A Decision Making Tool in FMS Design

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Abstract

In FMS design one of the initial fundamental decision concerns the flexibility level of the workstations to be implemented. New machining centers offer the possibility to carry out several operations on the workpieces to be processed, thus reducing the workload both of the material handling system and of the resources used to control the part flow in the FMS. In spite of advantages related to the use of the machining centers with high flexibility, the better typology of each workstation must be evaluated taking into account its influence on the tools fleet and on the workload of the handling and tool room subsystems.

This paper proposes a fuzzy decision support model to select the flexibility level of the workstations facing the uncertainty related to the dimension of the subsystems to be implemented in order to obtain a reliable tool flow.

Keywords

FMS design, fuzzy optimization

INTRODUCTION

In the Flexible Manufacturing Systems (FMS) design two main issues have to be considered: the flexibility and the integration level among the resources in the system.

The flexibility can be measured according to the amount of time and cost that the manufacturing system will spend to react to external changes, such as market changes, and internal changes, such as resources breakdown; the integration level can be evaluated by the influence of the management policies on the system performances (Alberti, N. et al. 1988).

The above characteristics make the FMS design more complex than a traditional system both for the larger number of design alternatives which have to be considered and for the uncertain impact of the above alternatives on the integration among the system resources and therefore on their performances.

Moreover the FMS design is characterized by an higher entrepreneur risk caused by the economic importance of each design alternative and by the wider integration due to higher use of shared resources when flexibility and production capacity are increased.

The FMS design parameters able to influence the system flexibility are the amount and the typology of the technological operations which will be processed by the manufacturing system; these parameters are usually evaluated taking into consideration the actual production plan in the short period and the opportunity production plan in the medium and long period (Perrone, G. et al., 1994a) (Perrone, G. et al., 1994b). The flexibility level gained will depend on the technological resources effectively installed in the system able to perform the above operations. This configuration impacts the operative execution of the operations in the production plan and then times and costs required to react to the changes.

One of the main design alternatives concerns the machine flexibility of each resource to install, that is:

- dedicated technological resources which are able to perform a small number of technological operations;
- general purpose technological resources able to perform a large number of technological operations in the same machining center.

Even if the emerging trend seems to encourage flexible manufacturing systems consisting of general purpose work-centers (Semeraro, Q. et al., 1993) in order to reduce the workload of the material handling system, to improve the utilization rate of the machining centers and finally to make easier the modularity of the production system, it is necessary to consider both the alternatives because they require different investment and running costs due to the number of workstations to be installed, to their utilization rates and to the tool fleet design.

A system characterized by dedicated technological resources asking for an almost static tool management allows to reduce the tool fleet dimension and the tool handling system, but on the other side it penalizes the utilization rates of the machines and it requires an higher investment cost of the material handling system; on the contrary, a system characterized by general purpose machine allows to improve the resources utilization rates, but it asks for a wider tool fleet and a more complex tool handling system (La Commare, U. et al., 1993).

The paper proposes a model able to support the FMS designer in getting a satisfied cost compromise solution between the two alternatives above discussed allowing the designer to put into the model some vague information that characterize the design phase.

MODEL ASSUMPTIONS

The tool fleet and management tool system investment costs

Tools, tool fixtures and tool handling system are resources whose cost can be compared with workstations in a FMS environment; late technical and economical estimations have been figured out that for each CNC machine center installed tools accounts for 29% and fixture for 28% of the total invested capital; 16% of scheduled production cannot be met because of tooling is not available; 30-60% of tooling inventory is somewhere on the shop (Gaalman, G. J. C. et al., 1994). Therefore, in order to avoid high production costs caused by idle times on machine centers due to tools unavailability, it is necessary to dimension the tools fleet and its management system in order to guarantee an high reliability level of the tools system.

In order to evaluate all of the costs involved with the tool system in the early phase of the FMS design the proposed model considers the following assumptions.

A different tool code for each technological operation

This statement allows to assign both the tools and the machining operations to each workstation and therefore to figure out the number of tools with the same code duplicated in each workstation tools storage. If the workpiece part program in a given workstation requires many times the use of the same tool code, all of those technological operations are considered as a unique operation with a tool time equal to the sum of the partial tool times.

In this way the minimum number of tools, with the same code in the tool fleet, depends on the typology of the installed workstations being necessary to foresee that code in each workstation where that operation is performed.

The designer should be able to approximately evaluate the amount of time required to regenerate each tool and to handle it from/to each workstation

The tool fleet have to be designed in order to assure the availability of the tool on the machine storage when it is required by the part program. This condition it is not of easy achievement because of the great number of variables involved in it, such as the production policies and the detailed working conditions of the tool system.

Furthermore, while it is well known that the demand rate of spare tools on each workstation depends on technological parameters, on tool service times and on temporal distribution of the part type demand, and that the regeneration tool time, which affects the tool lead time between tool room and workstation, depends on the amount of resources available on the tool room and on the utilized tool handling system, the estimation of an analytical function able to express such dependencies is almost impossible.

