Job Rotation model in manufacturing systems to reduce ergonomic risks due to work

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Abstract

Doing Risky works continuously by an operator can result in harmful effects on the health and performance of operator over time because of ergonomic hazards. In order to reduce these negative effects, it is necessary for the labors to be exposed to such dangers with the same amount. A branch of operation research that analyzes the allocation of staff to different tasks in order to balance the ergonomic risks and complications of doing continuous risky works in planning horizon in known as job rotation. In the present work, we want to simulate the job rotation problem of staff with different skills in cell production systems and show the efficiency of meta-heuristic algorithms to solve this NP_Hard model. In order to evaluate the efficiency of the proposed solutions, a number of sample problems have been generated randomly and they have been solved by meta-heuristic simulated annealing, and then its results has been compared with accurate methods of optimization in which the comparison of these results shows the high efficiency of proposed meta-heuristic algorithm and the better performance in the quality of results considering time resolution.

Keywords: job rotation, ergonomic risk, cellular manufacturing simulated annealing, staff skills.

1. Introduction

According to the advent of mass production approach, the increase of industrial production amount and the need to develop large industrial units, paying attention to the new industrial technologies has become an imperative need for some organizations. This led to the creation of new production techniques and continuous improvement of these methods. Today, production systems, depending on order in the industry situation and its competitive advantages, and other factors affecting their performance, they use various production methods such as, workshop production, cellular manufacturing and other manufacturing systems. In cellular manufacturing, a family of components is processed on a series of machines or manufacturing processes, which are often called cells.

This group of components, products and processes has been created by group technology. A group technology is a manufacturing aspect which uses products and tasks' simulations for grouping machines, processes and labors to cells Bidanda B. et al, (2005). From the perspective of manpower planning in different cells, it is necessary to consider three points:

A) Cellular manufacturing needs staff that do the required process on the families of products or series of similar components in cells or groups of machines which may have different performance Bidanda B. et al, (2005).. Exchanging the eligible operators between cells to work on different machines results in an increase of flexibility, skills, motivation of staff and job satisfaction, and would facilitate and expedite matters and save time and resources. Warner et al. (1997) suggested assigning workers to machine cells based on their human and technological skills. It is especially useful for dynamic tasks, which require variations in muscular load (Jonsson, 1988).

B) On the other hand, in some manufacturing processes, working conditions in different cells in terms of noise, exposure to harmful rays, the terms of ergonomic workstations such as standing or sitting operator during his job and etc. causes the ergonomic effects by working continuously. One possibility is to rotate workers based upon a specific policy such as choosing not to assign a worker to two stressful tasks in succession (Henderson, 1992). Job rotation also yields such benefits to workers as reducing the injuries due to performing repetitive tasks as well as the worker's fatigue especially if the worker is exposed to various muscular loads during task operation (Hinnen et al., 1992; Henderson, 1992).

C) In addition, cellular manufacturing system have been made in order to increase production system capabilities for facing the increase of products' variety in new market and changes in customer tastes especially in packed products which have a huge amount of manufacturing industries. So by considering the ability to change the quantity or type of production, it may be possible to change the required number of staff for working on machines from one shift to another in each cell which will cause to change in the volume of work assigned to facilities in various cells. In such circumstances it is necessary to move staff between different cells for reducing operators' workload and providing a balance. Job rotation efficiency, in relation to musculoskeletal stressing, is based upon the proper balancing of stresses across the employee's body Jorgensen et al(2000). Therefore, the correct workstation and tools design will decrease the amplitude of the risk, and the rotation program will decrease the frequency and the duration of the exposure (Winkel and Westgaard, 1996).

Today, having flexible employees and managers, skilled or multi-skilled may be perhaps a wish for every system. Having such people in the activities of each series can facilitate and expedite the work and save time and even provide resources Federica Origo, Laura Pagani, (2008) and it can be an opportunity to develop the skills and providing motivation Richard Olorunsola,(2000).In order to increase flexibility, motivation and satisfaction of the workforce, reduce the ergonomic influences and balance the workload assigned to the workforce, it is imperative for staff to be transferred between consecutive work shifts in different cells while having required skills. An important area of operation research in which analyzes the allocation of staff to different tasks during planning horizon is known as "job rotation scheduling". Job rotation involves assigning employees to jobs that require different knowledge and skill levels [Kuijer PPFM, van der Beek AJ, van Dieën JH, Visser B, FringsDresen MHW (2005)].In recent years some research has been done about job rotation by considering the above assumptions [Kuijer PPFM, van der Beek AJ, van Dieën JH, Visser B, FringsDresen MHW (2005)].Job rotation is well-renowned for increasing employees' abilities [Eriksson, T., Ortega, J., (2006)]and is therefore used as an on-the-job training tool.

