Alternative Layout Procedures for Multi Period Production Environments

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Abstract

Manufacturing companies, often operate in dynamic and uncertain environments. Therefore, future expectations, risks and opportunities arising from uncertainties should be considered in the design phase of a facility. This paper focuses on reconfigurable, robust and dynamic layouts in a multi period manufacturing environment. One of the artificial immune system (AIS) algorithms named clonal selection (CSA) is proposed to evaluate the layouts for multi period environments. Several cases are introduced where the material handling and relayout costs are considered as deterministic. A numerical example is also studied to illustrate the outcomes of diverse strategies.

Keywords: Artificial immune systems, clonal selection algorithm, facility layout, multi period

1 Introduction

A facility layout problem deals with the assignment of machines to the appropriate locations. What makes the facility layout problem difficult to solve is the large combinatorial search space. The problem has to be solved in real time in general. A typical contemporary manufacturing company faces constantly changing product volumes and mix, which make it necessary to update layout accordingly in order to operate efficiently.

Next generation manufacturing systems should be responsive to the market for surviving in uncertain market conditions through a customizing policy in order dynamically to adjust system elements to new circumstances. The need to respond rapidly to changes in market demands creates a need for new designs of MSs. In order to sustain competitiveness in dynamic markets, manufacturing organizations should provide sufficient flexibility to produce a variety of products on the same system [1].

This paper aims to summarize the basic differences between the layout strategies that are available for multi period manufacturing environments. After a brief literature survey the definitions of the layout problems are given. A new solution procedure named CSA is introduced for the layout problems. To prove the validity of the algorithm a computational example is studied. Based on the data from a test problem, reconfigurable, robust and dynamic solutions are generated and the outcomes are discussed.

2 Literature Review

Reconfigurable, robust and dynamic facility layout problems, as well as solution strategies attract the attention of most researchers. The number of studies considering these problems is increasing in literature in recent years.

[2] present Reconfigurable Manufacturing System (RMS) characteristics through comparison with conventional manufacturing systems by using analytic hierarchy process (AHP). [3] propose (re)configuring products before manufacturing. [4] investigate the

L. Magdalena, M. Ojeda-Aciego, J.L. Verdegay (eds): Proceedings of IPMU'08, pp. 622–629
Torremolinos (Málaga), June 22–27, 2008

possibility of using a non-cooperative game theoretic technique for reconfiguration decisions making at the resource controller level in such an environment. [5] classify three families of exceptions as out-of-order events such as machine breakdowns, operational out-of-ordinary events such as rush orders and deteriorations of manufacturing resource performance such as reductions of machines' utilization. [6] investigate the affect of different machine layouts, such as parallel, serial and hybrid for adaptability against the changing demands. [7] propose a 3D graphics simulation environment for the analysis and design evaluation of a layout reconfiguration process. [8] presents a formulation of the facilities block layout problem which explicitly considers uncertainty in material handling costs on a continuous scale by use of expected values and standard deviations of product forecasts. [9] developed algorithms to generate robust algorithms for single and multiple period problems. [10] tries to find a robust layout that minimizes the total material handling cost, when the product market demands are uncertain variables. [11] discussed the problem of determining one new layout for a given period of time, known as the *robust* machine layout problem, by use of ant colony optimization. [12] propose a theory based on the analysis of the stochastic nature of the flow matrix and it seems to be promising for formulating indices that can predict a priori the layout robustness in the case of stochastic demand scenarios. [13] introduced the dynamic facility layout problem where the model takes into consideration of material handling cost as well as the cost of relocating of machines from one period to the next. Variations of the basic dynamic layout problem are studied in [14]. [15] explain quadratic assignment algorithms for dynamic layouts. [16] studied static and dynamic facility problems. A survey on dynamic layout problem models and algorithms are available in [17]. [18] explored the design of a multiple-floor dynamic facility that is able to respond to frequent production demand and mix changes. A genetic algorithm based heuristic is used for solving the design problem. [19] used a hybrid incremental solution method. [20] proposed a nested loop GA for DFLP. [21] defined a simulating annealing algorithm for DLP that performs best for large scale problems. In [22] a multi-population approach is presented. Also, [23] examined a cooperative coevolutionary genetic algorithm to DLP. [24] propose a hybrid GA. [25] presented an algorithm combining dynamic programming and genetic search for solving DLP. [26] dealed with dynamic and uncertain environments . [27] presented a three-phase approach and [28] two SA heuristics to solve DLP. In [29], hybrid ant systems are developed for DLP, as modifications of the hybrid ant colony system applied to the QAP presented by [30]. [31] proposed ant colony algorithm for unconstrained DLP.

