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Projection of Cyclic and Non-Cyclic Job Rotation to Reduce Exposure to Ergonomic Risks

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Abstract: Currently, production lines have demanded a workload and a level of complexity of movements that can represent ergonomic disturbances to employees. One way to reduce these effects is to apply rotation of work activities. However, building task rotation plans is a complex problem, as it has a multifactorial character, ranging from the effects on the organization of the work environment to the impacts that each disturbance can cause. The aim of this article is to present a convolutional neural network application to produce rotation schemes, considering injury potentials and their workloads. From these relationships, the algorithm can generate rotation schedules, organize tasks into rotation groups and determine the sequence to be performed to minimize the effects of stress and fatigue on employees. Despite the complexity of the problem in real environments, the presented algorithm can be a tool to be considered in the projection of work turnover scales, improving the management of the risks of accidents caused by musculoskeletal disorders. The advancement of technologies has allowed a greater degree of security for various facets of society, such as biometrics for banking operations, identity verification through devices such as cell phones and even facial recognition. Facial recognition algorithms are widely used for access control in spaces such as buildings, condominiums, companies, educational institutions, etc. facilitate access through a browser. The results obtained indicated a facial recognition rate of around 93.86% of the presented faces.

Key words: job rotation, musculoskeletal disorders, evolutionary algorithms

1. INTRODUCTION

Job Rotation integrates a set of strategies aimed at work organization with the aim of reducing workers' exposure to ergonomic risks, in addition to maintaining labor standards and legislation [1]. Its use introduces the strategy of changing tasks or jobs during the working day. Thus, it is possible to state that the application of the job rotation strategy is useful for both workers and companies. When the problem is observed from the perspective of the worker, the rotation of functions in their working day can be considered a safety operation by reducing monotony and the level of stress, in addition to expanding their mastery over the process, allowing new skills to be developed. are developed, known and practiced [2]. It is possible that, as a complementary gain from the practice of job rotation, a more complete perception of the process will help workers to correct their ways of carrying out their tasks, correcting deviations and thus improving the quality of the product. Still on the benefits, we call for the identification of the complexities and capacities of the collaborators, so that there is greater integration with those identified with some degree of disability [7, 10, 11, 12].

Scientific sources and work standards indicate that there are three factors that represent the risk of ergonomic exposure, which are the magnitude of the risk itself, the time of exposure and the frequency [13, 14]. The magnitude of the risk depends on an analysis by who coordinates the production lines, based on the experiences of the line itself and on work safety standards. The factors of time and frequency of exposure can be attacked by applying job rotation [15, 16]. Thus, in this work, task rotation is treated as a preventive strategy against factors that are associated with WMSDs, such as repetitive movements, handling loads, inadequate postures or vibrations, and in the prevention of these factors on ergonomic risk [13, 14, 17, 18]. The practice of job or task rotation requires a minimum number of people to be involved so that the benefits of its application are perceived, as it encompasses the use of a number and duration of routines and breaks, mapping the muscle groups involved in the task and, finally, the physical and psychological limitations of workers [19]. Only one aspect of applying job rotation requires greater attention: critical jobs. Critical jobs that require a lot of effort, attention or that are classified as dangerous cannot be included in the rotation at the beginning because a process of reducing their own complexity and risks is necessary [2]. This is necessary for the rotation objectives to become effective [20].

Companies that have more innovative profiles in their working methods introduce the job rotation system with the aim of enhancing the set of good practices, increasing the mastery and competence of employees in their tasks, and expanding the possibilities for these workers to travel for different tasks without loss of quality [21, 22].

Developing a job rotation plan is a complex problem [23]. The type of task rotation implemented affects the results in terms of satisfaction and productivity, with several criteria and constraints that must be considered simultaneously to obtain an efficient solution [24]. For example, it is necessary to find the task sequence that maximizes the variation in the muscle groups used by the workers and the optimal duration of the rotation interval to reduce monotony and boredom [25, 26]. At the same time, it is necessary to meet organizational requirements such as the balance between position and salary and the physical and mental capacity of employees to perform assigned tasks. Otherwise, the result can be a poorly designed job rotation plan that can adversely affect working conditions [27].

Numerous approaches adopted to design task rotation schemes point out that it is necessary to have a set of workers and their mapped workstations in hand to be able to establish a rotation schedule, which observes the ergonometric improvements and meets the criteria of combinatorial optimization [28]. Although there are some other techniques applied to solve this type of problem, such as Integer Programming [9,10,29], one of the most common ways to obtain good solutions in short times is the use of heuristics and metaheuristics such as genetic algorithms or search tabulated [25,30,31,33,34,37]. This paper presents RGA, an evolutionary algorithm [37] to generate job rotation schemes to prevent WRMDs, which simultaneously solves important organizational problems encountered when job rotation schemes are implemented in real environments. A rotation plan establishes the workstations that a set of workers occupies in each rotation. If the number of jobs (and workers) involved in the rotation system is large, procedures for generating job rotation schedules generate solutions involving complex sequences of jobs that workers must follow.

Implementing a complex rotation schedule presents some organizational problems. Each worker must follow a different and complex path, and workers must memorize the sequence of workstations. Without a schedule, workers move chaotically, causing confusion and wasted time.

On assembly lines, it is common for one worker to be responsible for a small group of workers. In some cases, a worker, also called a monitor, may not be assigned to a particular workstation, but they are able to replace workers who are temporarily absent from their workstation, or during work shift changes, so to avoid interruptions and delays in the production process.