Ergonomic job rotation scheduling problem (EJRSP) which aims to smooth ergonomic hazards among workers through minimizing ergonomic pressure for workers who are more exposed to ergonomic hazards was provided by Carnahan et al (2000). They stated that job rotation reduces the physical and environmental impact on employees and reduces the amount of injuries. Aryanezad et al (2008) have presented a job rotation planning model with two goals in which staff with different skills were allocated to various works during planning horizon for fulfilling these two goals: first minimizing damages caused by exposure to occupational noise and second minimizing physical injuries (such as backache). Seçkiner et al(2007)modeled and solved job rotation scheduling of staff with similar skills in service environments while having various demands over planning horizon in order to minimize allocated workload to each operator. Seçkiner and Kurt (2007, 2008) implement ideas of EJRSP to formulate a shift assignment problem with an ergonomic objective, which they solve with ant colony optimization and simulated annealing algorithms. Carnahan et al. (2000) propose a genetic algorithm to solve EJRSP and use a neuronal network algorithm to find promising rules for job rotation. Tharmmaphornphilas and Norman (2007) develop a greedy heuristic for EJRSP. These ideas are further extended by Tharmmaphornphilas and Norman (2007) who persuasively show the need for specialized effective algorithms for EJRSP, since standard software is not able to solve instances of real-world sizes.

The model in the present work, is a combination of research conducted by Aryanezad et al (2008) and Seçkiner et al(2000) in which the job rotation schedule in cellular manufacturing environment is analyzed while staff with different skills are being rotated between certain stations in different cells with variable demand by minimizing the operators workload so that the matter has not been studied in previous research. In this paper, the possibility of the absence of some operators in some work shifts by reasons such as holidays is taken into account.

The continuance of this article consists of three parts: In the first part we will present integer programming model in ergonomic job rotation scheduling. In the second part we will recognize the proposed solving method by simulated annealing meta-heuristic algorithms and the third part is comprised of some examples and conclusions.

2. Definition and modeling the problem

2.1. Definition of the problem

The problem is defined in a cellular environment in which each cell has a set number of collections of machine groups and some workers who are classified with different skill levels in different skill groups, considering the days they are off from job, will work with this set of machines in which Each machine group in different periods require different numbers of operators with certain workload and operators will be affected by them. Each operator per shift can only be associated with one of the devices in the machine group and should have the necessary skills for working with it. The aim is to reduce the workload of staff working on machines in the time horizon of the study, and we want to provide a schedule keeping in mind the staff skills and Working days of staff and the number of staff required per shift with creating a job rotation among employees for minimizing their workload so employees can be productive between the cells and can have job rotation in the cells.

a. Mathematical modeling

i. Model assumptions

1. Every worker has the skill level in which the employees' level of skill is fixed over the time horizon of the study.
2. The number of employees required for each specific machine is specified.
3. The number of machines in each cell is specified.
4. Each worker can only be allocated to the machines that have the necessary expertise to work on them.
5. Each worker should be N- shifts a week off.
6. Each working day is comprised of two shifts..
7. A certain number of machine groups with different workloads is in each cell and these differences depend on the day and the type of machine.
8. The production system of the plant is cellular manufacturing system.
9. The amount of ergonomic risks in two shifts is independent.

ii. Parameters and variables of the problem:

E: The cost of the workload for each worker

D: weekdays

T_d: The number of shift in the day " d".

K: the number of different skill levels of employees

L_k: The number of employees in the skill level " k".

I: the number of manufacturing cells.

J_i : The number of machines in cell "i"

$C_{i,j,t,d}$: it is cost variable , which represents a real number of cost in terms of workload for each worker of every level of skill in cell "i", working with the complex of machinery "j" in shift "t" of the day "d".

