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Study on the Quasi-Dynamic Cell-Formation Problem

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Abstract: A new concept is presented in this study of quasi-dynamic cell-formation for design of cellular manufacturing system, based on analyzing the fact that static and dynamic cell-formation could not reflect the real situation of modern cellular manufacturing system. Further, a uniform abstract function for cell formation problem is put formation though analyzing the different between static cell-formation, dynamic cell-formation and quasi-dynamic cell-formation.

Key words: Quasi-dynamic, abstract function, cell formation

INTRODUCTION

Cellular manufacturing can assist enterprises to improve their productivity, decrease material handling cost and respond to market demands through a reasonable cell design and layout. These concerns have been of broad interest in cellular manufacturing for the past last 30 years. One of the main challenges in cellular manufacturing is cell formation.

Static Cell-formation Problem (SCFP) classifies machine cells and part families over a period according to product batch requirements, machine production capacities, machine purchasing prices and a variety of other factors. Jayaswal and Adil (2004) proposed a model that considers part batch, operations sequence, alternative routes, cellular size limitation and multiple machines. This model aims to determine the minimum materials handling cost, the machine operations cost and the machine investment cost. Diaby and Nsakanda (2006) presented a general integer programming method for the parts-processing path problem which considered that each part could be operated by alternative routes and different costs at different machines. The objective is to obtain the minimum for materials handling cost, production cost, outsourcing and manufacturing cost. The authors used a relaxed Lagrange method to obtain a near-optimal solution because of the complexity of the problem. Foulds *et al.* (2006) also put forward similar model for SCFP.

Dynamic Cell-formation Problem (DCFP) is involved in how to divide part families and machine groups to obtain the minimization of various costs or exceptional element number according to different product types and the demand quantities in different periods. Defersha and Chen (2006) considered the following factors in cell formation: dynamics, alternative route, operation sequence, subcontract, cell reconfiguration, machine loads and so on. The objective of their model is cost minimization while considering machine maintenance and repairmen costs, machine purchasing cost, materials handling cost, machine operations cost, tool use cost, setup cost, reconfiguration cost and subcontract cost. Tavakkoli-Moghaddam *et al.* (2008) considered that one model does not yield the best cell formation globally, although it yields the best formation for a given period because of the difference in demand types and quantities of parts in different periods. Thus the reconfiguration of part families and machine groups must be considered for cell formation. Wang (2009) proposed a multi-objective dynamic cell-formation model. The objective function includes reconfiguration cost, machine utilization rates and materials handling cost. He also presented a dynamic cell-formation model under a machine redundancy environment. Fan *et al.* (2010), Ahkioon *et al.* (2009) and Bajestani *et al.* (2009) also advanced similar model for DCFP.

As mentioned above, CFP chiefly involves dividing part families and machine cell operations according to the correlation factors among operation route and sequence, part demand and other factors to minimize setup time, material handling cost, machine cost and to improve the production efficiency of a CMS. The difference between SCFP and DCFP is that the later considers several periods to obtain a cell classification scheme for each period and that the former considers only one period. However, these two problems assume the creation of a single new factory or workshop that is to say, they don't consider the effect of original manufacturing system and machine layout on

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cell formation. In fact, most of enterprises build one cell manufacturing system based on an original layout, so it is necessary to consider the effect of an original layout on cell formation machine reconfiguration. Cellular reconfiguration requires a substantial amount of manpower, material resources and time. An enterprise cannot conduct frequent cellular reconfigurations within a short time period. And it is also difficult for an enterprise to meet a relatively accurate change of demand in 2-3 years because market demands are always changing. Thus, it is more difficult to meet the real requirements and there is a larger risk when comprehensive cell formation planning is performed for a longer period of time. Also some researchers want to decrease the risk come from predicting of imprecise data by using fuzzy technology, for example, (Cao and Chen, 2005) set q kinds of demand situation and each situation expresses with a certain probability. Arýkan and Gungor (2009) considered fuzzy of other parameters just like purchasing price of machines, machines capability and material handling cost and so on besides demand. But fuzzy technology overwhelms for production technology, production process path changing and other factors that effect production time, machines loading, so these factors are of vital importance in CFP. Therefore, this study aims to modify SCFP and DCFP concept and proposes a new concept: a quasi-dynamic cell-formation and tries to solve the Quasi-dynamic Cell-Formation Problem (QCFP).

