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Design and performance evaluation of agile manufacturing systems

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Design and Performance Evaluation of Agile Manufacturing Systems

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Abstract

In this paper, we present a framework for determining the type of layout to use in a manufacturing environment characterized by constantly changing product volumes and mix. Much of the production equipment is assumed to be relatively light weight and therefore their location can be easily changed to suit the current production environment. The framework allows several alternate layouts to be developed and evaluated with respect to deterministic (material flow and machine relocation) criteria as well as stochastic (queuing) criteria.

Keywords
Next generation layout, performance evaluation, design

2000 Mathematical subject classification
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1. Introduction
The current day manufacturing environment is characterized by numerous challenges and changes. A typical manufacturing company faces constantly changing product volumes and mix. Simultaneously, the production environment has seen rapid advances take place in materials engineering and manufacturing technology. Composite materials are replacing traditional material such as cast iron and steel. Not only are these materials light weight, they also have excellent mechanical and structural properties. For example, these materials can be made so as to have strong tensile and vibration absorbing properties. In addition, machining technology is also advancing rapidly. Non-abrasive manufacturing technology such as electron beam welding, laser cutting are replacing traditional machining processes. This trend is likely to continue well into the next two decades. In fact, through a workshop and a delphi survey, the committee on Visionary Manufacturing Challenges for 2020 has identified *adaptable processes and equipment* and *reconfiguration of manufacturing operations* as two key enabling technologies that will help companies overcome two of the six grand challenges or fundamental goals to remain productive and profitable in the year 2020 [1]. These grand challenges are to "achieve concurrency in all operations" and to "reconfigure manufacturing enterprises rapidly in response to changing needs and opportunities". In this paper, we discuss a new framework that can be applied to determine whether the current layout must be changed and if so, what the new layout must be given that there is a change in the production mix and volume during the next production planning period.

A direct result of the two advances in the materials and machining fields mentioned in the previous paragraph is that machines need not be heavy requiring elaborate foundation. Also, since the payload is light weight, material handling systems can also be designed to be relatively light weight. One can envision a manufacturing system of the future to be made of light weight manufacturing and materials handling equipment that can configured and reconfigured as and when needed - perhaps even on a monthly or weekly basis! A primary advantage of reconfiguring a layout when warranted by changes in product mix and volume is that material handling cost can be minimized because equipment can be reconfigured to suit the new production mix and volume. Of course, this cost must more than offset the cost of moving equipment from its current location to a new one. In addition, due to the short term life of a given layout and production data availability for this time period, it is possible to consider optimizing operational performance measures such as minimizing part cycle times, work in process inventory, etc. To summarize, the potential to frequently alter layouts, therefore, in a sense, transforms the modern layout problem from a strategic problem in which only long term material handling costs are considered to a tactical problem in which operational performance measures such as reduction of product flow times, work in process inventories, and maximizing throughput rate are considered in addition to material handling and machine relocation costs when changing from one layout configuration to the next.

2. Literature Review

Benjafaar et al. [2] mention that the design of next generation factory layouts can be done using two approaches. The first is to develop layouts that are robust for multiple production periods or scenarios. The second approach is to develop flexible layouts that can be reconfigured with minimal effort to meet the changed production requirement. The underlying assumption of the first approach is that production data for multiple (future) planning periods is available at the initial design stage. In the event that we do not have this luxury, this approach assumes a robust layout with inherent features can be developed so that changes in production over the multiple periods can be accommodated with little material handling cost. Examples of papers that assume rich data is available at the initial design stage include [3], [4], [5] and [6]. Calling the problem a dynamic layout problem, these papers use various strategies to find a layout that is robust over multiple periods. Since these approaches assume production data for multiple periods is available in the initial design stage when in fact, these are highly unlikely to be available in next generation factories, it appears that the dynamic layout approach will be unsuitable in the new environment. Approaches that assume a layout with built-in features (for example, duplication of key resources in strategic locations) can be developed to handle production changes over future periods include [7], [8] and [9], among others. Although elements of this approach could be applied to design next generation factory layouts, one disadvantage is that it calls for duplication of key resources in strategic locations. Not only are the key resources expensive, but identifying strategic locations for future production periods (of which we do not have too many details) is a difficult task.

In today's volatile manufacturing environment, it is common to see drastic production changes take place very frequently. It is also common to see old production resources being de-commissioned and new ones being commissioned rather frequently. What is challenging for designers is that very often, the changes that are to take place in a production cycle (whether it is change in products, routings, production volume or commissioning and de-commissioning of resources) are known only slightly ahead of the start of the new production cycle. Thus, it seems reasonable for a designer not to look beyond the next period and instead generate layouts that can be reconfigured quickly and without much cost to suit the upcoming period's production requirements. This idea is discussed in detail in [10]. Advances taking place in materials and mechanical process engineering, for example, lighter composite materials, nano-technology and laser cutting, will allow companies to reconfigure machines rather easily on a frequent basis. A genetic algorithm approach to solve such a re-configurable layout problem is presented in [11].

