Configuration of multiperiod variable batch units for complex products in cloud manufacturing mode

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Abstract: In order to find an effective approach to decrease tardiness of the heat transfer element with no increase of equipment and human resource cost on one hand, and to enhance productivity on the other hand, the paper proposes to establish an integer programming model. The paper uses the branch and bound method to address the first issue, whose results are analyzed to acquire the optimal solution under the principle of POSP-FM scheduling. With examples, the paper verifies the effectiveness of decreasing tardiness with no increase of equipment cost and human resources cost, and provides advices on the way to construct multichannel so as to decrease tardiness.

1. Introduction

The line-cell (line-seru)conversion, conceived at Sony, is an innovation of assembly system used widely in the Japanese heat transfer element industry. A detailed introduction of seru system and its managerial mechanism can be found in(Yu Yang, Gong Jun & TAND JUN.2012). A seru system ,which consists of one or more serus,is more flexible and agiler than the assembly line.To improve the flexible of assembly lines(Guo,Z.X.,Wong,W.K.,Leung,S.Y.S.&Fan,J.T.2009), proposed an intelligent production control decision support system to solve the flexible assembly line (FAL) problem with flexible operation assignment. In addition, the seru system has a better balance than assembly line, because in seru system the balanced capacity can be improved by the workers assignment(SunWei, Yu Yang, Tang Jiafu & Kaku Ikou. 2004).

To deal with issues of resource allocation, the paper establishes the aforementioned two-phase nonlinear integral model, adopts the branch and bound algorithm, and designs the production scheduling program for the minimum tardiness.

2. Description of the issue and mathematic model

To transform variable production line into multichannel is virtually to split one production line into several multichannel with the same function, which is shown in Figure 1. Issues that need to be resolved cover the number of separable multichannel, the way to distribute equipment and operators, and the way to schedule products. By setting tardiness as the objection function, the approach herein will directly influence performance of corporations.

2.1 Assumptions

There are I types of production and L batches. Each batch corresponds to one and only product. Also, the size of batches is restricted.

One batch should be finished in no more than one multichannel. Splitting is not considered here.

Equipment and operators are available for each period. Equipment breakdown and absence of personnel are excluded here.

The construction of multichannel is fixed in the whole production process.

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Each and every operator can execute all the working procedures of the multichannel.

The parameters herein are as follows:

SJ_{ij}: operating time of the ith product at one single work station in the jth workplace in variable production line;

D_{ti}: Quantity demand for the ith product at the tth period;

TI_t: lead time at the tth period;

CM_i: the cycle of the ith product in variable production line;

SC_j: the number of equipment in j workplace in variable production line;

RC: the number of operators in variable production line;

CA: the setup time of one single operator in preparation for one type of product;

Q_{il}: binary variable, whose value is 1 if the type of the l batch is i, or 0 if it is not;

B_l: the minimum value of the batch.

The variables are as follows:

ZB_l: the setup time of l batches in production line;

TG_l: the passing time of l batches in production line;

KS_l: the startup time of l batches in production line;

ZB_l: the setup time of l batches in multichannel, which is 0 if the lth batch shares the same production type with the last batch before it, or $CA * \sum_{w=1}^{W} Y_{kw} * Q_{il}$, if it doesn't. Related equation is as follows.

$$ZB_l = \begin{cases} CA * \sum_{w=1}^{W} Y_{kw} * Q_{il}, & Q_{il} = 1, Q_{il'} = 0 \\ 0, & Q_{il} = Q_{il'} = 1 \end{cases}$$
$$(l' \mid Z_{lktq} = 1, Z_{l'kt(q-1)} = 1, \forall k, q) \quad (1)$$

TG_l: the passing time of the lth batch in multichannel, which is related with the size of the batch, the number of operators multichannel, and cycles of the batch, as shown in Equation (2) as follows.

$$TG_l = \sum_{l=1}^{L} \sum_{q=1}^{Q} \sum_{w=1}^{W} C_w * cp_{lkt} * P_{lkt} * Z_{lktq} * Y_{wk} \qquad \forall k, t \quad (2)$$

KS_l: the startup time of l batches in k multichannel, which equals to the sum of passing time and setup time for the previous. batches of the production unit, as shown in equation (3) as follows.

$$KS_l = (ZB_l + TG_l) * Z_{lkqt} * Z_{l'kt(q-1)} \qquad \forall q \quad (3)$$

X_{vkj}: it is 1 if there are v work stations in j workplaces of k production lines, or else it is

Y_{kw}: it is 1 if there are w operators in k units, or else it is 0.

