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ADVANCED MANUFACTURING SYSTEMS AND TECHNOLOGY

FIFTH INTERNATIONAL CONFERENCE ON
ADVANCED MANUFACTURING SYSTEMS
AND TECHNOLOGY
PROCEEDINGS

EDITED BY

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UNIVERSITY OF UDINE



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FROM FUNCTIONAL TO CELLULAR MANUFACTURING SYSTEMS

EVALUATION OF ATTRACTIVENESS

A. De Toni and A. Meneghetti
University of Udine, Udine, Italy

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ABSTRACT

In the last decade some case and simulation studies showed how moving from a traditional functional layout to a group technology cellular one could be disadvantageous, opening a debate about the actual attractiveness of such a conversion.

Basing on a simple analytical queueing model, we compare a work shop performance to a partitioned system one, obtained by dedicating some machines to a family of products. We recognise how four parameters that describe both the unpartitioned and the new system characteristics can affect the value of a proper indicator, which measures the convenience of changing the manufacturing system and it is function of the lead times of the two manufacturing environments.

A simulation model is built to verify what the analytical model suggests; results confirm how the four parameters actually affect the convenience indicator; particularly interesting is the relevance of the factor which counts for the different process time of the various products and that distinguishes this research from previous studies.

1. INTRODUCTION

During the last three decades Group Technology principles have spread all around the world asserting the convenience of moving from a traditional functional layout to cellular manufacturing. Nevertheless, at the beginning of '70s some researchers as Leonard and Rathmill [1] expressed their doubts about the effective reduction in flow times and work-in-process achievable by cells. They claimed that several successful applications of cellular

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manufacturing were not compared to efficient job shops, but to the poor performing functional layout which many firms started with. Successive simulation studies, as Flynn and Jacobs [2], Morris and Tersine [3], confirmed how, under many operative conditions, functional laid out systems gain better performance than cells. It was so highlighted what Shambu et al. [4] term the “cellular manufacturing paradox”. More recently published articles try to explain this paradox by developing analytical models that can overcome the particularity of simulation experiments and give a more general understanding. In particular Suresh [5], [6] and Suresh and Meredith [7] represent the original system and the new partitioned one, formed by cells and a remainder system, by queuing models in which all the products are supposed to have the same process time (the so termed “single-class” products) and only a single production step is considered. They deduce a deterioration of performance in the remainder system due to a loss of pooling synergy that erodes the advantages associated with the cells and often make the change not so attractive. The flexibility required to job shops makes the hypothesis of single-class products quite restrictive; we believe, instead, that the “multi-class” characteristic of the most functional laid out systems, i.e. the presence of very different process times, plays an important rule on determining the success of any cellular transformation. Thus, we introduce a multi-class factor in our analytical model to count the possibility that very different items have to be processed in the original system. The survey of Wemmerlov and Hyer [8] reports that the 43% of the respondents implemented cellular manufacturing as a machine dedication without moving the equipment to create cells. Therefore we decided to investigate how a multi-server work shop performs when some machines, which form a production step of the virtual cell, are formally assigned to a part family. The basic idea is to express the performance of the partitioned system as a function of the characteristics of the original work shop and some proper factors describing the type of change. Then we used simulation experiments to validate what our analytical model suggests about the cellular paradox.

2. ANALYTICAL INSIGHTS

We consider a typical work shop (marked by sub-index w) with m machines and describe it as a queueing system with m servers and both the interarrival and process times belonging to a Markovian distribution, i.e. we use a $M/M/m$ queueing model. Since actual systems have often to manage different products, each with its own processing time and arrival rate, we try to extend Suresh’s analysis to the multi-class problem.

Following Whitt [9] and Bitran and Tirupati [10] approach, first an “aggregate product” is formed by properly combining the data of the different items. This aggregate product is then used to replace all the parts that have to be processed in the work shop; in this way the multi-class problem can be brought back to a single-class one, which is more easy to manage. Several assumptions are made for reason of tractability.