In this work environment, the implementation of rotation schemes presents difficulties for both monitors and other workers. Workers assigned to a monitor follow very different sequences of workstations, making the task of monitoring difficult. With each rotation, the monitor can be in different positions and workers must look for the monitor in case of problems or replacements. In many cases, these problems lead to the abandonment of rotation plans.

One strategy used to implement simpler rotation schemes is to group workstations into several small rotation groups. For example, Figure 1b shows that the 16 workstations in the previous example were grouped into four rotation groups. Each rotation group has four workstations and four workers assigned to them. In the example in the Figure, workstations 1-4 form rotation group 1, and workers 1-4 are assigned to these workstations. Next, four independent rotation schemes are generated, one for each rotation group.

While this approach avoids the organizational problems encountered in generating a global schedule for the entire set of workstations, it has important drawbacks. Normally, groups of castors are created by grouping workstations close to each other, without considering ergonomic criteria in the grouping process. Likewise, workers are allocated in rotation groups considering only organizational issues. However, in order to achieve the expected benefits with rotation, it would be convenient for the movements required in the tasks performed in the workstations of the same rotation group to be different. Likewise, workers must be allocated in rotation groups considering their capabilities, preferences and time constraints.

To face these problems, this work proposes a different approach to create job rotation schemes. The use of learning algorithms based on neural networks generate rotation schemes grouping jobs in the rotation plan so that a set of workers rotates cyclically over a small number of jobs. The algorithm determines how to group the workstations, which workers are best suited for each rotation group, and the rotation sequence. With this, it is intended to: reduce the risk of musculoskeletal injuries, increase the diversification of tasks to be performed throughout the working day, consider the possible disabilities of employees, simplify task changes and monitoring.

This paper is organized as follows: In Section 2, an overview is presented on the construction practices of the requirements of computational systems aimed at monitoring work rotation through a survey of articles. Section 3 presents a set of works related to requirements engineering practices and Job Rotation. In Section 4, the process of gathering functional and non-functional requirements and business rules for building work rotation systems is shown. Section 5 presents the criteria and metrics adopted to evaluate and validate the requirements adopted in the development of the systems. Section 6 offers a discussion of the topics worked on and used to establish a case study as a reference for this study.

2. METHODOLOGY

This section describes the procedure used to verify the ability of the RGA algorithm to generate cyclic job rotation schedules that minimize the effects of repetitive movements while simplifying scheduled changeovers at each rotation. To do this, RGA was used to design a cyclic rotation schedule for a set of 16 workplaces and workers in a spare parts assembly line.

The methodology indicates a set of steps to be followed in order to establish the relationships for gathering information about the scenario, the people and the complexities of the tasks in order to establish the rotation schedule (Figure 1).

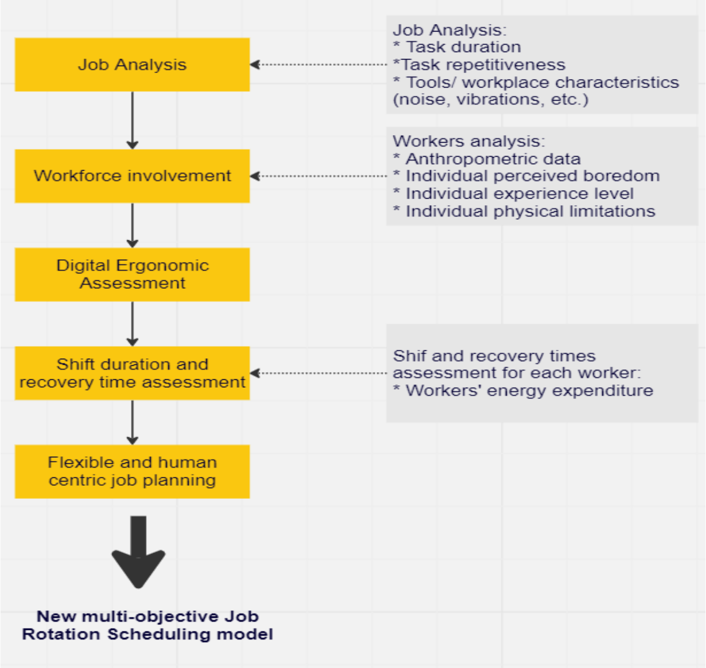


Figure 1 - Methodological framework supporting the implementation of new Job Rotation.

Cyclic rotation schedules are preferable from an organizational point of view. However, it is not the same from an ergonomics point of view. All the solutions in the RGA's initial population are cyclic rotation schedules. On the other hand, crossover and mutation in RGA are closed operators (they always produce valid cyclic schedules) and then, all the solutions in the population of RGA are always cyclic rotation schedules. Therefore, the solution space in which RGA searches for a solution to the problem is formed by all the possible cyclic rotation schedules. This solution space is a subset of all the possible schedules (including all the no-cyclic schedules). As a result, from an ergonomics point of view, the quality of the best schedule in the RGA´s solution space will be equal or worse than that of the best schedule in the global solution space including no-cyclic schedules.

RGA's approach looks for a compromise between ergonomics and organizational criteria to generate rotation schedules. To check this compromise, the problem under consideration was solved using RGA to obtain the best cyclic rotation schedule. Then, a modified version of the algorithm (RGAm) was used to obtain the best no-cyclic job rotation schedule. Finally, the scores of the fitness function of both solutions were compared. To create a schedule in RGAm, the workers are randomly assigned to the workstations without creating rotation groups. In the same way, the crossover operator does not consider rotation groups and creates offspring from parents in an unrestricted way.