K: the number of multichannel;

P_{lt}^{k}: the number of production of l batches in k production lines at the tth period;

cp_{lk}: the cycle of l batches in k units;

Z_{lktq}: it is 1 if the sequence of l batches in k units at the tth period is 1, or else it is 0.

2.2 Objective function

The minimum tardiness lies in the objective function in equation (4). Equation (5) denotes the constraint for labor time, that is the sum of setup time, passing time, and start up time should not exceed the lead time at the current period. Equation (6) denotes the constraint for the number of operators in k production lines, which means that there should be at least one operator at each multichannel. Equation (7) denotes the value range of the total number of equipment at the same workplace for each of the multichannel, which is no more than the number of equipment at the same workplace in variable production line. Equation (8) denotes the value range of operators. Equation (9) denotes the constraint for production distribution in multichannel. Equation (10) denotes the constraint for the number of work positions in j workplaces in k production lines.In equation (4), k is unknown. The decision of objective function is directly related to the decision of X_{vjk}, Y_{wk} and Z_{lktq}. The initial issue is divided into X_{vjk}. Y_{wk} is called as the issue of of multichannel construction (ACL), while Z_{lktq} is called as the issue of multichannel loading (ACF).

$$f = \min \sum_{T'=1}^{T} \sum_{k=1}^{K}\sum_{i=1}^{I}[D_{iT'} - \sum_{s=1}^{T'} (P_{iks} - D_{is})] \tag{4}$$

$$\sum_{l=1}^{L}(ZB_l + TG_l + KS_l) \leq TI_t \quad \forall t,k \tag{5}$$

$$\sum_{w=1}^{W} Y_{wk} \geq 1 \qquad \forall k \tag{6}$$

$$\sum_{v=1}^{V} \sum_{k=1}^{K} X_{vjk} <= SC_j \qquad \forall j \tag{7}$$

$$\sum_{w=1}^{W} \sum_{k=1}^{K} Y_{wk} = RC \tag{8}$$

$$\sum_{k=1}^{K}\sum_{q=1}^{Q}\sum_{t=1}^{T} Z_{ikqt} >= 1 \qquad \forall i \tag{9}$$

$$\sum_{v=1}^{V} X_{vkj} \geq 1 \qquad \forall k, j \tag{10}$$

3. Preliminary theoretical analysis

Theorem 1 the objective function of correlated ACF and that of ACL is positively correlated.

Proof: *f* is the objective function of *ACF* as shown in equation (12). f_1 is the objective function of *ACL* as shown in equation (13). In equation (11), CM_{qtk} is the cycle of *q* that is the final distributed product in the *k*th channel at the *t*th period. As the number of multichannel, the number of periods, the number of operators in each multichannel, and the scheduling rule are all determined, and $Z_{ikqt}, Y_{kw}, CM_{qtk}$ are all parameters, then the result of the expression (14) can be equivalent to a constant, namely *b1*. Therefore, equation (11) can be expressed as $F_t = \sum_{t=1}^{T}(B_t \times f_1 + C_t)$, where $B_t = b1 \big/ CM_{qtk}$ and $C_t = \sum_{k=1}^{K}(\sum_{i=1}^{I}(CA \times \sum_{w=1}^{W} Y_{kw} \times Z_{ikqt}) - TI) \big/ CM_{qtk})$. When *t* is fixed, *f* is proportional to F_t, and F_t is proportional to f1. Then it can be deducted that f is proportional to f_1, which means that the objective function of *ACF* is proportional to that of *ACL*.

As shown in Fig 2, the objective function of ACL is the smallest sum of average cycle, while the objective function of ACF is the minimized tardiness.

