THE RESEARCH OF VARIABLE PRODUCTION LINE INTO MULTI-CHANNEL

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ABSTRACT: In order to explore an effective way to reduce the number of tardiness by means of variable production line to the multi-channel line, without any increase in cost of equipment and human resources are studied under the premise of through the variable production line to multi-channel to reduce the number of tardiness, and improve production efficiency. Proposed tardiness quantity as objective function, equipment cost and manpower cost as constraint of single objective model. Because of the complexity of the variable line to multi-channel model, according to the characteristics of the model, put forward the problem is decomposed into two child resource allocation and product scheduling problem. To the problem of resource allocation, presents a branch and bound method; In view of the resource allocation as a result, the POSP - FM scheduling rules, get under the rules of the scheduling of the optimal solution. Through the calculation example,variable production line to multi-channel can be without any increase in cost of resources under the premise of effectively reduce the number of tardiness, and on the basis of experimental results shows how to make the structure of the product unit in order to reduce the number of tardiness.

KEY WORDS: PID Control The variable production line to multi-channel, Tardiness quantity, Branch and bound, Equipment cost, Human resource cost.

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1 INTRODUCTION

The traditional production model represented by assembly line provides an efficient way for mass production. However, in the face of current production requirements such as short life cycle, unfixed types, mass batches, and small quantity for each batch, a train of issues has emerged for the traditional assembly line due to its low flexibility and large investment. For example, there are extra working stations for the assembly line; the requirements for floor space are high; there is low rate of equipment utilization due to short production period, frequent exchange, and long setup time; the efficiency of operators is low; and there is poor adaptivity to production changes for each production period.

The line-cell (line-seru) conversion, conceived at Sony, is an innovation of assembly system used widely in the Japanese electronics industry. To compete in a turbulent market, in 1992, several mini-assembly units were created in one of Sony's video-camera factories for an 8-millimeter CCD-TR55 video-camera, after dismantling a long assembly conveyor line. As did the original conveyor line, each mini-assembly unit produced the entire product. In 1994, Tatsuyoshi Kon, a former Sony staff, called this mini-assembly organization seru, a Japanese word for cellular organism. 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 (Sun Wei, Yu Yang, Tang Jiafu & Kaku Ikou, 2004).

To respond to the uncertain demands from a turbulent marker, a new management principle-Just-In-Time Organization System is used to manage a seru system (Yu Yang, Tang Jiafu & Gong Jun. 2013). To fit the specific layout of a seru factory, appropriate case-by-case approaches are usually used to adjust the floor space of seru factories. Fortunately, since serus can be modified, dismantled, and constructed easily and quickly, and most serus occupy small spaces, managers can often get huge benefits from the adjustment of floor spaces. For example, by adopting seru system,

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Canon and Sony reduced 720,000 and 710,000 square meters of floor space, respectively (Steche, K.E., Yin, Y., Kaku, I. & Murase, Y, 2012).

Scholars at home and abroad have undertaken large quantity of researches on splitting model of variable production line, resources distribution, and production scheduling. According to document (Yu Sakazume, 2005), the variable production line is divided into variable line and cell-line (seru). By establishing the multi-objective function with the shortest passing time and the highest operating efficiency, the document provides a small-scale simulation algorithm for the comparison between variable production line and combinatorial production line. The conclusion is that the combinatorial production line is better than the former one. Document provides the branch and bound algorithm to address small-scale issues arising from the model in document. Document (Yu, Y., Tang, J., Sun, W., Yin, Y. & Kaku, I, 2013a, b) adapts the model in document and then provides an approximate solution with the variable neighborhood search algorithm. Production cells apply dedicated production lines. With multi-stage production and changing batches, this production pattern will cause high idleness for some of the cells and unusually busy state for other cells. Meller (Meller, 2008) invented the multichannel manufacturing system. Multichannel denotes general production line, which is a concentrated variable production line with higher production flexibility. The multichannel system reduces the time for products to enter the system, and allows more choices.

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.

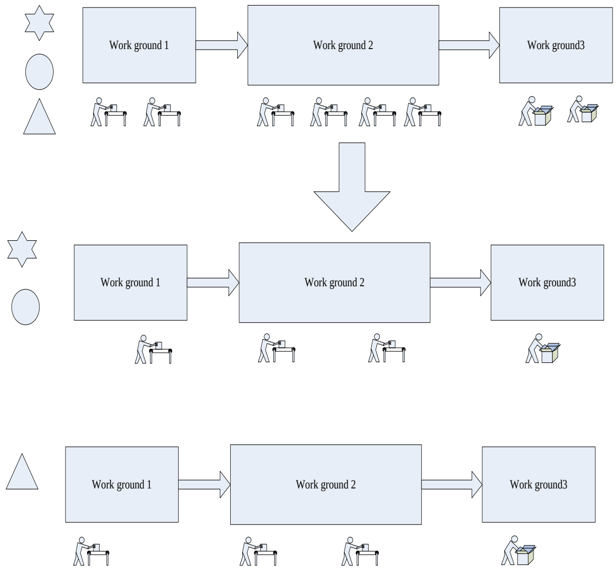

Fig 1. Transformation of variable production line into multichannel

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.