Let $\lambda_i = D_i / q_i$ be the mean arrival rate of the i -th part, supposed to follow a Poisson process, where D_i and q_i are its demand rate and lot size respectively. The arrival rate of the aggregate product to the work shop is still Poisson with a mean $\lambda_w = \sum_i \lambda_i = \sum_i D_i / q_i$. Its unit process time is supposed to be exponentially distributed, with a mean equal to a weighted

average of all part unit process (run) time: $t_w = \sum_i \lambda_i t_i / \sum_i \lambda_i$. The service rate will be $\mu_w = 1/(\tau_w + q_w \cdot t_w)$, where τ_w is the average setup time per batch and q_w the lot size of the aggregate product in the work shop, while utilisation is $\rho_w = \lambda_w / \mu_w$.

We can now obtain the lead time W_w and the minimum lot size $(q_w)_{\min}$ for stability [9] in the work shop, analysed at an aggregate level:

$$W_w = \left[\sum_{n=0}^{m-1} \frac{\rho_w^n}{n!} + \frac{\rho_w^m}{m!(1 - \rho_w/m)} \right]^{-1} \frac{\rho_w^m \mu_w^{-1}}{(m-1)!(m - \rho_w)^2} + \mu_w^{-1} \quad (1)$$

$$(q_w)_{\min} = \frac{D_w \cdot \tau_w}{(m - D_w \cdot t_w)} \quad (2)$$

where $D = \sum_i D_i$ is the total demand rate, q_w the lot size of the aggregate product and τ_w its average setup time per batch.

Suppose now to dedicate a certain fraction β of the m machines to some parts, which can be considered a family in a Group Technology philosophy. A “cell” and a “remainder system” can so be recognised.

Let k , γ be the fraction of the total demand rate and the fraction of the aggregate mean process time that can be assigned to the cell respectively. Denoting by sub-indexes c and r the cell and the remainder system, we have:

$$\begin{aligned} m_c &= \beta \cdot m & m_r &= (1 - \beta) \cdot m \\ D_c &= k \cdot D_w & D_r &= (1 - k) \cdot D_w \\ t_c &= \gamma \cdot t_w \end{aligned}$$

The aggregate process time in the remainder system can be evaluated as following:

$$D_w t_w = D_c t_c + D_r t_r \Rightarrow D_w t_w = k D_w \gamma t_w + (1 - k) D_w t_r \Rightarrow t_r = \frac{1 - k\gamma}{1 - k} t_w$$

As regards setup times we introduce a reducing factor δ to account for advantages in the cell due to similarity of items, while we consider the aggregate setup time in the remainder system unchanged with respect to the original work shop:

$$\tau_c = \delta \tau_w \quad \tau_r = \tau_w$$

Even the cell and the remainder system have so been brought back to a single-class multi-server case and relations (1), (2) can be used to evaluate time-related performance in terms of the original work shop data (D_w, t_w, τ_w, m) .

Since we want to avoid that a comparison between the original work shop and the partitioned one could be distorted by the poor performance related to non-optimised systems, we determine for each system the lot size which leads to the minimum lead time. Since Karmarkar et al. [11] have demonstrated that lead time is a convex function of the lot size, we calculated the optimal value of lot size by progressively increasing the minimum lot given by relation (2) until lead time starts to grow.

An indicator has to be properly created to evaluate the convenience of moving from a traditional work shop to a partitioned one. Since a time-based competition approach is supposed to be coherent to market characteristics, we believe that the faster the deliveries the higher the price a customer is inclined to pay, so that, if W is the lead time and P a

proper constant, the unit price is $P_u = P/W$ [£/units]. The partitioned system has to be preferred if the related revenue in a time period T is greater than the unpartitioned one in the same period, i.e. if:

$$R_c + R_r - R_w > 0 \quad (3)$$

The dedication of some machines in a work shop may be associated to parts strategically important and therefore benefits expected from improving their lead time are greater than those obtained by increasing the performance of the others. Thus, we introduce a weight s to possibly increase the revenue associated to items diverted to the cell whether their strategic rule has to be considered.