4. Algorithms

4.1 The principle of branching and trimming

By branching, the initial issue is separated into several sub issues. The issue herein is to distribute the equipment and operators in variable production line into several channels, and each branch corresponds to one scheme of resource distribution. Theorem 1 has proved that the number of branches is increasing exponentially with the increasing of the scale .

Trimming is cutting off branches that have no optimal solution. Based on the features of multichannel and theorem 2, the multichannel of cells is acquired, namely the indivisible multichannel. It should satisfy the following conditions:

- The multichannel of cells can manufacture all types of products, which means that the work stations in each workplace is not zero.

- The sum of average cycle for all products is minimum in the multichannel of cells.
- The multichannel of cells is undividable, and will not satisfy any of the above two conditions if it is divided.

The number of the multichannel of cells is equal to the upper bound of multichannel that is determined by theorem 3.

Theorem 3 any of the branch that excludes the multichannel of cells or the combination of multichannel of cells should be trimmed.

Proof: as can be seen from the definition of the multichannel of cells, the sum of average cycles that excludes the multichannel of cells exceeds that with the multichannel of cells. According to theorem 2, the objection function is proportional to the sum of average cycle. Therefore, theorem 4 is proved.

4.2 The solution to ACF

The constant-speed parallel machine with the minimum tardiness as shown in equation (15) ACF should be regarded as follows

According to the features of the scheduling issue, the paper formulates the principle of POSP-FM (product of shortest part on the fastest MCM), which means that at any time, the product with the shortest part should be processed on the fastest MCM, and the product with the second shortest part should be processed on the second fastest MCM. This pattern continues until all the channels the number of products that should be manufactured during the extra time should be cut off and go through redistribution.

The algorithm of POSP-FM is described as follows.

Step 1 sequence the multichannel with no decrease of processing speed.

Step 2 sequence the products with no increase of cycles.

Step 3 the first k products should be distributed orderly into the first k multichannel. Patterns go like this until the product with the maximum cycle is distributed to the last multichannel. Are distributed. After the first product is manufactured, the next distribution is decided by how much time each channel leaves. If there is extra time for some of the multichannel in the current distribution, then

Step 4 each time when processing of products is finished, the next distribution should be decided by the cycle sequence in Step 2. If there is extra time for some of the multichannel in the current distribution, then the number of products that should be manufactured during the extra time should be cut off and go through redistribution. Step 2 and Step 3 are repeated until all the products are distributed.

4.3 Steps of the branch and bound algorithm

Step 1 Initialize the upper bound of the objective function as a, which is the tardiness of variable production line, and the lower bound of the objective function as b, which is the number of tardiness in variable production line. The initial number of multichannel is 2. The final value is K.

Step 2 based on the principle of branching and trimming, the set of the results of resource distribution is obtained as C.

Step 3 extract elements in C orderly, formulate the principle of POSP-FM according to 4.3, distribute orders, and seek the number of tardiness.

Step 4 the finally obtained upper bound is the optimal solution.

5. Analysis of the algorithm

The paper adopts MATLAB2012 to construct production cells and multichannel. All the experiments are executed in Microsoft Windows XP with 2GB ROM and Pentium®Dual-Core CPU E5500@2.8GHz.

5.1 Testing examples

Specific parameters and numbers of examples for experimental use are shown in Table 1 and Table 2.

After the production line is divided, the configuration of resources for a while remains unchanged, which is verified in Table 3. Table 4 shows the comparison between tardiness of multichannel and that of production cells at the time when the number of orders is changing.