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

2.2 Index set

The index sets herein are as follows:

I: production types (i=1,2,…,I), I denotes the sum of production types;

t: sequence number of periods (t=1,2,...,T);

j: working procedures (workplace) (j=1,2,...,J);

l: the number of batches (l=1,2,...,L);

P: operators (p=1,2,...,P);

k: the number of production lines (k=1,2...,K);

q: the production sequence of a product under a production line ($q=1,2,...,Q$);

v: the number of work stations ($v=1,2,…,V$).

2.3 Parameters

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.

2.4 Variables

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.

$$ZB_l = \begin{cases} CA * \sum_{w=1}^{W} Y_{kw} * Q_{il}, & Q_{il} = 1, Q_{il'} = 0 \\ 0, & Q_{il} = Q_{il'} = 1 \end{cases}$$

$$(l' \big| Z_{lktq} = 1, Z_{l'kt(q-1)} = 1, \forall k, q) \qquad (1)$$

multichannel, and cycles of the batch, as shown in Equation (2) as follows.

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

time for the previous. batches of the production unit, as shown in equation (3) as follows.

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

multichannel construction (ACL), while Z_{lktq} is called as the issue of multichannel loading (ACF).

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

S,t,

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

$$\sum_{w=1}^{W} Y_{wk} \ge 1 \qquad \forall k \qquad (6)$$

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

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

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

$$\sum_{v=1}^{V} X_{vkj} \ge 1 \qquad \forall k, j \qquad (10)$$

K , P_{kit}, cp_{ik} : is

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 quantitative range of multichannel

Theorem 2 there are at least two multichannel. And the number of multichannel is not supposed to exceed the minimum value of work stations in the workplace.

Proof (by contradiction): if the number of multichannel exceeds the minimum level of work stations in workplaces, there will be at least one multichannel that cannot cover all the workplace, or rather it cannot manufacture all products. Thus it contradicts the assumption that the multichannel can manufacture all the products.

$$F_t = \sum_{t=1}^{T} [(\sum_{k=1}^{K} (\sum_{i=1}^{I} (CM_i \times \left\lceil \frac{RC}{\sum_{w=1}^{W} Y_{kw}} \right\rceil \times Z_{ikqt} + CA \times \sum_{w=1}^{W} Y_{kw} \times Z_{ikqt})) - TI) \Big/ CM_{qtk}] \quad (11)$$

$$f = \sum_{t=1}^{T} (t \times F_t) \quad (12)$$

$$f_1 = \sum_{k=1}^{K} (\sum_{i=1}^{I} (CM_i \times \left\lceil \frac{RC}{\sum_{w=1}^{W} Y_{kw}} \right\rceil) \quad (13)$$

$$\frac{\sum_{k=1}^{K} (\sum_{i=1}^{I} (CM_i \times \left\lceil \frac{RC}{\sum_{w=1}^{W} Y_{kw}} \right\rceil \times Z_{ikqt})}{\sum_{k=1}^{K} (\sum_{i=1}^{I} (CM_i \times \left\lceil \frac{RC}{\sum_{w=1}^{W} Y_{kw}} \right\rceil} \quad (14)$$

4.2 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.

4.3. The solution to ACF

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

$$Q_k \,|\, prep \,|\, \sum U_j \quad (15)$$

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.

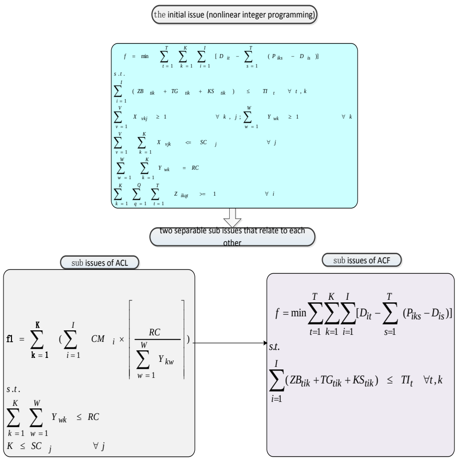

Fig 2. Sub steps of the model

4.4. 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.