QCFP considers cell formation for a period based on the original manufacturing system. It is based on the current enterprise situation to avoid potential risk coming from inaccurate forecast data. Quasi-dynamic cell-formation can be viewed as a static problem because it considers only one period but can also be viewed as a dynamic problem because for a single period of cellular planning based on an original layout, it considers a combination of the material handling cost and the machine reconfiguration cost.

ABSTRACT FUNCTION FOR SCFP

Abstract function for SCFP: As mentioned above, SCFP classifies machine cells and part families over a period according to product batch requirements, machine production capacities, machine purchasing prices and a variety of other factors. So obviously, the input of SCFP is basic information just like part-machines relationship matrix, machines capability, part demand, production process and so on and the output are cell formation scheme and cost based on the scheme. Then we can define as follows:

$MGPF_S$ = Cell formation scheme for static cell formation problem
V_S = The cost based on the cell formation scheme
$\alpha, \beta, \gamma, \omega$ = Parameters just like part-machines relationship matrix, machines capability, part demand, production process and so on
F_S = Static cell formation function
G_S = Cost function for static cell formation

According to the defined above, we can gain the abstract function for SCFP as follows:

$$MGPF_S = F_S(\alpha, \beta, \gamma, \cdots, \omega) \tag{1}$$

$$V_S = G_S(MGPF_S, \alpha, \beta, \gamma, \cdots, \omega) \tag{2}$$

where, Eq. 1 means the function relationship between $MPGF_S$ and parameters of α, β, γ,..., ω; Eq. 2 means the function relationship between V_S and $MPGF_S$ and α, β, γ,...,ω.

ABSTRACT FUNCTION FOR DCFP

The difference between SCFP and DCFP is that the later considers several periods to obtain a cell classification scheme for each period and that the former considers only one period. So the input of DCFP should be different basic information in each period and the output also should be different scheme for each period, so we can define as follows:

$$\overrightarrow{MGPF_D} = [MGPF_1, MGPF_2, \cdots, MGPF_n]$$
$$\vec{V}_D = [V_{D1}, V_{D2}, \cdots V_{Dn}]$$
$$\vec{\alpha} = [\alpha_1, \alpha_2, \cdots, \alpha_n]$$
$$\vec{\beta} = [\beta_1, \beta_2, \cdots, \beta_n]$$
$$\vec{\gamma} = [\gamma_1, \gamma_2, \cdots, \gamma_n]$$
$$\cdots$$
$$\vec{\omega} = [\omega_1, \omega_2, \cdots, \omega_n]$$

where, n means period number; $\overrightarrow{MGPF_D}$ means cell formation scheme vector for all period; $\vec{V}_D$ means cost vector; $\vec{\alpha}, \vec{\beta}, \vec{\gamma}, \cdots, \vec{\omega}$ mean basic information vector:

V_{TD} = The total cost for all period
F_D = Dynamic cell formation function
G_D = Cost function for dynamic cell formation

Then we can gain the abstract function based on input and output information and function:

$$\overrightarrow{MGPF_D} = F_D(\vec{\alpha}, \vec{\beta}, \vec{\gamma}, \cdots \vec{\omega}) \quad (3)$$

$$V_{TD} = G_D(\overrightarrow{MGPF_D}, \vec{\alpha}, \vec{\beta}, \vec{\gamma}, \cdots \vec{\omega}) = \sum_{t=1}^{n} V_{Dt} \quad (4)$$

where, Eq. 3 means the function relationship between $MGPF_D$ and parameters of $\vec{\alpha}, \vec{\beta}, \vec{\gamma}, \cdots, \vec{\omega}$; Eq. 4 means the function relationship between V_D and $MGPF_D$ and $\vec{\alpha}, \vec{\beta}, \vec{\gamma}, \cdots, \vec{\omega}$.