$N_{i,j,t,d}$: The number of human resources required for cell" i" on the complex of machinery "j" in shift "t" of the day "d".

$$r_{l,k,t,d} = \begin{cases} \text{if the number 1 worker of the skill level "k" in the work shift "t" of the day} \\ \text{"d" is not off} \qquad\qquad \text{, otherwise} \end{cases}$$

$I_{i,j,k} = \begin{cases} \text{if the number 1 worker of the skill level "k" can work on the machine "j" of} \\ \text{the cell "i" , otherwise} \end{cases}$

$x_{l,k,i,j,t,d} =$ if the number 1 worker of the skill level "k" in the day "d", shift "t" in the cell "i" can work on the machines collection "j" , otherwise

iii.Mathematical model of the problem:

$Min \quad E$

$s.t:$

$\sum_{i=1}^{I}\sum_{j=1}^{J_i}\sum_{d=1}^{D}\sum_{t=1}^{T_d} c_{i,j,t,d} . x_{l,k,i,j,t,d} \leq E \; \forall l,k$

$\sum_{i=1}^{I}\sum_{j=1}^{J_i} x_{l,k,i,j,t,d} \leq 1 \; \forall l,k,t,d$

$\sum_{k=1}^{K}\sum_{l=1}^{L_k} x_{l,k,i,j,t,d} \geq N_{i,j,t,d} \; \forall i,j,t,d$

$\sum_{i=1}^{I}\sum_{j=1}^{J_i} x_{l,k,i,j,t,d} \leq r_{l,k,t,d} \; \forall l,k,t,d$

$x_{l,k,i,j,t,d} \leq I_{l,k,i,j} \; \forall l,k,i,j,t,d$

$x_{l,k,i,j,t,d} = 0 \; or \; 1 \; c_{i,j,t,d} \in \mathcal{R} \; \forall l,k,i,j,t,d$

1. The objective function

The purpose of the problem is minimizing the maximum workload (E) found in the in the time horizon of the study, so for this purpose the problem would force the integer programing model to find a set of values of $X_{\mathrm{l,k,j,t,d}}$ related to job rotation scheduling to minimize the maximum amount of workload between staff.

2. Constraints of the problem

The first Constraint includes the most demanding of work (workload) for employees based on the allocation of tasks and the amount of "E" calculated for each worker. The second Constraint requires that at every stage of the workflow, each worker has to be allocated to one kind of machine. The third Constraint requires that the number of employees at every stage of each day's planning who are dedicated to a machine should be larger or equal to the number of personnel required to operate the machines of that type.

The fourth Constraint ensures that each employee is allocated a certain amount of workload, or in other words, each worker must leave and work in "n" days a week. The fifth Constraint ensures that employees have to be allocated only to the machinery by having the ability and skills needed to work on them as well. The sixth limitation shows being a zero-one problem.

2. **Solution**

Due to the fact that it is NP_Hard problem which have been mentioned in relevant articles such as Otto et al (2012) and Seçkiner et al (2008), to solve the model simulated annealing algorithm, along with a review of the improved response with new structure has been proposed.

Simulated annealing (SA) is a way of innovative seeking for combined optimized problems. The algorithm based on the physical sciences in the beginning was presented by Kirkpatrick et al (1983) and it has the ability to get out of the local optimality to be close to a global optimum. This algorithm is able to accept the worst answers with possible rate. The possibility of acceptance by a controller parameter (temperature) will be determined during the process of SA algorithm reduction.

3.1 The answer space structure

Consider the example of two shifts per day and there are 3 cells in manufacturing system where there is two types of a set of different machines in the first cell ,five types in the second cell and three types in the third cell and there are seven operators in three specialized groups (skills) with the order that in the first group there are three operators, in the second group two operators and in the third group two operators.

In both proposed algorithms every solution is a combination of three views of different dimensions, so that initially for creating primary response we use a three-dimensional matrix which firstly is used in different skill levels of staff, secondly a set of machines in different working cells and thirdly various working shifts in different days is shown.

To create this kind of matrix which is the primary answer for the algorithm, the Constraints of the model should be considered to have a justified primary answer. Due to this for creating the basic answer of a model for all three skill

Constraints, off day's Constraints and the number of personnel limitation needed for a set of different machines has been considered.

By using the created zero-one matrix that is three-dimensional, two matrixes have been defined as a set of machines matrix and cell matrix. That a set of machines matrix has two dimensions: the first represents the employees, and the second shows the working shift and each element in this matrix represents a set of machines in which the operator in that shift is working on it. The general view of this matrix is shown in the example of Table 1.