3. Framework for Generating and Evaluating Re-configurable Layouts

The approach being proposed to solve the re-configurable layout problem is a four phase iterative one (see figure 1). Whenever there is a reasonable change in the production mix and volume, the model can be run to see whether the new manufacturing environment warrants a new layout. In the first phase, a group technology model is used to determine a preliminary grouping of machine cells and corresponding part families. This grouping must be done such that operational performance measures are optimized. In the second phase, a cellular manufacturing layout is generated based on the grouping. In addition, a job shop (process) layout which minimizes material handling costs is also generated. In both cases, a detailed layout is developed so that material handling costs as well machine relocation costs are minimized using a suitable algorithm.

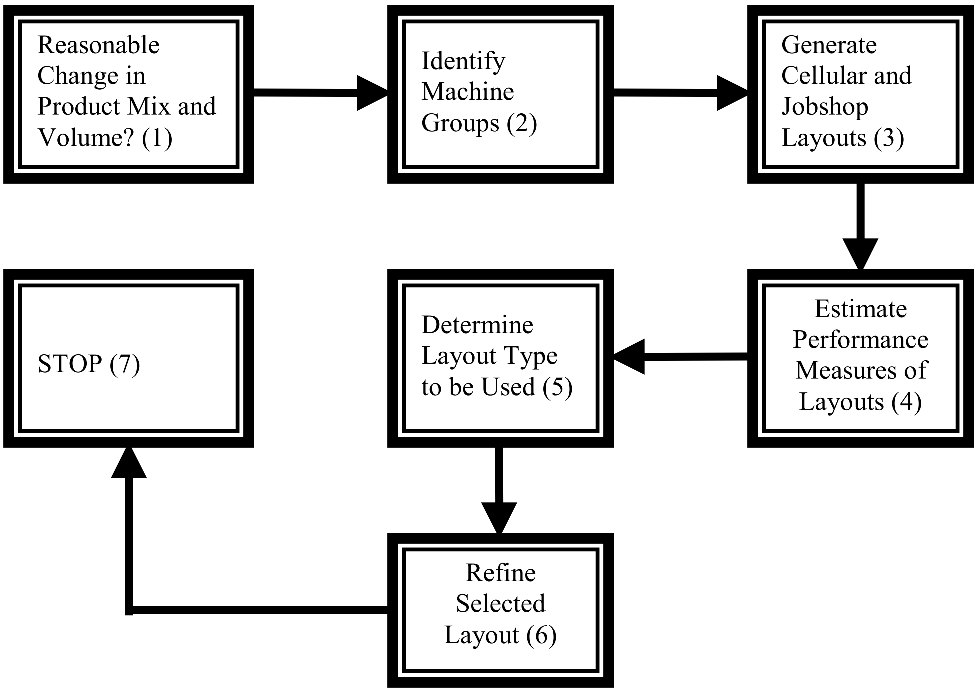

Figure 1. Four phase approach for design and analysis of agile layouts

An open queuing network model discussed in [12] is used in the third phase to estimate the steady state operational performance measures for each of the three layouts. Then, in the fourth phase, a decision on which of the three layouts - the current layout, the generated group technology layout or job shop layout, is to be used is made for the upcoming production period. This decision is based not only on deterministic material handling and machine relocation costs but also on stochastic operational performance metrics. After such a decision is made, the selected layout is refined so that it performs well with respect to material handling and machine relocation costs as well as operational performance metrics. This refinement is a manual process and is done as outlined below.

An analysis of the performance measures may suggest minor changes to the design and layout. For example, the bottleneck identification (location as well as extent) might suggest changes to design (for example, addition of highly utilized resources) or layout (re grouping of machines) which will improve performance of the system. These changes will be incorporated in a modified layout whose operational performance in turn will be estimated via the queuing network model. The above procedure of generating a layout, estimating its operational performance, making suitable changes to the design, re-developing the layout, estimating the new system performance measures will be repeated until a satisfactory design - one that is optimal or near optimal with respect to design and operational performance factors, is obtained.

4. Grouping and Layout Technique

Among the three types of layout considered - group technology, job-shop and flow-line, it is expected that in the new manufacturing environment previously described, it is highly unlikely that a flow-line layout will be employed. This is primarily because of the widely held belief that manufacturing in the future will be primarily concerned with high variety, low volume production making it uneconomical to use a flow-line layout due to the lack of dominant product lines or flow patterns. Although other types of layout have been discussed in the literature, for example, virtual cellular layouts, holonic layouts, etc., these are either inadequate from the material handling and queuing points of view or specific procedures to develop such layouts have not yet been developed. Moreover, the flow-line and job-shop layouts are two extreme types of layouts and the group technology layout is in between the two extremes and it can be modified to fit any part of the spectrum between the two extreme types of layouts.

In the second phase, a grouping algorithm such as the one in [13] is used to determine a grouping of the machines into respective cells. This grouping must be such that it is efficient with respect to material handling and machine relocation considerations as well as operational performance measures.