3 Facility Layout Problems in Multi Period

By considering multiple periods and stochastic parameters one can generate more than one (certain or uncertain) scenarios. These aspects make the layout problem more reflective of actual situations, although they complicate the solution approach.

The main idea of multi-period layout formulations is to consider any expansion and reconfiguration costs in the determination of the initial layout. The assumptions necessary for these formulations include the ability to specify all relevant time periods, projected departmental interactions for each time period, and rearrangement costs for each department for each period.

The detailed definitions for reconfigurable, robust and dynamic layouts are given in the next sections.

3.1 Reconfigurable layout problem

In the design of reconfigurable layouts the cases where resources can be easily moved around so that frequent relocation of departments is considered as feasible. This is motivated by the fact that in many industries (e.g., consumer electronics, home appliances, garment manufacturing, etc), fabrication and assembly workstations are light and can be easily relocated [32]. In fact, even in the metal cutting industry, recent advances in materials science and processing technology are making to configure the manufacturing facilities easier on a more frequent basis. As a result, it may not be too far fetched to say that the layout will be changed several times a year.

However, there will probably be some loss in production capacity during the relocation process, and a relocation cost associated with the physical movement of resources (e.g., labor cost, dismantling and reconstruction costs, rewiring costs, and startup/setup costs), we must account for these costs when deciding whether it is beneficial to remove a resource or leave in its current location. The magnitude of the relocation costs determine whether a relayout is carried out or not. In one extreme, where relayout costs are insignificant, an entirely new layout can be generated during each period. On the contrary, if relayout costs are prohibitive, the existing layout would be retained. In practice, the two extreme scenarios would be implausible Instead it would be desirable to relocate some of the resources during each period.

3.2 Robust layout problem

Robust layout problem addresses the stochastic single or multiple period layout contexts where demand for one planning period is uncertain (thus multiple demand scenarios exist for each period). It is motivated by the fact that layout design is usually done in the early stage based on the forecast of future product demands, and this forecast usually turns out to be highly inaccurate. This makes the optimal design of layout problem meaningless. Another situation where a robust layout is desired is in the multiple period layout environments where the relocation cost is prohibitive and therefore the same layout across all planning periods need to be used. To solve a robust layout problem, only one layout is chosen which may not be optimal for a particular demand scenario or planning period, but optimal or near-optimal considering all possible scenarios and planning periods.

3.3 Dynamic layout problem

Assuming (deterministic) production data for multiple future planning periods are available, the dynamic layout problem attempts to find a sequence of layouts corresponding to the multiple planning periods. Since multiple planning periods are considered, it is necessary to consider the cost of switching from one layout in one planning period to another in the next. The objective function is then to minimize the material handling cost over all periods and the overall cost of relocating machines in consecutive layouts.

4 An AIS Algorithm for Evaluating the Alternative Layouts

AIS algorithms were inspired from the verbatim immune systems as neural networks have imitated principles of the human neural system, and can be classified into two main groups as network based and population based. The population based algorithms have some similarities with genetic algorithms. In GA the solution is represented by chromosomes where it is represented by antibodies in CSA. In both algorithms the solution is obtained by applying evolutionary strategies.

In the following section CSA which is one of the population based algorithms of AIS is defined for layout problems in multiple periods.

4.1 Clonal selection principle

The efficient mechanisms of immune system as clonal selection, learning ability, memory, robustness and flexibility make AIS a useful tool for combinatorial problems [33]. Based on the accessible literature, it can be stated that AIS is not applied to layout problems. In this study a new solution approach for machine layout is introduced. Possible layouts are represented by integer-valued strings of length n. The n elements of the strings are the machines to be considered. The strings correspond to the antibodies in AIS. The algorithm reaches to the solution by the evolution of these antibodies. Evolution is based on two basic principles of the vertebrate immune system: clonal selection and affinity maturation [34]. The proposed flowchart for the problem is presented in the Appendix.

Each layout (antibody) represents a possible solution and has a cost value that refers to the affinity value of that antibody. In this layout problem the places that the machines will be located are assumed as equal areas. Therefore, the distances between their centers of gravity are taken as one unit.