Table 1: machine complex matrix

		Day 1		Day 2		Day 3	
		Shift 1	Shift 2	Shift 1	Shift 2	Shift 1	Shift 2
Skill	Operator	1	2	3	4	5	6
1	1	1	2	4	0	2	1
	2	4	0	3	4	4	4
	3	3	1	0	0	2	2
2	4	0	4	2	0	3	4
	5	3	0	1	2	1	0
3	6	2	1	3	3	0	0
	7	0	3	2	1	4	3

The element in different color suggests that the operator 4 (the first operator of skill level 2) in shift 3 (first shift of second working day) is allocated to machine 2 (the second machine in the first cell).

The cell-matrix has a form like the series machines matrix except that each element in the cell-matrix represents the cell number that a special operator in the specified shift is working on it.

3.2 Calculation of the objective function

To calculate the workload of each operator in a week, it is necessary that the workload of each operator per shift per day be calculated and this amount depends on each operator per shift is working on which set of machines because the workload of each set of machines per shift may vary. Due to a series of machines and the workload per shift each day workload of each operator in each shift, for the example mentioned in one of the last repetition of answers, it is shown in a matrix named the matrix of costs shown in like Table 2.

Table 2: the cost matrix

		Day 1		Day 2		Day 3	
		Shift 1	Shift 2	Shift 1	Shift 2	Shift 1	Shift 2
Skill	Operator	1	2	3	4	5	6
1	1	9	24	56	20	25	21
	2	54	43	17	53	8	37
	3	54	26	53	33	6	46
2	4	15	29	26	41	53	37
	5	26	13	56	42	53	45
3	6	40	24	50	49	35	47
	7	35	54	17	58	8	23

The element in a different color suggests that the operator 4 (first operator in skill level II) in shift 3 (the first shift of the second day) has a workload of 26. The workload (scores of ergonomic hazards) of each operator during the working week that is the sum of all ergonomic scores work in all shifts during the week is a measure for calculating the workload of each operator. The goal is to minimize the maximum workload of operators which is obtained from all columns in each row of cost matrix.

4 Simulated annealing operator

We should consider a few criteria for producing neighborhood response which are the limitations of the model, so that to produce response to the neighborhood two operators have to change their place in a common shift, But for this workflow (work stream) the limitations of the model should be considered.

operators can have job rotation together in which(1) they are both working in that particular shift , (2) they are not off or without any special responsibility, (3)they have necessary skills to work on the set of machines that is they are going to work on it.

To create this neighborhood with the mentioned limitations all the above methods has been considered in models and machine-cell matrixes have been used.to choose two operators for job rotation two methods have been used and for set of machines matrix it has been shown as figure 1:

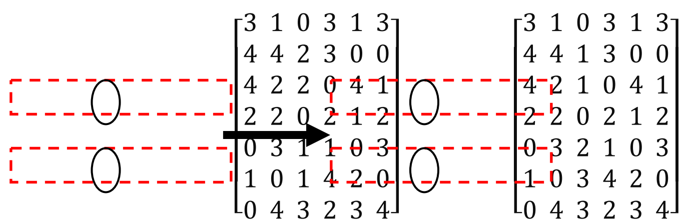

Figure 1: Machine matrix before and after producing neighborhood operator

In proposed SA algorithm, operators with the highest and lowest workloads are transferred and if the transference is not possible because of limitations, the transference would be randomly and the neighborhood response production for cell-matrix would be similar to a set of machines matrix.

4.1 Utility function

The criteria for measuring the utility of answers in algorithms is the reduction in maximum workload of operators that the results of this algorithm is presented in the next section in order to have a better measurement of the performance of each algorithm.

4.2 Parameters regulation

To arrange the parameters of the algorithms in this study Taguchi method have been used. The amount of parameters of this method for the initial SA temperature, the rate of simulated annealing, the number of repetitions and freezing temperature are 100, 0.9,500 and 0.1 respectively.

4.3 Computational results

For this model different designed tests are solved that the problems and their results have been presented in Tables 3 and 4.