In the analyzed spare parts assembly line, there was an eight-hour workday. RGA was used to design a cyclic rotation schedule with four rotations; the first three rotations with a duration of 2 h, and the last one of 1 h. There was one-hour break for lunch between the second and the third rotations. All the 16 workstations belonged to same line and the distances between them allow for quick changeovers. The 16 workers had skills to perform the task required at any of the workstations.

2.1. Scores of the Workers and the Workstations

The movements and skills needed to perform the task at each workstation on the assembly line were analyzed. Scores ranged from 0 to 3 for each item in the movement group (Table 1) depending on the frequency of each movement (Table 2).

Table 1 - Criteria employed to characterize workers and workstations. The skills and capacity to perform the movements of the workers are matched with those required by the jobs.

Movements	**General Skills**	**Mental and communication Skills**
Arm Abdution	Standing	Resoning
Arm extension	Sitting	Taking complex decision
Arm flexion	Walking	Responsibility
Elbow flexion	Climbing	Cooperation
Neck extension	Coordinating movements	Attention
Neck flexion	Applying force standing	Initiative
Neck turning	Applying force in movement	Autonomy
Neck lateralization	Driving vehicles	Long distance vision
Shoulder raising	Working at height	Color vision
Trunk flexion	Using personal protection equipment	Hearing
Trunk rotation	Staying confined/ restricted spaces	Locating direction of sound
Trunk extension		Tactile sensivity Smelling/ tasting
Trunk Lateralization		Writing
Pincing with fingers		Speaking
Hand flexion		Using a keyboard
Hand extesion		Using a mouse
Pronation/ Supination of hands		
Radial/ Cubital deviation of hands		

The tasks involved in the rotation have analysis given by the literature on the relationship of body movements and the frequency they are performed [11]. This analysis provides a numerical value for the movement items required to perform the tasks at each workstation according to the scoring system shown in Table 2.

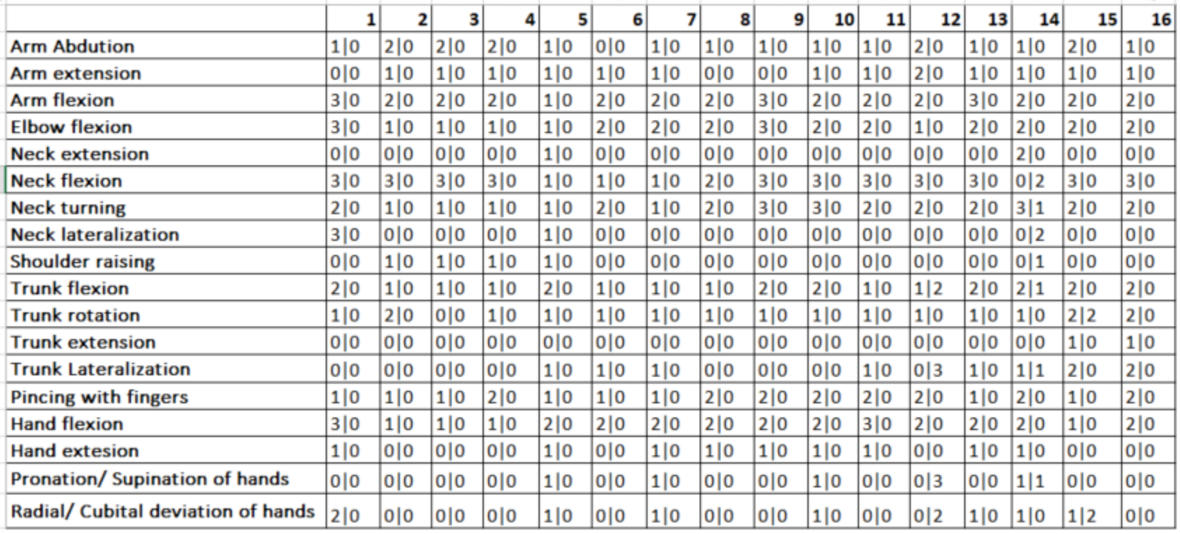
Additionally, the workers' ability to perform the movements listed in the Movement items is scored. The score is 0 if the worker has no limitation to perform the movement, 1 if the worker has little limitation in movement, 2 if the limitation is high, and 3 if the worker is unable to perform the movement. In practical application, medical guidance is needed to assign scores to the workers' items according to their ability to perform each movement and to decide whether any worker has any limitations to perform any activity. The scoring of General and Mental and Communication skills items for positions and workers is qualitative. If a skill is required to perform a certain task, the corresponding item is scored as “Necessary”, otherwise it is scored as “Not Required”. Worker skill items take on the values “With limitation” or “Without limitation”, depending on whether or not the worker has limited ability to perform the skill specified in the item.

Table 2 - Score assigned to the workstations depending on the frequency of movements that must be performed.