Relation (3) can be rewritten as:

$$\begin{aligned} s(P/W_c)D_cT + (P/W_r)D_rT - [s(P/W_w)D_cT + (P/W_w)D_rT] &> 0 \Rightarrow \\ s(P/W_c)kD_wT + (P/W_r)(1-k)D_wT - [s(P/W_w)kD_wT + (P/W_w)(1-k)D_wT] &> 0 \Rightarrow \\ s \cdot k \left(\frac{1}{W_c} - \frac{1}{W_w} \right) + (1-k) \left(\frac{1}{W_r} - \frac{1}{W_w} \right) &> 0 \end{aligned} \quad (4)$$

If we denote with R the left-hand side of the above inequality, we obtain a proper indicator to compare the original work shop to the partitioned system. R is a function of the original work shop data and the type of change introduced into the system; the four factors β , k , γ , δ , in facts, describe the new partitioned system in terms of number of original machines and demand rate devolved to the cell, characteristics of the portion of products processed in the cell and the expected setup time reduction due to similarity. Thus, given a work shop, it is possible, on the basis of the values assigned to the four factors, describe different potential cellular layouts and evaluate if the related change is advantageous from a time-based competition point of view.

3. RESULTS FROM THE ANALYTICAL MODEL

In general we can observe how partitioning the original work shop leads to an improvement of the cell performance but a deterioration in the remainder system. Thus, the change looks convenient only if cell improvement can overcome the worse performance obtain in the remainder system due to what Suresh and Meredith [7] define a loss of pooling sinergy.

Varying one factor at a time it is possible to draw the behaviour first of the lead time in the cell and in the remainder system, as showed for example in figure 1, and then the values assumed by the indicator R , measuring the opportunity of a system change (see figure 2).

From the analytical model we can deduce the existence of proper combinations of the four factors leading the partitioned system to perform better than the original work shop ($R > 0$). Varying the four design factors outside this optimal four-dimension region leads to a poorly performing system (see the negative values of R assumed in figure 2); it is so underlined that partitioning a work shop is not always correct and cellular manufacturing has to be carefully adopted.

As expected, the strategic weight of cell products s is able to enlarge the region of factors' variation which ensure the opportunity of partitioning the original work shop.

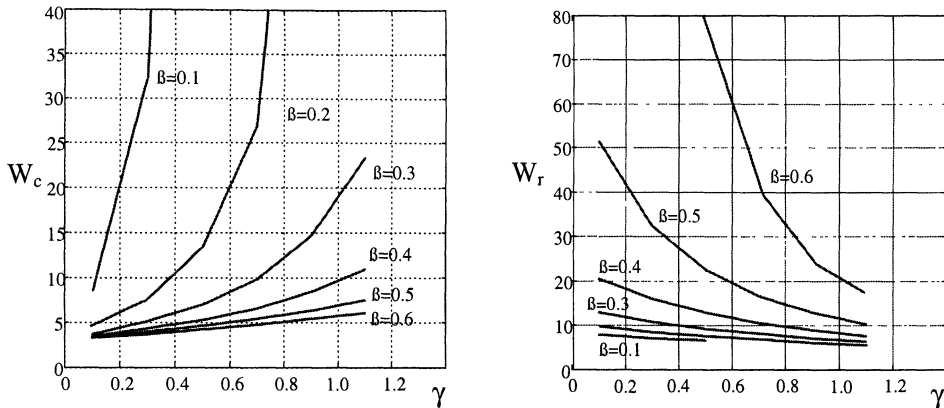


Figure 1 Lead time [h/batch] W_c in the cell and W_r in the remainder system varying β and γ

Particularly interesting is how the multi-product factor γ , which has been introduced to describe the multi-class characteristic of the analysed systems, can really affect their performance and consequently the opportunity of a change. This suggests that if the chance for a work shop to process products with very different run times is ignored, i.e. a single-class model is adopted, wrong decisions can be taken.

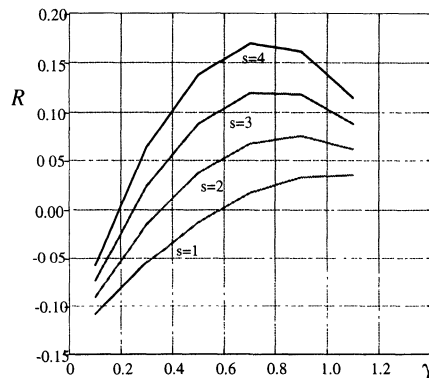


Figure 2 The indicator R varying the multi-class factor γ and the strategic weight s .