Table 3: related information for the solved example of the model

Numbers Variables	Numbers limitations	Numbers Working shifts	Numbers Working days	Number of sets Machines	Numbers Cells	Numbers Operators	Numbers of levels Skill	Number Example
96	316	12	6	2	2	4	2	1
432	1137	12	6	4	2	9	3	2
600	1510	12	6	5	2	10	3	3
864	2100	12	6	6	2	12	5	4
840	2090	12	6	5	2	14	4	5

1260	2979	12	6	7	3	15	4	6
3300	7357	12	6	11	4	25	6	7
4752	10473	12	6	12	3	33	8	8
13920	29188	12	6	29	5	40	9	9
18720	39252	12	6	26	6	60	12	10
30660	63565	12	6	35	6	73	14	11
38880	80265	12	6	40	11	81	18	12
50052	103045	12	6	43	14	97	25	13
90036	183879	12	6	61	23	123	41	14
110160	224511	12	6	68	20	135	36	15

Table 4: The results of solving by SA and Lingo

Model	SA				best obj	obj bound	time(min)
The example number	sd	Max E	Min E	time			
1	11	278	261	15(s)	278	278	2
2	74	286	84	23(s)	286	286	3
3	68	309	105	56(s)	268	268	10
4	43	302	172	3(min)	267	267	24
5	74	270	61	5(min)	234	234	12
6	46	315	184	11(min)	276	275	>112
7	52	311	117	14(min)	248	245	>104
8	56	278	20	18(min)	205	202	>190
9	53	241	98	26(min)	224	211	>113
10	64	282	60	29(min)	_	_	_
11	62	335	211	33(min)	_	_	_
12	58	367	190	37(min)	_	_	_
13	61	399	126	41(min)	_	_	_
14	72	334	83	45(min)	_	_	_
15	56	516	33	58(min)	_	_	_

The results of solving problems the LINGO software was used in small and medium size and resolution of all issues with SA algorithm in sizes like small, medium and large reflect the exact performance of the algorithm and the closeness to effective answers in large sizes. The first column in SA algorithm shows the standard deviation between staff in the specified time horizon that indicates the amount of difference among the workload of works and the lower rate shows the balance between employees. The second and third columns indicate the maximum and minimum amount of workload in the time horizon in which the difference between these two amounts reveals the difference between the workers in terms of workload. The third column shows when the simulated annealing algorithm is solved and the next columns represent the results of solving problems with LINGO software. The results of resolution of simulated annealing algorithm are shown in as a sample in figure 2.

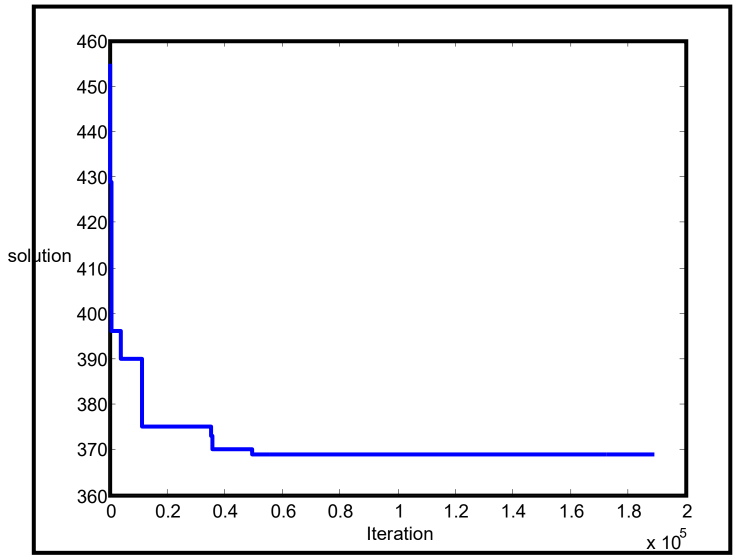

Figure 2: The SA answer chart for the example 12

5 Conclusion

In this paper, a new model to implement a job rotation scheme in cellular manufacturing systems is provided.
The model is trying to minimize the damage caused by the staff exposure to workplace ergonomic risks, in this regard staff skills is in high importance and job rotation is possible in particular cell because of the difference between the amount of workload in different cells.
The result in this model illustrates that for solving the problems of large size which LINGO software is not able to solve them, or it can solve them in a very long time, simulated annealing algorithm will gain very close results to optimal answers in a short time.
It is recommended for future research to study job rotation within and between cells, and at the present time some research is being pursued by the authors of this article. Also, the skill level of employees is assumed to be stable, but for future research it is suggested that staff skills be considered dynamically.
Another proposal is taking into account the ergonomic risks so that each employee is not only exposed to the influence of ergonomic risks of machines that he is working on but also the other machines which are involved in the cell.

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