Frequency of Moviments per minute	Score
0	0
1-2	1
3-7	2
>7	3

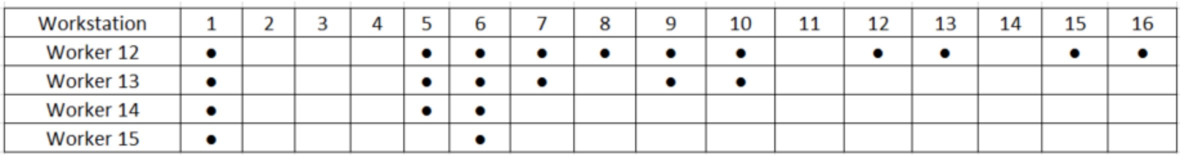
Table 3 shows the scores of the items of the movements group for each workstation and for each worker. The skills and capacities needed in each workstation and the skills and limitations of the workers were matched to determine which workers should not be assigned to some jobs (penalized assignments). Table 4 shows the penalized assignments.

Table 3 - Scores of the items of the “Movements” group for the 16 workstation and workers. The first number in each cell is the workstation score, the second one is the worker score.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Arm Abdution	1|0	2|0	2|0	2|0	1|0	0|0	1|0	1|0	1|0	1|0	1|0	2|0	1|0	1|0	2|0	1|0
Arm extension	0|0	1|0	1|0	1|0	1|0	1|0	1|0	0|0	0|0	1|0	1|0	2|0	1|0	1|0	1|0	1|0
Arm flexion	3|0	2|0	2|0	2|0	1|0	2|0	2|0	2|0	3|0	2|0	2|0	2|0	3|0	2|0	2|0	2|0
Elbow flexion	3|0	1|0	1|0	1|0	1|0	2|0	2|0	2|0	3|0	2|0	2|0	1|0	2|0	2|0	2|0	2|0
Neck extension	0|0	0|0	0|0	0|0	1|0	0|0	0|0	0|0	0|0	0|0	0|0	0|0	0|0	2|0	0|0	0|0
Neck flexion	3|0	3|0	3|0	3|0	1|0	1|0	1|0	2|0	3|0	3|0	3|0	3|0	3|0	0|2	3|0	3|0
Neck turning	2|0	1|0	1|0	1|0	1|0	2|0	1|0	2|0	3|0	3|0	2|0	2|0	2|0	3|1	2|0	2|0
Neck lateralization	3|0	0|0	0|0	0|0	1|0	0|0	0|0	0|0	0|0	0|0	0|0	0|0	0|0	0|2	0|0	0|0
Shoulder raising	0|0	1|0	1|0	1|0	1|0	0|0	0|0	0|0	0|0	0|0	0|0	0|0	0|0	0|1	0|0	0|0
Trunk flexion	2|0	1|0	1|0	1|0	2|0	1|0	1|0	1|0	2|0	2|0	1|0	1|2	2|0	2|1	2|0	2|0
Trunk rotation	1|0	2|0	0|0	1|0	1|0	1|0	1|0	1|0	1|0	1|0	1|0	1|0	1|0	1|0	2|2	2|0
Trunk extension	0|0	0|0	0|0	0|0	0|0	0|0	0|0	0|0	0|0	0|0	0|0	0|0	0|0	0|0	1|0	1|0
Trunk Lateralization	0|0	0|0	0|0	0|0	1|0	1|0	1|0	0|0	0|0	0|0	1|0	0|3	1|0	1|1	2|0	2|0
Pincing with fingers	1|0	1|0	1|0	2|0	1|0	1|0	1|0	2|0	2|0	2|0	2|0	2|0	1|0	2|0	1|0	2|0
Hand flexion	3|0	1|0	1|0	1|0	2|0	2|0	2|0	2|0	2|0	2|0	3|0	2|0	2|0	2|0	1|0	2|0
Hand extesion	1|0	0|0	0|0	0|0	1|0	0|0	1|0	1|0	1|0	1|0	1|0	0|0	1|0	1|0	0|0	0|0
Pronation/ Supination of hands	0|0	0|0	0|0	0|0	1|0	0|0	1|0	0|0	0|0	1|0	0|0	0|3	0|0	1|1	0|0	0|0
Radial/ Cubital deviation of hands	2|0	0|0	0|0	0|0	1|0	0|0	1|0	0|0	0|0	1|0	0|0	0|2	1|0	1|0	1|2	0|0

Table 4 - Scores of the items of the "Movements" group for the 16 workstation and workers. The first number in each cell is the workstation score, the second one is the worker score.



Workstation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Worker 12	●				●	●	●	●	●	●		●	●		●	●
Worker 13	●				●	●	●		●	●						
Worker 14	●				●	●										
Worker 15	●					●										

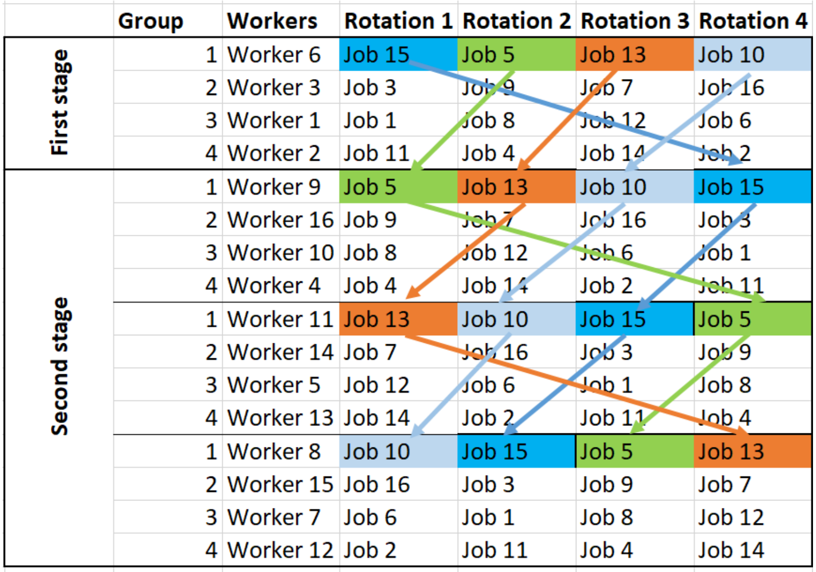
2.2. RGA Algorithm

The algorithm proposed in this article follows the general principles of evolutionary algorithms [41]. A set of structures representing solutions to the problem is developed by performing a stochastic guided search for the best solution.