DCFP need consider the cell reconfiguration cost when appearing different cell formation scheme between adjacent periods. It need decide cell formation scheme for each period based on weighing between reconfigure cost and material handling cost, Variation of each period cell-formation scheme will cause machines configuration or material handling for other period, so cell formation scheme of each period will influence each other and the cell formation scheme of the first period and the t^{th} period can be represented, respectively as follows:

$$MGPF_t = F_D\begin{pmatrix} MGPF1, MGPF2, \cdots, MGPF_n, \\ \alpha_t, \beta_t, \gamma \cdots, \omega_t \end{pmatrix} \quad (5)$$

$$MGPF_t = F_D\begin{pmatrix} MGPF1, MGPF2, \cdots, \\ MGPF_{t-1}, MGPF_{t+1}, \\ \cdots, MGPF_n, \alpha_t, \beta_t, \gamma_t \\ \cdots \omega_t \end{pmatrix} \quad (6)$$

ABSTRACT FUNCTION FOR QCFP

QCFP considers cell formation scheme for a period based on the original manufacturing system and basic information, so we can define the abstract function according to the SCFP and DCFP abstract function:

$MGPF_Q$	=	Cell formation scheme for QCFP
V_Q	=	The cost based on the cell formation scheme
$\alpha, \beta, \gamma, ..., \omega$	=	parameters just like part-machines relationship matrix, machines capability, part demand, production process and so on
F_Q	=	Static cell formation function
G_Q	=	Cost function for static cell formation
$MGPF_0$	=	The initial cell formation scheme

Then the abstract function of QCFP can be gained:

$$MGPF_Q = F_Q(MGPF_0, \alpha, \beta, \gamma, \cdots \omega) \quad (7)$$

$$V_Q = G_Q(MGPF_Q, \alpha, \beta, \gamma, \cdots \omega) \quad (8)$$

where, Eq. 7 means the function relationship between $MGPF_Q$ and parameters of $\alpha, \beta, \gamma, ..., \omega$; Eq. 8 means the function relationship between V_Q and $MGPF_Q$ and $\alpha, \beta, \gamma, ..., \omega$.

According to abstract of three cell formation problems, we can gain the abstract for CFP as follows:

$$MGPF = [MGPF_1, MGPF_2, \cdots MGPF_n] = F\left(MGPF_0, \vec{\alpha}, \vec{\beta}, \vec{\gamma}, \cdots, \vec{\omega}\right)$$

- When $MGPF_0$ and n = 1, this function represent SCFP
- When $MGPF_0$ and n>1, this function represents DCFP
- When $MGPF_0$ and n = 1, this function represents QCFP

Analysis for multi-period CFP when $MGPF_0$ and n>1: We can gain different abstract function by different cell formation principle as mentioned above but the cell formation problem that $MGPF_0 \neq$ and n>1 can be seen as dynamic cell-formation problem because of n>1 according to the DCFP concept. And it also can be seen as quasi-dynamic cell-formation problem because $MGPF_Q \neq 0$ according to the QCFP concept. But the last cell formation scheme maybe different based on these two different formation principles.

Analysis for multi-period CFP when $MGPF_Q \neq 0$and n>1 by quasi-dynamic cell-formation principle: From QCFP point of view, cell formation scheme of each period is based on the relation parameters of this period and initial machines layout and part family division. So we can divide the cell formation problem that $MGPF_0 \neq$ and n>1 into n single quasi-dynamic cell-formation problem

According to 3.2 and 3.3, we can redefine some parameter for multi-period cell-formation problem as follows:

$MGPF_{QT}$	=	The cell formation scheme of period t
V_{QT}	=	The cost of period *t* according to $MGPF_{QT}$

Then we can gain the formulae as follows:

$$\begin{cases} MGPF_{Q1} = F_Q(MGPF_0, \alpha_1, \beta_1, \gamma_1, \cdots \omega_1) \\ MGPF_{Qt} = F_Q(MGPF_{t-1}, \alpha_k, \beta_k, \gamma_k, \cdots \omega_k) \end{cases} \quad (9)$$

$$\begin{cases} V_{Q1} = G_Q(MGPF_0, MGPF_1, \alpha, \beta, \gamma, \cdots \omega) \\ V_{Qt} = G_Q(MGPF_{Q(t-1)}, MGPF_{Qt}, \alpha_k, \beta_k, \gamma_k, \cdots \omega_k) \end{cases} \quad (10)$$

The total cost of n period is:

$$V_{TQ} = \sum_{t=1}^{n} V_{Qt} \quad (11)$$

Equation 9 means the first period cell-formation scheme is depended on the $MGPF_0$ and basic information α_1, β_1, γ_1,... ω_1 and period t is depended on the $MGPF_{t-1}$ and basic information α_k, β_k, γ_k,...ω_k. Equation 10 means cost function for the first period and period t. Equation 11 means the total cost equal cost sum of all period.