The cloning process of the proposed algorithm is inspired by the roulette wheel methodology. Objective function values of layouts are used for selection and cloning. Therefore, clones of lower cost antibodies gain higher chance to be selected in the new generated clone population. Clone sets which have the same size of the total antibody population are obtained. A two phased mutation procedure called inverse mutation and pairwise interchange mutation are used. If the *cost* of the mutated layout (after pairwise interchange mutation) is smaller than the original layout, the mutated one is stored in the place of the original one. If the algorithm can not find a better layout after the two mutation procedures, then it stores the original sequence.

After cloning and mutation processes, receptor editing mechanism is applied where worst %B of the antibodies in the population are eliminated and randomly created antibodies are replace them. This allows finding new layouts that corresponds to new search regions in the total search space.

4.2 Computational experience

The flowchart for multi period environments for CSA is given at the appendix, and the algorithm is coded by using Visual Basic based on this definitions. The user can input the antibody population size, elimination ratio (%B) of antibodies, and iteration number parameters of AIS. Also the number of machines and number of periods and layout area can be defined with an interface.

The performance measure for layouts is the sum of material handling and relayout costs. Five possible cases for a multi period problem are defined.

Case 1: Relayout costs are insignificant; an entirely new layout can be generated during each period (disregarding of the previous period).

Case 2*:* Relayout costs are prohibitive; the existing layout would be retained.

Case 3: Relayout cost is prohibitive and therefore a rough and ready layout across all planning periods should be used.

Case 4*:* Minimize sum of the material handling cost over all periods and the overall cost to relayout machines in consecutive layouts

Case 5: Best layout for each period without considering any relayout costs (static layout problem)

A deterministic environment is assumed, where the flow between machines are known for a given finite horizon. The relayout costs of the machines are assumed to be same in all periods. A data set from Conway and Ventakaraman (1994) given in Table 1 is used to test the defined cases.

While traditional, dynamic and robust layout problems are based solely on future planning periods, reconfigurable layout problem addresses the transition from the current period to the next.

Table 1. Flow matrix and relayout costs for 9 machine 5 period problem

	Machines								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
	0	3622	258	493	697	296	627	552	287
	991	0	316	443	570	684	334	283	1043
	673	6522	0	484	114	324	611	762	762
	791	4369	203	0	170	1031	598	923	788
Period 1	867	5146	56	203	0	1121	309	154	361
	894	3264	71	62	769	0	664	343	282
	714	3113	240	506	831	1183	0	1144	311
	588	1319	319	161	826	1194	744	0	773
	1096	6521	335	317	459	439	416	1222	0
	0	136	6371	886	1596	213	499	1378	476
	657	0	3461	1275	567	254	405	263	449
	590	528	0	488	498	273	311	1277	486
	179	684	1305	0	1748	101	462	1008	559
Period 2	772	550	6113	478	0	261	53	1134	1285
	511	822	2046	1105	1404	0	384	405	875
	577	690	2362	925	944	139	0	847	312
	300	461	3343	514	676	128	487	0	214
	291	560	6306	397	235	243	466	963	0
	0	265	720	3275	361	230	580	221	1433
	695	0	816	5276	636	683	637	1877	203
	901	1535	0	2322	323	592	129	857	979
	1138	298	987	0	400	1051	163	238	924
Period 3	619	478	856	4205	0	615	81	991	990
	647	1373	441	722	608	0	128	603	1040
	1008	1383	772	3552	497	836	0	1795	211
	1348	682	233	892	206	600	448	0	679
	1291	2281	595	3972	89	840	257	348	0
	0	753	632	1686	722	241	192	510	63
	840	0	897	795	3331	1274	426	611	442
	2138	895	0	1277	3019	693	88	470	514
	561	445	1444	0	1123	385	523	2015	428
Period 4	335	421	1549	560	0	820	251	1480	455
	636	515	776	1590	5257	0	781	504	416
	571	625	765	1304	5312	954	0	647	82
	1675	297	176	1137	1240	1313	715	0	321
	1187	1550	751	441	840	336	252	1695	0
	0	1017	663	1460	1118	804	256	1291	246
	854	0	1102	1476	1109	2931	975	1032	403
	850	1017	0	1503	412	4102	613	1083	140
	525	205	792	0	1060	3647	196	591	981
Period 5	1653	113	1133	1501	0	2160	203	706	695
	981	686	184	852	450	0	155	560	962
	781	1010	353	319	648	2043	0	914	185
	2031	701	930	755	1113	1883	772	0	175
	867	580	377	478	284	4879	106	325	0
	Relayout costs								
	802	985	517	500	736	910	768	564	923

Reconfigurable layout problem aligns itself with the notion of real time enterprise in which the changes to layout context are readily available. Since real life data is not obtained, some assumptions are made for case 1 and case 2 in this paper.