Initially, a set of solutions is created (usually randomly) by encoding each solution by a vector or matrix (chromosome or individual). The set of solutions is called the population. In the RGA algorithm, each chromosome represents a complete rotation schedule, establishing the workstation that each worker must occupy in each rotation. The population is then transformed to obtain a new set of solutions. The new solutions are obtained by applying operators such as "selection", "crossover" or "mutation" that transform the solutions by combining or modifying the chromosomes of the current population. These operators act according to the adequacy of each solution. The fitness of a solution is obtained through a previously defined objective function. The new population goes through the same process, and this procedure is repeated until a stopping condition is reached.

2.3. Solution Encoding and Initial Population

The refined genetic algorithm (RGA) generates an initial population of solutions of size n. Each solution is a job rotation schedule that is coded using a matrix of size nw × 1 + nr, where nw is the number of workers involved in the schedule and nr is the number of rotations during a work day (Figure 2). The number of workers must match the number of jobs to be occupied and must be divisible by nr.



	Group	Workers	Rotation 1	Rotation 2	Rotation 3	Rotation 4
First stage	1	Worker 6	Job 15	Job 5	Job 13	Job 10
	2	Worker 3	Job 3	Job 9	Job 7	Job 16
	3	Worker 1	Job 1	Job 8	Job 12	Job 6
	4	Worker 2	Job 11	Job 4	Job 14	Job 2
Second stage	1	Worker 9	Job 5	Job 13	Job 10	Job 15
	2	Worker 16	Job 9	Job 7	Job 16	Job 3
	3	Worker 10	Job 8	Job 12	Job 6	Job 1
	4	Worker 4	Job 4	Job 14	Job 2	Job 11
	1	Worker 11	Job 13	Job 10	Job 15	Job 5
	2	Worker 14	Job 7	Job 16	Job 3	Job 9
	3	Worker 5	Job 12	Job 6	Job 1	Job 8
	4	Worker 13	Job 14	Job 2	Job 11	Job 4
	1	Worker 8	Job 10	Job 15	Job 5	Job 13
	2	Worker 15	Job 16	Job 3	Job 9	Job 7
	3	Worker 7	Job 6	Job 1	Job 8	Job 12
	4	Worker 12	Job 2	Job 11	Job 4	Job 14

Figure 2 - Solution encoding and procedure for the generation of individuals.

The objective of the RGA algorithm is to define the cyclical time of each group of workers in a small number of workstations. The number of rotation groups is obtained by dividing the number of workers by the number of stations.

In the matrix used to code the solutions (Figure 2), the Workers column indicates a worker, and the remaining columns of the line indicate the job that this worker will occupy in each rotation.

The first row of the matrix contains a worker from the first rotation group, the second row a worker from the second rotation group, and so on up to row n. Line ng+ 1 contains a worker from the first rotation group, line ng+ 2 a worker from the second group, and so on. That is, line i indicates the jobs belonging to the rotation group i − {ng× [(i−1)/ng]} assigned to a worker in each rotation. For example, in the case of a work schedule that has 4 rotations, 16 workers and 16 jobs (Figure 2), lines 1, 5, 9 and 13 will have:

- Workers and jobs in rotation group 1;
- Lines 2, 6, 10 and 14 are those of group 2;
- Lines 3, 7, 11 and 15 are those of group 3; It is
- Lines 4, 8, 12 and 16 for group 4.

The presentation of a solution is carried out in two steps. In the first step, the rotations of the first ng lines are generated. These lines contain one worker from each rotation group. ng workers are randomly assigned to cells in the Workers column. A workstation is also randomly assigned to the remaining cells in the rows. Since the number of cells is ng × nr, workstations will not be repeated on the same line. In the second step, the remaining workers are randomly assigned to the first column of rows ng + 1 to nw. Workers in the same rotation group must occupy the same set of workstations in different rotations.

In a first phase, the set of jobs assigned to each group is defined and a worker is assigned to each rotation group. Each new worker in a rotation group will receive the tasks that the previous worker performed in previous rotations to complete the matrix. This procedure for completing a solution is called “Assignment Extension”.

In the example in Figure 2, the first line, generated in the first step, indicates that worker 6 is successively assigned in each rotation to jobs 15, 5, 13 and 10. All these jobs belong to group 1. To complete the jobs in the fourth row, also corresponding to rotation group 1, is assigned the same work sequence as the first row, but now shifted 1 element. Therefore, worker 9 will receive job 5 in the first rotation, then job 13, job 10, and finally job 15 in the fourth rotation. In this way, workers in each rotation group will rotate cyclically in the same set of jobs. This procedure is repeated until the n individuals that make up the initial population are generated. In the tests carried out, a population of 50 individuals was used to produce 4 rotations out of 16 results.