Analysis for multi-period CFP when $MGPF_0 \neq 0$ and n>1 by dynamic cell-formation principle

Problem analyses based on accurate prediction data: If each parameter is prediction and defined as 3.2, then we can gain global optimal scheme for each period. And the abstract function is same as Eq. 3 and 4:

$$\overrightarrow{MGPF_D} = F_D(\vec{\alpha}, \vec{\beta}, \vec{\gamma}, \cdots \vec{\omega})$$

$$V_{TD} = G_D(\overrightarrow{MGPF_D}, \vec{\alpha}, \vec{\beta}, \vec{\gamma}, \cdots \vec{\omega}) = \sum_{t=1}^{n} V_{Dt}$$

$$\overrightarrow{MGPF_D} = [MGPF_1, MGPF_2, \cdots, MGPF_n]$$

$$\vec{V}_D = [V_{D1}, V_{D2}, \cdots, V_{Dn}]$$

Problem analyses based on inaccurate prediction data: Dynamic cell-formation principle synthetically analyzes multi-period cell-formation problem and get global optimal scheme for each period, so it need predict all parameters for all follow-up periods beginning of the first period. And data precision including part demand, production process and machines capability effect directly on the validity of all period schemes. But with speed accelerating of product update and improving of science and technology, it can only gain comparatively accurate prediction data for next period and it has greater risk for predicting parameters of other follow-up periods. The period more lately, the deviation between forecast data and actual data will be bigger and the risk will be increasing gradually.

For solving the risk from prediction deviation, many researchers have applied fuzzy technology but fuzzy technology can only deal with demand prediction, machines capability prediction, operation cost and other cost prediction and overwhelms for production technology, production process route changing and other factors that effect production time, machines loading that are of vital importance in CFP. So it has bigger risk to analyze cell formation problem using dynamic cell-formation principle.

The result of cell formation problem is discrete, so the influence of parameters on the cell division is also discrete. The final scheme of each period will be changed only when parameter deviation has exceeded a certain critical value Δc.

Supposing it has a reasonable range deviation for parameter i in the period t that is $\Delta_i \leq \Delta_{ci}$, it only lead to a cost fluctuate ΔV_{Dt} for period t (where, Δ_G means the critical value for parameter i) , the cost of period i V_{Dt} is changed to $\bar{V}_{Dt} = V_{Dt} + \Delta V_{Dti}$ and the final schemes for all period are not changed.

But supposing the deviation of parameter i in the period t exceed the critical value V_{Gt} that is $\Delta_i > \Delta_{Ct}$, then the final schemes of each period are no longer the optimal solution. At this moment, the cost of period t need add a punishment cost besides adding ΔV_{Dti} and then the cost function of period t is as follows:

$$V_{Dt} = \begin{cases} \bar{V}_{Dt} & \Delta i \leq \Delta c_i \\ \bar{V}_{Dt} + C & \Delta i > \Delta c_i \end{cases} \tag{12}$$

Supposing there has m parameters for cell formation problem and the probability that deviation of parameter i in period t exceeds critical valve Δ_{Ct} is P_{ti}, then the total probability that will lead to optimal scheme invalidation for period t is:

$$P_t = \sum_{i=1}^{m} P_{ti}$$

Then we can gain cost expected value for period t:

$$E(V_{Dt}) = V_{Dt} + \Delta V_{Dt} + P_t \times C = \bar{V}_{Dt} + P_t \times C \tag{13}$$

Then the total cost expected value for all period is:

$$\bar{V}_{TD} = \sum_{t=1}^{n} E(V_{Dt}) = \sum_{t=1}^{n} \left(V_{Dt} + \Delta V_{Dt} + P_t \times C\right) = \sum_{t=1}^{n} \left(\bar{V}_{Dt} + P_t \times C\right) \tag{14}$$

According to prediction theory, the prediction precision is decreasing with the adding of period n. On the same conditions for cell formation problem, with the adding of period the probability of leading to optimal scheme invalidation is increasing that is $P_1 < P_2 < ... P_n$.