Once the machine grouping and corresponding part family formation are determined, a detailed layout must be developed using an appropriate algorithm. There are a number of possible techniques and these have been reviewed in [14]. In addition, a detailed job shop layout must also be developed for the new production planning period. At the end of phase 2, we have three detailed layouts - the existing layout, cellular manufacturing layout and job shop layout.

5. Evaluating Layouts Using Stochastic Models

In the third phase, the two layouts developed in the preceding phase as well as the existing layout are evaluated using an open queuing network model. The purpose of this phase is to determine the type of layout that would be preferable for the given data concerning product mix, volume, routing probabilities, machine service rate, capacity and capability information. The primary objective here is to identify the type of layout to use in order to minimize cycle time and work in process inventory. An open queuing network model for performance evaluation of cellular and job-shop systems is provided in [12]. This is based on the model in [15] and proceeds by performing a higher level analysis to determine the first two moments of the effective arrival rates of each product into each cell. Using these results, it then performs a detailed analysis to provide specific detailed information on estimates of performance measures at the cell level. In the analysis at the higher level, the material handling system (MHS) used to transfer parts between cells is modeled as another network of discrete material handling devices (MHDs). In general, the MHDs in the MHS node are similar. However, in a particular situation, if they are dissimilar, the resulting node would have to be treated as a multiple server node with non-identical servers and appropriate models used to analyze it as in the case of manufacturing cells with dissimilar machines. More details can be found in [12].

6. Conclusions

Our approach to designing agile layout systems assumes production data are available at best for the upcoming production period since it is unreasonable to assume we would know this data at the initial design stage for multiple production periods in the future. Two delphi surveys - the *millennium project* panel consisting of 200 futurists, scholars and policymakers from 50 countries [16] and the *National Research Council's Panel for Visionary Manufacturing Challenges in 2020* [1] have also suggested that it will be increasingly difficult to make forecasts too far into the future. In fact, the latter also mentions that facility configurations will be continually changing and must therefore be easily adaptable and re-configurable to survive in the competitive environment of next generation manufacturing systems. We believe that the time is ripe to consider adaptive manufacturing systems that can be easily reconfigured and that future research incorporate deterministic material flow based measures as well as stochastic queuing effects in analysis of re-configurable layouts. This paper presents a framework to aid in this effort.

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References

1. National Research Council, *Visionary Manufacturing Challenges for 2020*, 1998, National Academy Press, Washington, D.C.
2. Benjaafar, S, Heragu, S.S., and Irani, S.A., 2000, "Next Generation Factory Layouts: Research Challenges and Recent Progress," DSES Technical Report No. 38-00-482, Rensselaer Polytechnic Institute, Troy, NY.
3. Shore, R. H. and J. A. Tompkins, 1980, "Flexible Facilities Design," *AIIE Transactions*, 12(2), 200-205.
4. Rosenblatt, M. J. and Lee, H.L., 1987, "A Robustness Approach to Facilities Design," *International Journal on Production Research*, 25(4), 479-486.
5. Palekar, U.S., Batta, R., Bosch, R.M., and Elhence, S., 1992, "Modeling Uncertainties in Plant Layout Problems," *European Journal of Operational Research*, 63, 347-359.
6. Urban, T.L., 1998, "Solution Procedures for the Dynamic Facility Layout Problem," *Annals of Operations Research*, 76, 323 – 342.
7. Montreuil, B. and Venkatadri, U., 1991, "Strategic Interpolative Design of Dynamic Manufacturing Systems Layout," *Management Science*, 37(6), 682-694.
8. Yang, T., and Peters, B.A., 1998, "Flexible Machine Layout Design for Dynamic and Uncertain Production Environments," *European Journal of Operational Research*, 108, 49-64.
9. Benjaafar, S, and M. Sheikhzadeh, 2000, "Design of Flexible Plant Layouts," *IIE Transactions*, 32, 309-322.
10. Heragu, S.S. and Kochhar, J.S., 1994, "Material Handling Issues in Adaptive Manufacturing Systems", *The Materials Handling Engineering Division 75th Anniversary Commemorative Volume*, ASME, New York, NY.
11. Kochhar, J.S. and S.S. Heragu, 1999, "Facility Layout Design in a Changing Environment", *International Journal of Production Research*, 37(11), 2429-2446.
12. Heragu, S.S., Zijm, W.H.M, van Ommeren, J.C.W., and Meng, G., 2000, "An Open Queuing Network Approach to Evaluating Cellular and Jobshop Layouts," DSES Technical Report, Rensselaer Polytechnic Institute, Troy, NY.
13. Chen, J., and S.S. Heragu, 1999, "Stepwise decomposition approaches for large scale cell formation problems," *European Journal of Operational Research*, 113, 64-79.
14. Meller, R. and K. Y. Gau, 1996, "The Facility Layout Problem: Recent and Emerging Trends and Perspectives," *Journal of Manufacturing Systems*, 15(5), 351-366.
15. Whitt, W., "The Queuing Network Analyzer", *The Bell Technical Systems Journal*, Vol. 62, No., 9, pp. 2779-2815, 1983.
16. Cook, R., 1999, "Facilities Management and Design for the 21st Century," March, *Site Selection*.