6	597.6
D13	515.6	524.0	621.2	574.3
D14	536.2	534.6	672.8	576.4
D15	579.7	514.0	661.3	626.3
D16	505.4	503.3	622.0	552.0
D17	535.9	510.1	565.9	675.9
D18	494.0	567.0	578.9	715.4
D19	540.9	552.6	616.0	642.7
D20	520.2	521.6	649.6	666.1
D21	510.0	564.0	611.3	681.7
D22	499.8	520.6	582.3	654.0
Average	532.7	523.1	626.4	614.4

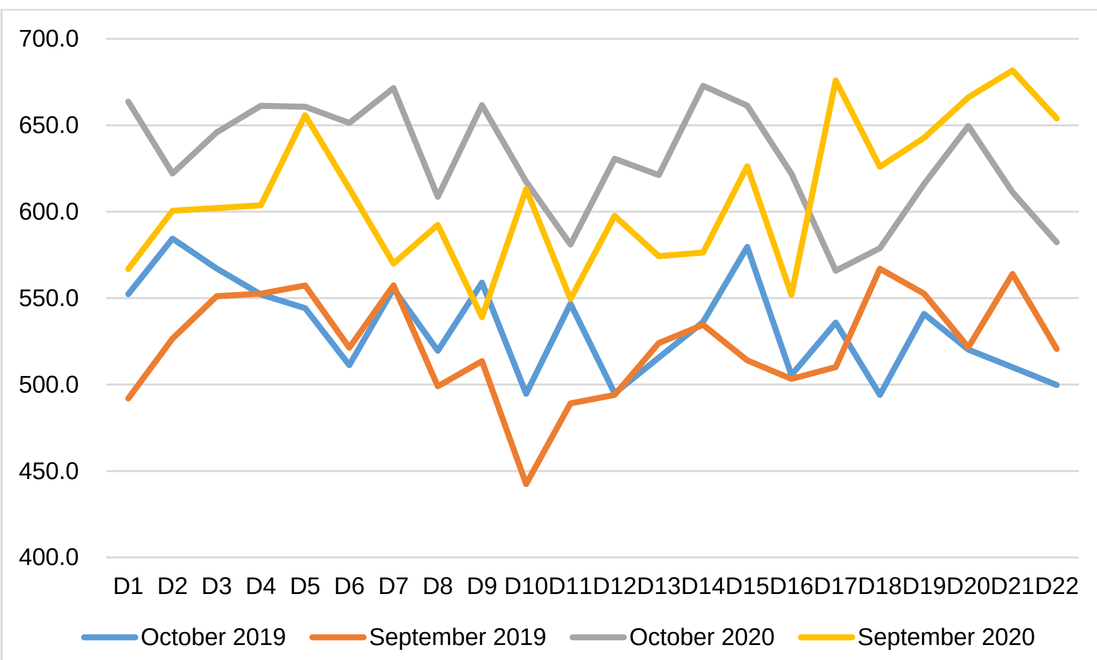

Fig. 7. Average number of panels packed per person per day

Packaging Corrugated Paper

The number of packaging corrugated paper units purchased for 10 months before and after optimization was counted, and the corresponding total number of panels was counted. By calculating the ratio of the two, it was found that the average amount of packaging corrugated paper used per panel had dropped by 12.4% (Table 13).

Table 13. Packaging Corrugated Paper Data Analysis

Month	Before(PC)	After(PC)
M1	70340	43675
M2	18800	7800
M3	62890	50300
M4	83902	59070
M5	78896	56970
M6	79331	77383
M7	76972	94859
M8	71520	88985
M9	85868	93300
M10	82738	78120
Sum	711257	650462
Total plate quantity	5223220	5248596
Ratio	0.136172131	0.123930666

Evaluation

After packaging optimization, the number of packaging quantity had been reduced, but the unit packaging time had increased slightly. Under the premise that other factors had not changed, the original packaging quantity per unit time of company A was assumed to be X. As shown in Table 14, although the optimized packaging scheme increased the unit packaging time, the production capacity, instead of being reduced, had actually experienced a slight increase due to the decline in the number of packaging quantity.

Table 14. Total Packaging Time Comparison

Original packaging quantity	X	Current packing quantity	(1-2.96%)×X
Original unit packaging time (s)	228. 043	Current unit packaging time	232.528
Original total packaging time (s)	228. 043×X	Current total packaging time	(1-2.96%)×X×232.528=225.645×X

After company A introduced IPACK software for the optimization, by comparing the four aspects of packaging quantity, packaging time, packing production and packaging corrugated paper, it was concluded that the optimized production capacity had been improved to a certain extent. Meanwhile, the bottleneck problems of packaging in company A had been solved thanks to the optimal packaging scheme under information integration.

CONCLUSIONS

1. The era of personalized customization has arrived. Traditional panel furniture companies must transform and upgrade to customization, and the traditional mode of manufacturing must also be transformed to intelligent manufacturing, which has been a consensus for panel furniture companies. Enterprises need to adopt more systematic, scientific, and information-based methods to guide the production on the shop floor.
2. Based on the analysis of the optimization points and essential nodes in the packaging process of panel furniture, it was found that the existing main bottleneck problem was the calculation of the optimal packaging scheme and the informatization upgrading of the packaging process.
3. Based on the heuristic algorithm, the calculation method of the optimal packaging scheme was proposed.
4. The upgrading of the packaging process information was the key to solve the problem of disconnectedness between the packaging information calculated by the packaging scheme and the production equipment.
5. Company A carried out the packaging optimization by using an intelligent packaging software and applied the Taguchi method to find the best optimization parameters. Comparing with the original packaging program, it was found that although the unit packaging time increased by 1.97%, the overall efficiency had improved because the number of packaging was decreased by 2.96%. At the same time, packaging production increased significantly, and the amount of packaging corrugated paper used for each panel dropped by 12.4%, which was a huge improvement. Company A successfully completed all-round packaging optimization.
6. In order to achieve the optimization and upgrading of packaging in panel furniture companies, it was important first to understand the bottleneck of the company in terms of packaging. The corresponding packaging rules should be formulated according to the company's process route, product characteristics, production line layout, *etc*., and the packaging information source can be formed by exploring the best packaging scheme. Finally, on the basis of integrating the packaging information in the existing information system of the enterprise, the packaging process can realize optimization by transmitting the integrated packaging information to the equipment on the production shop floor.
7. Being a subject of positive significance, the optimization of packaging has long been concerned and is worthy of in-depth research. The packaging optimization in panel furniture companies was conducted in this paper with an aim to enhance the quality of the packaging, but due to the limited knowledge of the authors, the research still has to be improved for further exploration in aspects of the carton box utilization rate, the worker's operation process, and the optimization of the packing filling volume. Furthermore, due to the space constraints, it hasn’t been explained thoroughly in the introduction of the packaging software and the comparison of the optimization effects before and after optimization.

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