2.4. Measuring the Fitness of the Rotation Schedules

Each employee population solution represents a rotation schedule. The suitability of a solution is obtained by applying the suitability inspection of the schedule itself. The adequacy of the schedule can be obtained by measuring the adequacy of the workers' assignments in each rotation. If worker i was assigned to workstation y in rotation z, the adequacy of that assignment can be measured by multiplying the item scores of work y by the item scores of worker i. By extending this procedure to all rotations and workers, we can measure the fitness (E) of a rotation scheme (Equation (1)). A workstation's scores are proportional to the need to perform some movements or activities in the task performed at this workstation, while a worker's scores are inversely proportional to the worker's ability to perform those movements or activities. Therefore, the value of E, calculated through Equation (1), will be lower for the most suitable schemes. The smaller the E, the better the schedule:

$$E = \sum_{i=1}^{n_w}\sum_{r=1}^{n_r}\sum_{j=1}^{n_j} I_j * w_j^i\,(r) * t_j\,(m^i\,(r)) * d_r \qquad (1)$$

In Equation (1), n_w, n_r, and n_j are the number of workers, rotations, and items considered. The coefficient I_j represents the relative importance of the item j with respect to the rest of the items, $t_j(m^i(\mathrm{r}))$ is the score of the item j of the job allocated to the worker i in the rotation r and d_r is the duration of the rotation r.

$w_j^i\,(r)$ is the score of the item j of worker i in rotation r. The capacity of a worker to perform a particular movement must be recalculated after each rotation, considering the effects of the jobs performed in earlier rotations, i.e., cumulative effect of fatigue on the muscle groups involved. To do this, the values of the workers' movement items $w_j^i\,(r)$ are recalculated for each rotation using the Equation (2) that considers the movements already performed by the worker in preceding rotations. If a worker had been assigned to a workstation requiring, for example, elbow flexion, in a rotation before the current rotation, the score of the worker's item for this movement would increase according to the physical effort and duration of the task. This will reduce the probability of assigning this worker to a job that requires elbow flexion in the next rotations:

$$w_j^i(r) = w_j^i + \frac{1}{r_d} * \sum_{h=1}^{r-1} \frac{t_j\left(m^i\,(h)\right) * l_h}{e_h} \qquad (2)$$

$$t_j\left(m^i(h)\right) > th$$

Equation (2) calculates the values of the movement items of the workers in each rotation $w_j^i\,(r)$ is the value of the item j of the worker i in the rotation r). This equation considers that the effort required at each workstation is given by the values of the workstation's movement items. The amount of changes that worker movement items will get in job rotations r depends on the duration of tasks involved in previous rotations. In this case, the quantity ih represents the duration of rotation h performed in the cycle before rotation r, and eh is the time between the end of rotation h and the beginning of rotation r. To calculate the time elapsed between rotations (Equation (3)), the existence of breaks or pauses is considered. In Equation (3), th,r is the break time between the current rotation r and a previous rotation h, and lg is the duration of the rotation g performed between h and r:

$$e_h = \begin{cases} t_{h,r} + \sum_{g=h+1}^{r-1} l_g \;; h < r-1 \end{cases} \qquad (3)$$

$$1; h = r-1$$

Equation (2) increases the scores of the items of a worker after each rotation if the items of the workstations of previous rotations are bigger than a threshold value (th). In the same Equation, the parameter rd regulates the size of the effect of tasks performed in preceding rotations on the items of the worker in later rotations. Considering the advice of the medical staff, the value of the parameter th was set to 1.5 and rd was set to 3.

2.5. Penalties

The fitness function presented in Equation (1) does not penalize the assignment of a worker to the same workplace in successive rotations. However, to get the expected benefits of job rotation, the worker must be assigned to different workstations. In this way, different muscle groups are used in each rotation and monotony is reduced.

To avoid assigning a worker to the same workstation in consecutive rotations, the tmax parameter is defined as the maximum consecutive time that a worker can be allocated to a workstation. The solutions in the population are reviewed to see if any workers are allocated to the same workstation for a time longer than tmax. When this situation occurs, the penalty is increased, thus reducing your chances of survival or reproduction.

Finally, solutions that encode unwanted assignments for organizational or medical reasons are also penalized.

2.6. Selection

In this phase, all solutions in the population are given a fitness value and a roulette wheel selection operator is used to select survival solutions (solutions that pass to the next population) [42]. In this selection process, the probability that a solution is selected to survive is proportional to the adequacy of the job rotation schedule that the solution represents. In RGA, the fitness of a solution, calculated using Equation (1), will be smaller for the most suitable schedules. Therefore, the smaller the E, the greater the probability of the solution being selected.

Roulette wheel selection operator does not guarantee that the best solutions of the population are always selected as survivor. This can lead to loosing good solutions. To avoid this, the best solutions of the population are always selected as survivors (elitism). Er is the number of the best solutions retained for the next generation (elitism rate).

The new generation of solutions is compounded of survivors, elite individuals, and new individuals obtained by crossover of solutions of the previous generation. The number of new individuals obtained by crossover is $n \cdot pc$, being n the population size and pc a parameter named crossover probability. The number of survivors selected by the roulette wheel selection method from the previous generation is $n \cdot (1 - pc) - Er$.