A rough estimation of the number of spared tools n_g , coded with g , can be figured out using the Little law, i.e.:

$$n_g = d_g \cdot T_g \quad (1)$$

where d_g is the mean demand rate, whose value can be evaluated referring to the total tool service time and to its mean useful life for specific machining conditions, and T_g is the mean throughput tool time between tool-room and work center.

The model assumes the hypothesis that the designer has enough experience in the early design phase for an approximate estimation of the variability range of T_g and so of the spare tools n_g to foresee in the tools fleet.

The uncertainty in the estimation of n_g is approached through a fuzzy number (Zadeh, L. A., 1965) which is an easy way to express in mathematical way vague concept such as "approximately".

Because of both d_g and T_g increase with the number of workstations which require the same tool code, the annual investment cost of the tool fleet and management tool system can be expressed as:

$$C_i = \sum_k y_k \cdot \tilde{n}_k \cdot \sum_i \beta_{i,k} \cdot z_{i,k} \quad (2)$$

where:

- $\beta_{i,k}$ is the equivalent annual investment cost, comprehensive of the direct cost of the tool fixture and of the quota of investment cost concerning the tool management system; this latter quota is assigned to the tool code required for the operation i performed on the workstation k ,

- y_k is the number of workstations of type k to be installed in the production system;
- $z_{i,k}$ is a binary coefficient equal to 1 if the operation i ($i = 1, \dots, I$) is performed on the workstation k , 0 otherwise;
- $\tilde{n}_k$ triangular fuzzy number (a, b, c) whose mean value b is equal to the most possible value and the extreme values a and c depend on the variability range of the dimension of fleet tools estimated by the designer.

Opportunity costs

Opportunity costs are those investment costs which are not necessary for production activities. They are caused by the unbalancement among the workstations in the FMS that determines an incomplete utilization of the technological resources.

This under utilization of the technological resources is due to the necessity to process simultaneously some part types with different process plans; therefore, these costs can be configured like fixed costs that the company decide to burden with in order to deal with the competitive advantages coming from a flexible manufacturing system.

These costs reduce the operative profit of the company and the investment net present value and they increase the investment payback period of the investment, so that they have to be minimized choosing the system configuration that better allows to utilize the resources assuring an high flexibility value.

The global opportunity cost to be considered in the choice of the technological resources is:

$$C_o = \sum_{k=1}^K y_k \cdot C_k \cdot (1 - u_k) \quad (3)$$

where:

- C_k is the annual equivalent investment cost of the workstation k ($k=1, \dots, K$), comprehensive of the direct costs and of the quota of investment cost concerning the logistic and control resources;
- u_k is the mean utilization rate of the workstation k .

The model

The model assumes a scenario in which the designer can choose the typology k ($k=1, \dots, K$) of each workstation inside a range K of possible alternatives characterized by different machine flexibility or abilities to perform various machining operations ($i=1, \dots, I$) involved in the mix production plan.

The criterion driving the model is the minimization of the investment cost of the workstations with the related material handling system, of the tool fleet and its management system cost and the opportunity cost. Since these fixed costs have different life cycle they have to be capitalized in a proper way. The model assumes for each one the annual equivalent cost. Let us indicate with:

- WL_i the total annual service time required by the machining operation i for realizing the required production plan;
- $x_{i,k}$ the percentage of WL_i to be assigned to the workstation k .

The workload for each workstation can be computed as:

$$T_k = \sum_{i=1}^I x_{i,k} \cdot WL_i \quad (4)$$

so that using the static allocation procedure the utilization rate for each workstation can be expressed as:

$$u_k = \frac{T_k}{y_k \cdot T} \quad (5)$$

where T is the annual availability time of each technological resources k and y_k is the number of resources k to be installed in the designing FMS.

With the above assumptions the analytical decisional model can be formulated as:

Model A (Decision variables: $y_k, x_{i,k}$)

$$\text{Min}(C_T) = \text{Min}(C_w + C_t + C_o) \quad (6)$$

subject to:

$$\begin{aligned} \sum_{k=1}^K x_{i,k} &= 1 \quad \forall i; \\ \sum_{i=1}^I x_{i,k} \cdot WL_i &\leq y_k \cdot T \quad \forall k \end{aligned} \quad (7)$$

$$z_{i,k} \geq x_{i,k} \quad \forall i, k$$

with:

- $C_w = \sum_k y_k \cdot C_k$ annual equivalent investment cost of the workstations and the related logistic and part control flow system.
- $C_t = \sum_k y_k \cdot \tilde{n}_k \cdot \sum_i \beta_{i,k} \cdot z_{i,k}$ annual equivalent investment cost of the tool fleet and the related management system.
- $C_o = \sum_k y_k \cdot C_k \cdot (1 - \frac{\sum_i x_{i,k} \cdot WL_i}{y_k \cdot T})$ opportunity costs.