4. SIMULATION EXPERIMENTS

The analytical model suggests that partitioning a work shop not always leads to an improvement of performance; the four factors introduced to describe the type of change applied to the original system seem to play an important rule for a successful result.

Thus, it is reasonable to deduce that before bringing any transformation to the system, attention has to be paid to decide the number of machines to be moved, the portion of demand rate devolved to the cell, to which items, in term of processing times, the cell is going to be dedicated and finally how much setup reduction can be made due to part similarity in the family. Since the analytical model is simplified for tractability, we

conducted simulation experiments to validate the conclusions it leads to, i.e. to verify if the four factors can really explain a successful or unsuccessful system change.

We simulated first a work shop made by 10 machines that processes 13 products for a total demand rate of 400 units/hour, with Poisson arrivals and different exponentially distributed process times. As the original work shop has to be optimised for a proper comparison, we chose the lot size of every item to ensure system stability and a low work-in-progress level. After calculated the lead time associated to this original work shop, we partitioned it dedicating a certain fraction β of machines to some products that can naturally form a family in a Group Technology meaning. The items diverted to the "cell" amount for a portion k of the total demand rate and their mean run time is γ times the mean run time of all the products. Also, due to similarity in the family, a setup reduction δ is applied in the cell. Then we varied the values of the four factors to measure deterioration or improvement of performance in the partitioned system by the indicator R . Items devolved to the cell are not recognised to be strategically relevant; therefore, $s = 1$.

We performed a 2^4 factorial design, considering for each of the four factors β, k, γ, δ only a low and a high level of variation, as showed in Table 1; 10 replications of experiments are made.

Factors	Description	Low level	High level
β	fraction of machines	0.4	0.6
k	fraction of demand	0.3	0.5
γ	fraction of process time	0.8	1.1
δ	setup reduction	0.6	0.9

Table 1 Levels for the 2^4 factorial design

5. SIMULATION RESULTS

The main effects, which represent the change induced on R if a factor moves from is low level to his high level, and the two-factor interaction ones statistically significant ($\alpha=0.1$) are shown in Table 2.

The three major effects are related to factors k, γ and the interaction of β and γ . Increasing the portion of demand rate devolved to the cell has a positive impact on R and therefore on the convenience of a system change; it may be deduced that dedicating some machines to particular items is worth-while only if there is a sufficient volume to be processed and conversely a low amount of demand has to face a loss of pooling synergy in the remainder system. This impact is strengthened if a setup reduction can be expected, as underlined by the negative interaction effect of k and δ (remember that a high level of δ is related to a low setup reduction and so a negative effect means a deterioration of performance if setup times are poorly reduced). In this case, in facts, a greater amount of demand can benefit by the shorter time spent in queue waiting for machines being set up. It has to be underlined how the relative small effect of δ on R can be associated to its quite small range of variation chosen for simulation experiments; this agrees with [5], [6] and [7] which recognised how a great reduction on setup times is required to face the loss of pooling synergy.