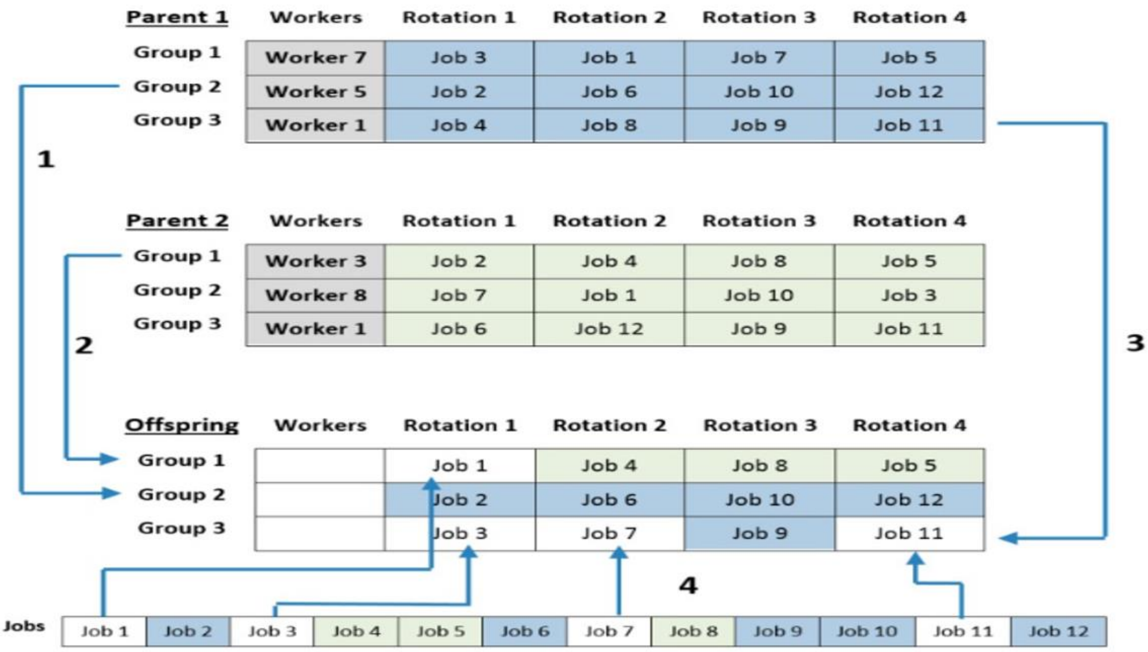
2.7. Crossover Operator

Solutions involved in the crossover procedure are also selected by roulette wheel selection. $n \cdot pc$ pairs of individuals (parents) are selected from the population. Each pair is crossed over and generates a new individual (offspring). The offspring passes directly to the new generation. The crossover procedure is performed as follows:

1. Two ‘parent’ solutions are randomly selected from the population and called Parent A and Parent B.
2. One of the first ng rows of the offspring that have not yet been selected (hereafter named row i) is randomly selected;
3. Each cell in the row i of the offspring is assigned the same value as the equivalent cell in the row i of parent A. If the value corresponding to a cell has already been assigned to any other cell of the offspring, then the cell will remain empty and will be marked as ‘to be completed later’;
4. Parent A will be now Parent B, and Parent B will be now Parent A. Steps 2, 3, and 4 are repeated until all the ng rows of the offspring have been selected;
5. The cells of the offspring marked as ‘to be completed later’ are randomly assigned the jobs that have not yet been assigned to any other cell;
6. After obtaining the first ng rows of the offspring, the remaining rows are generated by assignment extension;
7. One of the parents is randomly selected and the values of the column 1 (workers) are copied in the column 1 of the offspring.

Crossover operator considers only the first ng rows of the ‘parent’ individuals and creates only the first ng rows of the offspring. Then, the complete offspring is obtained using the assignment extension procedure.

Figure 3 shows an example of a crossover operation between two solutions with three rotation groups. In the first step, line 2 of parent 1 is copied to line 2 of a child. Then, in the second step, row 1 of Parent 2 is copied to row 1 of the child, except the job of the first rotation (Job 2), which had previously been assigned in Step 1. This cell is marked as ‘to be completed later’. The procedure is repeated with line 3 of Parent 1 in the third step. Finally, the marked cells are randomly populated with work not yet assigned in the last step.



Parent 1	Workers	Rotation 1	Rotation 2	Rotation 3	Rotation 4
Group 1	Worker 7	Job 3	Job 1	Job 7	Job 5
Group 2	Worker 5	Job 2	Job 6	Job 10	Job 12
Group 3	Worker 1	Job 4	Job 8	Job 9	Job 11

Parent 2	Workers	Rotation 1	Rotation 2	Rotation 3	Rotation 4
Group 1	Worker 3	Job 2	Job 4	Job 8	Job 5
Group 2	Worker 8	Job 7	Job 1	Job 10	Job 3
Group 3	Worker 1	Job 6	Job 12	Job 9	Job 11

Offspring	Workers	Rotation 1	Rotation 2	Rotation 3	Rotation 4
Group 1		Job 1	Job 4	Job 8	Job 5
Group 2		Job 2	Job 6	Job 10	Job 12
Group 3		Job 3	Job 7	Job 9	Job 11

Jobs											
Job 1	Job 2	Job 3	Job 4	Job 5	Job 6	Job 7	Job 8	Job 9	Job 10	Job 11	Job 12

Figure 3 - Generation of descendants through the crossing of two parents (represented by the numbers 1 to 4).

2.8. Mutation Operator

It is common to notice the emergence of mutations on randomly generated data. In these cases, the number of individuals that will mutate is n·pm, where n is the population size and pm is a parameter (mutation probability).