Different analysis for objective function of quasi-dynamic cell-formation principle and dynamic cell-formation principle: According to the analysis of 3.4.1 and 3.4.2, when the prediction data is precision, we can gain the total cost of all period for quasi-dynamic cell-formation principle and dynamic cell-formation principle, respectively:

$$V_{TQ} = \sum_{t=1}^{n} V_{Tt}$$

$$V_{TD} = \sum_{t=1}^{n} V_{Dt}$$

The dynamic cell-formation principle considers global optimum of all period and quasi-dynamic cell-formation principle only consider optimum for, so we can gain:

$$V_{TQ} = \sum_{t=1}^{n} V_{Qt} \geq V_{TD} = \sum_{t=1}^{n} V_{Dt}$$

But if it only can gain accurate data of next one period and other subsequent period data have a certain deviation, then the total cost expected value for all period according to dynamic cell-formation principle is as Eq. 14:

$$\bar{V}_{TD} = \sum_{t=1}^{n} E(V_{Dt}) = \sum_{t=1}^{n}\left(V_{Dt} + \Delta V_{Dt} + P_t \times C\right) = \sum_{t=1}^{n}\left(\bar{V}_{Dt} + P_t \times C\right) \quad (14)$$

Then:

$$V_{TQ} - \bar{V}_{TD} = \sum_{t=1}^{n} V_{Qt} - \sum_{t=1}^{n}\left(V_{Dt} + \Delta V_{Dt} + P_t \times C\right) = \Delta - \sum_{t=1}^{n} P_t \times C \quad (15)$$

Where:

$$\Delta = V_{TQ} - V_{TD} - \Delta V_{Dt} \quad (16)$$

Given:

$$\Omega = \Delta - \sum_{t=1}^{n}\left(P_t \times C\right) \quad (17)$$

It is obvious that the Ω value is decided by the deviation probability P. According to the analysis mentioned above, $P_1<P_2<...<P_n$, with the adding of period, the probability of leading to optimal scheme invalidation is increasing that is the value of P are increasing, the Ω value is tend to less than 0.

For the cell formation problem when $MGPF_0 \neq 0$ and n>1, if all data are accurate, the result of dynamic cell-formation principle will better than quasi-dynamic cell-formation principle; but data predict of long period often exist deviation and the result infeasible of optimal schemes of each period adds operation risk and cost for enterprises. So in multi-period circumstance, it will be more adaption for enterprises to using quasi-dynamic cell-formation principle than dynamic cell-formation principle considering the prediction deviation.

UNIFORM ABSTRACT FUNCTION FOR CFP

For the single period cell formation problem, static cell-formation principle do not consider effect of initial machines and part cell division on the optimal scheme. Of course, it also can be seen as the quasi-dynamic cell-formation problem without initial condition.

For the multi-period, the optimal scheme for each period may be infeasible because of prediction data deviation when using dynamic cell-formation principle, so it is better that using quasi-dynamic cell-formation principle than dynamic cell-formation principle to decrease the risk coming from data deviation.

Then for cell formation problem, we can use a uniform abstract function to describe as follows:

$$\overrightarrow{MGPF} = [MGPF_1, MGPF_2, \cdots, MGPF_n]$$

$$MGPF_t = F(MGPF_{t-1}, \alpha_t, \beta_t, \gamma_t, \cdots \omega_t) \quad (18)$$

$$\vec{V} = [V_1, V_2, \cdots V_n]$$

$$V_t = G(MGPF_{t-1}, \alpha_t, \beta_t, \gamma_t, ..., \omega_t) \quad (19)$$

where, n means period number; $\overrightarrow{MGPF}$ means cell division scheme vector; F denotes cell formation function; G denotes cost function and $\vec{V}$ means cost vector. Eq. 18 means the function relationship between $MGPF_t$ and parameters of $\alpha_t, \beta_t, \gamma_t, \cdots, \omega_t$. Eq. 19 means the function relationship between V_t and $MGPF_t$ and $\alpha_t, \beta_t, \gamma_t, \cdots, \omega_t$.

CONCLUSION

Manufacturing process is very complication and the manufacturing environment is unpredictable because of factors fluctuation inside and outside. So the scheme gained by dynamic cell-formation principle is always a real optimal solution for multi-periods problem and that lead to production confusion and extra manufacturing cost. Quasi-dynamic cell-formation principle divides the machines cell and part family according to the production progress and process adjustment information of previous period that makes up the risks from prediction information deviation and adapts to the development of enterprise actual demand and more acceptable for enterprises.

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