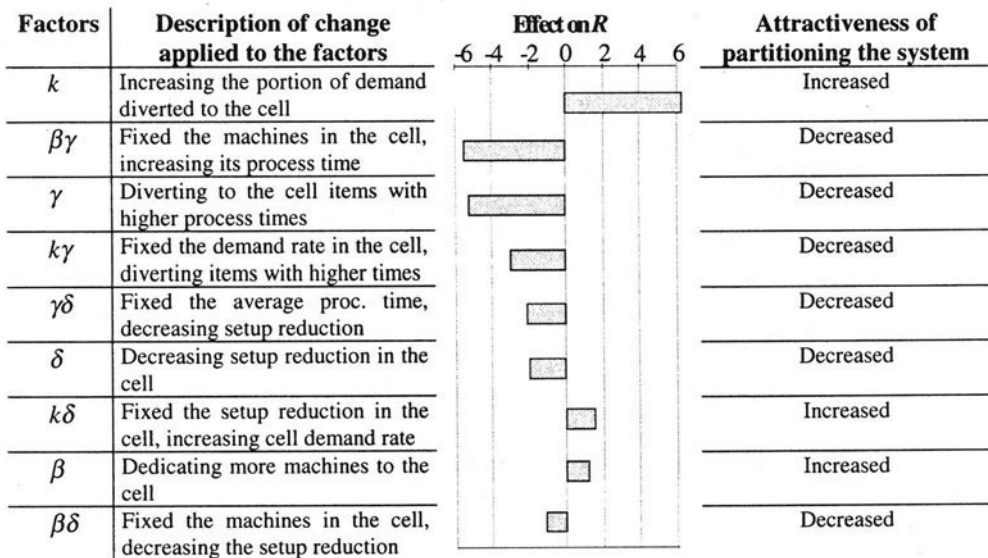


Table 2 Main and two-factor interaction effects on R statistically significant (W_c , W_r and W_{js} are expressed in seconds and effect values are E-06)

The remarkable negative effect of the multi-product factor γ attests what the analytical model suggests: the multi-class characteristic of a work shop cannot be disregarded while partitioning the system, because the longer the processing times of items diverted to the cell compared to the overall average processing time (i.e. the higher the value of γ), the greater the loss of pooling synergy. The interaction effect between β and γ shows, in facts, agreeing with the analytical model, how for a given β , i.e. a given number of dedicated machines, the advantage of partitioning the system decreases as the lead time of the cell grows due to the high run times of those items that cannot rely on the less loaded machines of the remainder system.

6. CONCLUSIONS

The analytical model and the simulation experiments shows that partitioning a work shop is not always advantageous. Attention has to be paid particularly to the portion of demand rate diverted to dedicated machines and to its processing times. It so underlined how a distorted expectation of improvement can be taken if the work shop is analysed as a single-class system. The cellular paradox stands out our study; it can be recognised, in facts, that successful changes in the system are made only if the relative factors fall in a proper region. This work can be regarded as a first step to better understand the effective attractiveness of moving from a functional to a cellular manufacturing system, when Group Technology is implemented as a machine dedication problem, without moving the equipment. Further analysis can be made to understand how several partitioned work

shops, that belong to a part family routing, interact and affect the overall production system performance.

REFERENCES

1. Leonard, R. and Rathmill, K., "The group technology myths", *Management Today*, January 1977, pp. 66-9;
2. Flynn, B. B. and Jacobs, F. R., "A simulation comparison of group technology with traditional job shop manufacturing", *International Journal of Production Research*, Vol. 24, 1986, pp. 1171-92;
3. Morris, J. S. and Tersine, R. J., "A simulation analysis of factors influencing the attractiveness of group technology cellular layouts", *Management Science*, Vol. 36, No. 12, 1990, pp. 1567-78;
4. Shambu, G., Suresh, N. C. and Pegels, C. C., "Performance evaluation of cellular manufacturing systems: a taxonomy and review research", *International Journal of Operations and Production Management*, Vol. 16, No. 8, 1996, pp. 81-103;
5. Suresh N.C., "Partitionig work centers for group technology: insights from an analitical model", *Decision Sciences*, Vol.22, No. 4, 1991, pp. 772-91;
6. Suresh, N.C., "Partitionig work centers for group technology: analytical-extension and shop-level simulation investigation", *Decision Sciences*, Vol. 23, No. 2, 1992, pp.267-90;
7. Suresh, N.C. and Meredith, J.R., "Coping with the loss of pooling synergy in cellular manufacturing systems", *Management Science*, Vol. 40, No. 4, 1994, pp. 466-83;
8. Wemmerlov, U. and Hyer, N. L., "Cellular manufacturing in the US industry; a survey of users", *International Journal of Production Research*, Vol. 27, 1989, pp. 1511-30;
9. Whitt,W., "The Queueing network analyser", *Bell System Technology Journal*, Vol. 62, No. 9, 1983, pp. 2779-2815;
- 10.Bitran, G. R. and Tirupati, D., "Multiproduct queueing networks with deterministic routing: decomposition approach and the notion of interference", *Management Science*, Vol. 34, No. 1, 1988, pp. 75-100;
- 11.Karmarkar, U. S., Kekre, S., Kekre, S. and Freeman, S., "Lot-sizing and lead time performance in a manufacturing cell", *Interfaces*, Vol. 15, No. 2, 1985, pp. 1-9.