Table 1 the distribution results of ACF operators and the value of objective functions when there are 32 operators

The number of multichannel	Operators scheduling	Objective function	The number of multichannel	Operators scheduling	Objective function
8	(4 4 4 4 4 4 4 4)	4248 (1)	4	(8 8 8 8) (12 8 8 4) (16 8 4 4) (20 4 4 4)	5884 6274 7109 8260
7	(8 4 4 4 4 4 4)	4657	3	(24 4 4) (20 8 4) (16 12 4) (16 8 8) (12 12 8)	10226 8669 7904 7518 7065
6	(8 8 4 4 4 4) (12 4 4 4 4 4)	5066 5452	2	(28 4) (24 8) (20 12) (16 16)	12584 10638 9464 9152
5	(8 8 8 4 4) (12 8 4 4 4) (16 4 4 4 4)	5475 5861 6700		Upper bound of the objective function Lower bound of the objective function	15392 2912

Table 2 the change of requirements for all products when the total requirements remain the same

variations (%)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	0	0	0	0	0	0	0	0	0	0
2	+20	+20	0	0	+10	0	0	0	0	-95
3	0	0	-100	0	0	0	+50	+50	+50	+50
4	+50	0	0	0	-50	-50	0	0	0	0

Table 3 the first five solutions when the minimum batch of the production unit under variable neighborhood search is 0

The number of operators	Operators scheduling	The number of tardiness	
		Variable line	Unit production
32	(7 7 7 4 4 3) (8 7 5 5 4 3) (8 7 6 6 3 2) (8 8 8 8) (13 11 8)	15392	5023 5036 5040 5151 7074

5.2 Conclusions

After transforming variable production line into multichannel with no increase of equipment cost and operators cost, the tardiness of multi-period products can be effectively reduced, which is shown in Table 1.

Tardiness is related to the minimum dividable batch. The smaller the batch is divided, the smaller the tardiness is, which is shown in Table 2.

Tardiness also has relation with the number of divided multichannel. However, it does not mean that more multichannel leads to smaller tardiness. With the information of product types, numbers of products, working procedures, workplaces, and work stations being input into the algorithm, the optimal number of multichannel can be then obtained under the scheduling principle herein, which is shown in Table 3.

When the number of orders is changing, it is better to divide variable production line into multichannel instead of production cells, which is shown in Table 4.

Table 4 the comparison between multichannel and production units

variations	Number of tardiness (the variable batch is 0)	
	multichannel	Production unit
1	4248	5023
2	5456	14449
3	1242	11861
4	5296	13675

6. Conclusion

In the face of current production requirements such as short life cycle, unfixed types, mass batches, and small quantity for each batch, the paper establishes a nonlinear integer model. Its objective function is tardiness, and its constraints are equipment cost and human resources cost. As tardiness are the results of resource distribution and product scheduling, and as scheduling is complex and diverse, the paper proposes a two-phase model, applies the branch and bound algorithm to simplify dimensions, and provides the scheme of POSP-FM product scheduling to obtain the optimal solution under the scheme.

The research herein factors out multi-skill labors. During actual production, it is important to configure multi-skill labors with regard to optimization of production lines. Consideration is possibly given to research on a split model of variable production line with multi-skill labors in the future.

References

[1] Kshirsagar P, Jiang D, Zhang Z. Implementation and Evaluation of Online System Identification of Electromechanical Systems Using Adaptive Filters[J]. IEEE Transactions on Industry Applications, 2016, 52(3):2306-2314.

[2] Puttonen J, Lobov A, Soto M A C. Planning-based semantic web service composition in factory automation[J]. Advanced Engineering Informatics, 2015, 29(4):1041-1054.

[3] Guo,Z.X.,Wong,W.K.,Leung,S.Y.S.&Fan,J.T,(2009).”Intelligent production control decision support system for flexible assembly lines.” Expert Systems with Applications Part,vol.36,no.3,pp.4268-4277,2009.

[4] Yazid Y. SEBBAR, “Experimental study of convective heat flow through a large opening in a partitionned enclosure,” Int J Heat & Tech, vol. 33, no. 4, pp. 211–216, Dec. 2015. DOI: 10.18280/ijht.330428.

[5] Siemia Tkowski & Mprzybylski,W.”Modelling and simulation analysis of process alternatives in the cellular manufacturing of axially symmetric parts.” International Journal of Advanced Manufacturing Technology, vol. 32, no. 5-6, pp. 516-530,2007.

[6] Steche,K.E.,Yin,Y.,Kaku,I.&Murase,Y.”Seru:the organizational extension of JIT for a super-talent factory.”International Journal of Strategic Decision Sciences,vol.3,no.1,pp.105-108,2012.