In order to find a solution to case 1, the data for first and second periods are considered, and the relayout costs between periods are assumed to be insignificant. Case 2 problem considered second and third period flow matrices also the relayout costs. In case 3 the relayout costs are assumed as too high and the average of flow matrices are considered to form a robust layout. The original test data was proposed to generate dynamic layouts (case 4). When the relayout costs are not considered the problem turned out to be a static layout problem where best layout is searched for each period in case 5.

In Table 2 the results for the cases are summarized. The first column defines the type of the problem and the second column states the relevant case number. The information of relayout costs are given in third column. The optimal solutions for cases 1-4 are not available (NA). Therefore only the dynamic and static case results from [35] are comparable with CSA. In the last column the obtained layout strings are illustrated.

Table 2. The results for the cases considered

Case no	C&V(1994)	CSA	Periods	Layout
1	-	232083	t	6 5 1 7 2 3 8 9 4
2	-	120171	t	8 2 6 7 4 5 1 9 3
			t+1	4 5 6 2 3 9 7 1 8
3	-	126277	for all t	1 8 7 4 2 5 9 3 6
4	608904	608737	1	1 3 4 5 2 9 6 7 8
			2	4 2 7 5 3 1 6 9 8
			3	8 2 7 5 4 3 6 9 1
			4	7 4 8 5 3 1 6 2 9
			5	1 5 4 8 3 6 7 2 9
5	592856	592029	1	1 3 4 5 2 9 6 7 8
			2	6 9 8 5 3 1 4 2 7
			3	1 9 3 7 4 5 8 2 6
			4	9 1 8 2 3 4 6 5 7
			5	9 2 7 6 3 8 4 5 1

The parameters for the problem as number of antibodies in a population, elimination rate and number of iterations are set as 100, 10 and 50 respectively. The total cost in case 1 for period 1 and 2 is calculated as 232083. In case 2, layouts for period 1 and 2 are calculated by considering relayout costs, but due to the high relocation costs the layout obtained in period one is used in the second period. Therefore the total cost for the two periods is 240342. Case 3 proposes a single layout for each period and the total cost for the whole planning horizon is 631385. In case 4, when the relayout costs are considered for each period and the total material handling and relayout costs are tried to be minimized. The overall cost for 5 periods is calculated as 608737. The optimum solution obtained by CSA for case 5 is 592029. The layouts related to this case correspond to the optimum layout for each case.

This study illustrates in brief how the calculations for multi period problems can be made and the alternative layouts are obtained. The choice of the appropriate layout for a facility depends not solely on the costs but also the layout of the machines.

The robust and dynamic layout problems assume the layout contexts (such as product mix and routings) are known for multiple future planning periods. This assumption makes it easy to solve the layout problem but it is not realistic in many situations. In reality, for many production systems, the product mix and routing changes for the upcoming period are known just slightly ahead of that period. It is therefore pragmatic to consider only the current period and the next in layout design.

Robust layout problem addresses the stochastic single or multiple period layout contexts where demand for one planning period is uncertain (thus multiple demand scenarios exist for each period). In a robust layout problem, only one layout is designed, which may not be optimal for a particular demand scenario or planning period, but optimal or near-optimal considering all possible scenarios and planning periods.

5 Conclusion and Results

This study attracts attention to the importance of multi period layout problems. From the literature review it is realized that no study had focused on the main differences between reconfigurable, robust and dynamic problems, and illustrated a numerical example. Therefore a novel optimization heuristic AIS, is introduced to solve the layout problems in multi period problems. A test problem from the literature with deterministic material handling and relocation costs are considered in this paper. But, in the following studies investigating the stochastic performance measures such as WIP inventory level, average waiting time in queue, average queue length and product lead time are also important for more reliable solutions. Especially for reconfigurable layout problems the use of concurrent data from a workshop should enable consistent decisions. In further researches a simulation model can be developed to analyze both deterministic and stochastic measures. Also, devicing of different scenarios for robust layout simulation is a crucial tool.

On the other hand the choice between existing and candidate layouts can be modelled as a multiple objective decision problem. Different companies might be concerned with different sets of cost terms. While most of them use deterministic terms such as material handling and relocation costs as well as stochastic terms such as WIP inventory cost and lead time, some companies might deal with non utilized space, machine utilization or cell/machine center contours into consideration. Therefore a decision analysis methodology such as analytical network process (ANP) can be used to evaluate the alternative layouts in further studies.

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APPENDIX: The CSA flow chart for multi dimensional layout