In order to get a solution of the model A it is necessary to apply a method able to compare triangular fuzzy numbers each other; in order to obtain a crisp linear model that can be resolved using an integer linear programming resolutor the Integral Value Method (Liou, T. S. et al., 1992) is suggested. Moreover, the uncertainty about the tool fleet dimension

$\left(\tilde{n}_k = (a_{n_k}, b_{n_k}, c_{n_k}) \right)$ can be observed in the expression of the cost C_T that becomes a triangular fuzzy number too: $\tilde{C}_T = (a_{C_T}, b_{C_T}, c_{C_T})$, where a_{C_T} and c_{C_T} are the values assumed by C_T with the workstations typology corresponding to the solution of the crisp model when the minimum a_{n_k} and the maximum c_{n_k} values of $\tilde{n}_k$ are considered.

In order to control the investment risk due to the uncertainty the following complementary linear objective function can be introduced:

$$\text{Min}(U) = \text{Min}(c_{C_T} - a_{C_T}) \quad (8)$$

Adding the above objective function to the model A, it becomes a multiple objective model. A fuzzy multiple objective programming method able to find a compromise solution with Pareto optimum will be used (Lee E.S. et al., 1993). The new linear model can be formulated as:

Model B (Decision variables: $y_k; x_{i,k}$)

$$\text{Max}[\gamma \cdot \lambda_1 + (1 - \gamma) \cdot \lambda_2] \quad (9)$$

subject to:

$$\lambda_1 \leq \frac{C_{T \max} - C_T}{C_{T \max} - C_{T \min}} \quad \lambda_1 \text{ pushes the cost } C_T \text{ to the minimum value}$$

$$\lambda_2 \leq \frac{U_{\max} - U}{U_{\max} - U_{\min}} \quad \lambda_2 \text{ pushes the uncertainty } U \text{ to the minimum value}$$

Other constraints

Equations (7) of the model A

where:

- $U_{\max}, U_{\min}$ are the maximum uncertainty considered obtained with the model A and the minimum uncertainty obtained minimizing eq. (8) with constraints (7) respectively;
- $\gamma \in [0, 1]$ is the weight measuring the relative importance of the two objectives.

NUMERICAL EXAMPLE

The proposed model has been tested by a proper numerical example in which it has been supposed to design an FMS able to manufacturing a mix of parts requiring 15 different machining operations. The global machining times (WI_i) for the operations, referred to the annual availability (T) of the FMS, are reported in the table 1.

To perform the operations the designer can choose 7 different typology of workstations ($k=1, \dots, 7$). An annual equivalent investment cost decreasing with the flexibility has been assigned to each typology; in fact the increment of the investment cost of a machining center with higher flexibility is absorbed by the lower quota of the logistic and part flow control resources costs for that station.

Table1 Design data

Table 2 Model results

	$K=1$	$K=7$	$K=1$	$K=2$	$K=3$	$K=2$	$K=3$	$K=4$	$K=5$
$Op.$	$X_{i,1}$	$X_{i,7}$	$X_{i,1}$	$X_{i,2}$	$X_{i,3}$	$X_{i,2}$	$X_{i,3}$	$X_{i,4}$	$X_{i,5}$
1	100%		100%					6%	94%
2	11%	89%	100%					100%	
3	100%		100%						100%
4	100%		100%					100%	
5		100%		100%		100%			
6		100%		100%		100%			
7		100%		100%		100%			
8		100%		100%		65%		35%	
9		100%		100%		100%			
10		100%		100%		100%			
11		100%			100%		100%		
12		100%			100%				100%
13		100%			100%		90%		10%
14		100%			100%		100%		
15		100%			100%				100%
	Results ($\gamma=1$)		Results ($\gamma=0$)			Results ($\gamma=0,5$)			
y_k	2	7	3	5	3	4	2	1	2
	$\left(\frac{C_T}{C_7}\right)^* = 12,78$		$\left(\frac{C_T}{C_7}\right)^* = 19,6$			$\left(\frac{C_T}{C_7}\right)^* = 13,72$			
	U = 2,36		U = 0,3			U = 0,44			

Observing the results shown in table 2 the relation between the typology of the workstations and the objective employed by the decision maker can be pointed out; considering only the economic objective in the model B ($\gamma = 1$) machining centers with higher flexibility are suggested, while reducing the risk due to the uncertainty ($\gamma = 0$) more and more dedicated resources are preferred.

CONCLUSIONS

The proposed model can be considered a tool to support the selection of the workstations typology to be considered in the early phase of a FMS design when a lot of variables are affected by uncertainty. The model assumes that workstation flexibility scenario is correlated to the social environment in which the company is operating; this kind of social constraints can bound the possible technological alternatives reducing the capability of choice in selecting appropriate manufacturing technologies with related economical implications.

The fuzzy approach presented gives the opportunity to evaluate in an interactive way the economical consequences of each alternative offering to the designer the possibility to choose between the minimum investment cost and the minimum uncertainty investment cost, or a trade-off solution.

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