Table 1. The work procedure for the ten products

		J1	J2	J3	J4	J5	J6	J7	J8	J9	J10
P1	SJ_{ij}		860	364			960		380	850	
P2	SJ_{ij}						960	1332	368	850	
P3	SJ_{ij}	850				848	960			850	
P4	SJ_{ij}	850				480	1328			850	
P5	SJ_{ij}		636	640		650				720	
P7			900								960
P8	SJ_{ij}			428	430				188		720
P9	SJ_{ij}			460					428		960
P10	SJ_{ij}			920							960
The number of work stations in each workplaces		8	16	16	8	8	12	12	8	8	16

Table 2. The number of orders in the twelve phases for the ten

Lead time / products	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
P1	330	350	180	180	180	180	180	180				
P2		180	180	180	180	180	180	180				
P3	330	160	160	160	160	160	160	160	350	350	350	350
P4			160	160	160	160	160	160	350	350	350	350
P5	180	180	180	180	180	180	180	180	180	180	180	180
P6	260	260	260	260	260	260	260	260	280	280	280	280
P7	350	220	160	160	160	160	160	160				
P8		120	180	180	180	180	180	180	320	320	340	340
P9	330	320	160	160	160	160	160	160	120	120		
P10			180	180	180	180	180	180	220	220	340	340

Table 3. 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 4. The first five solutions when the minimum batch of the production unit under variable neighbourhood 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

Table 5. 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 6. 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

After the production line is divided, the configuration of resources for a while remains unchanged, which is verified in Table 5. Table 6 shows the comparison between tardiness of multichannel and that of production cells at the time when the number of orders is changing.

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 3.

Tardiness is related to the minimum dividable batch. The smaller the batch is divided, the smaller the tardiness is, which is shown in Table 4.

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 5.

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 6.

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 is 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.

7 REFERENCES

►Araz, O. U. & Salum, L., (2010), A multi-criteria adaptive control scheme based on neural networks and fuzzy inference for DRC manufacturing systems[J]. International Journal of Production Research, 48(1): 251-270.

►Boysen, N., M. Fliedner & A. Scholl., (2008), Assembly line balancing: Which model to use when? International Journal of Production Economics, 111(2): p. 509-528.

►Dan Jonsson, Lars Medbo & Tomas Engstrom., (2004), Some Considerations Relating to the Reintroduction of Assembly Lines in the Swedish Automotive Industry[J]. International Journal of Operations and Production Management, 24(8): 754-772. 118.

► 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, 36(3, Part 1),4268-4277.

►Ikou Kaku, Jun Gong, Jiafu Tang & Yong Yon., (2008), Parts storage performance in line-cell conversion. Nusa Dua Bali-Indoneszа December 1(1): 3-5.

►Katsuhide Isa & Tsuyoshi Tsuru., (2002), Cell Production Innovation in Japan: toward a New Model for Japanese Manufacturing [J]. Industrial Relations, 41(4): 548-578.

►Li Xiag, Chen Qingxin & MAO Ning., (2014), Buffer allocation optimization of flow shop based on queueing network model[J]. Computer Integrate Manufacturing System, 20(4): 890-897 (in Chinese).

►Liu Chengang, Stecke, E. & Lian Jie., (2012), Reconfiguration of assembly systems: from conveyou assembly line to serus. Journal of Manufacturing Systems, 31(3): 312-325.

►Meller, R.D., (1998), White paper on multi-channel manufacturing. Technical Report Department of Industrial and Systems Engineering [J]. 42(5): 19-20.

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

►Steche, K.E., Yin,Y., Kaku, I. & Murase, Y., (2012), Seru: the organizational extension of JIT for a super-talent factory. International Journal of Strategic Decision Sciences, 3(1), 105-108

►Sun Wei, Yu Yang, Tang Jiafu & Kaku Ikou., (2004), Research on buffer capacity in assembly system, Computer Integrated Manufacturing Systems, 12(1): 34-37.

►Yu Sakazume., (2005), Is Japanese Cell Manufacturing a New System: A Comparative Study between Japanese Cell Manufacturing and Cellular Manufacturing? Journal of Japan Industrial Management Association, 55(6): 341-349.

►Wang Xin., (2011), The Simulation and optimization of resource allocation in automation workshops. Dalian: Dalian University of Technology, 36(2): 3652-366.

►Yin.Y., Steche.K.E., Swink. M. & Kaku, I., (2012), Integrating lean and agile production in a highly volatile environment with seru production systems:Sony and Canon case studies. Working paper, Yamagata University, Japan.

►Yin. Y., Steche. K.E., Li, M. & Kaku, I., (2011), D mining: Concepts, methods and uncertain demand with seru. Workong paper, Yamagata University. ata

►Yu Yang, Gong Jun & TAND JUN., (2012), How to do assembly line-cell conversion? a discussion based on factor analysis of system performance improvements [J]. International Journal of Production Research, 50(18): 5259-5280.

►Yu Yang, Tang Jiafu & Gong Jun., (2013), Multi-objective optimization model of line-cell conversion towards reducing workers, Journal of Northeastern University: Natural Science, 34(1): 17-20 (in Chinese),

►Yu, Y., Tang, J., Sun, W., Yin, Y. & Kaku, I., (2013a), Combining local search into nondominated sorting for multi-objective line-cell conversion problem International Journal of Computer Integrated Manufacturing, 26(4), 316-326.

►Yu, Y., Tang, J., Sun, W., Yin, Y. & Kaku, I., (2013b), Reducing worker(s) by converting assembly line into a pure cell system. International Journal of Production Economics, 145(2), 799-806.