The procedures that deal with data mutation for the Job Rotation problem are divided into two distinct phases. The first phase deals with the assignment of jobs to each rotation and the second deals with the assignment of workers to each group. This procedure is repeated n·pm times:

1. One individual is randomly selected from the population.
2. A rotation group j is randomly selected.
3. Two rows, between 1 and ng, are randomly selected (i1, i2).
4. The jobs assigned to cells (i1, j) and (i2, j) are swapped.
5. The assignment is extended (Section 2.2.1).
6. Two workers of column 1 are randomly swapped

3. RESULTS

The execution of the RGA algorithm made 10 cycles (10 times) using the scores shown in Table 3 and the penalties shown in Table 4. In order to standardize the process, each cycle was stopped after 10,000 iterations. Then, the modified version of the algorithm (RGAm) was run 10 times using the same scores and parameters to obtain the best non-cyclic task rotation schedule. The algorithms were run on a personal computer with a 4-core 2.6 GHz CPU and 16 GB of RAM. The average execution time of the 10 runs was 8.36 min for the RGA algorithm and 6.24 min for the RGAm algorithm.

Considering the average time operators spend at their workstations, a rotation of two hours was set for the first, second and third cycles, and just one hour for the fourth cycle, identified as tmax. Thus, the tmax variable represents the maximum consecutive time that a worker can be assigned to a workstation. This criterion was established so that penalties could be applied when a worker was reassigned to the same job, with the same task in two consecutive rotations. Coefficients I1 to I18 were fixed at 1 (see Equation (1)). These coefficients represent the relative importance of each item in relation to the rest of the items. In this case, all were considered with the same level of importance.

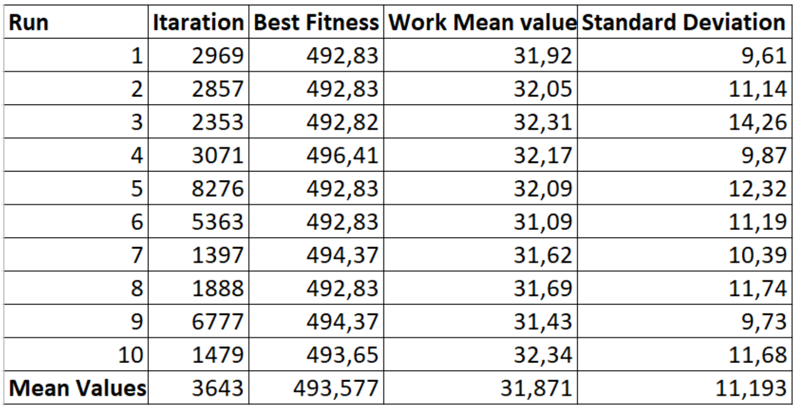
Some tests were performed to establish the best combination of the rest of the parameters of RGA. In general, RGA is a robust algorithm and slight changes in the parameters do not affect the results. After running the algorithm several times, the population size (n) was set to 50, the crossover probability (pc) was set to 0.6, and the mutation probability (pm) to 0.3. The elitism rate (Er) was set to 1.

The results of each RGA and mRGA run are presented in Table 5 and Table 6, respectively. The first column of the tables shows the number of runs, the second (Iteration) shows the generation in which the best schedule was found and the third (Best

Fitness) the fitness value of the best schedule. The fourth column (mean value of workers) indicates the average contribution of each worker's assignments to the total fitness of the best solution. Finally, the last column shows the standard deviation of the contribution of each worker's assignments to the adequacy of the best solution. The values in the last column indicate whether tasks were evenly assigned to workers. A high value in this column means that some workers are assigned to more difficult jobs (with high scores on movement items) while others perform lighter work. Therefore, lower values are preferable in this column.

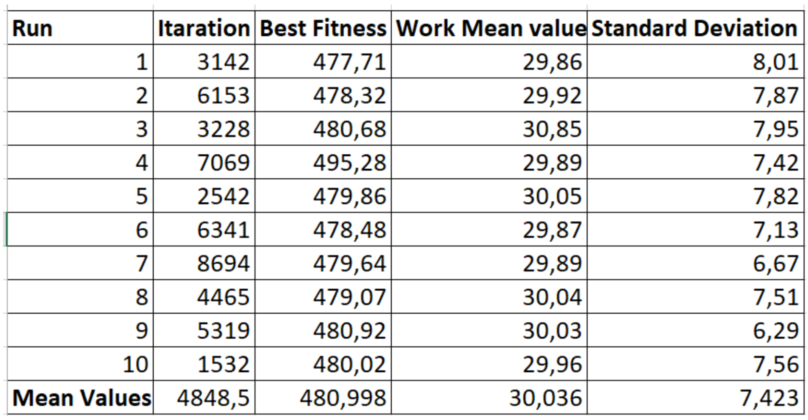
The algorithms were able to obtain viable solutions in all executions and the constraints of the problem were satisfied. The fitness value of the best scaling provided by RGA was 492.82, while the value of the best solution obtained by RGAm was 477.71. The average value of workers was 31.871 for RGA and 30.036 for RGAm. On average, RGA obtained the best fitness in iteration 3643 and RGAm in iteration 4848.50.

Table 5 - Results of the RGA algorithm.



Run	Itaration	Best Fitness	Work Mean value	Standard Deviation
1	2969	492,83	31,92	9,61
2	2857	492,83	32,05	11,14
3	2353	492,82	32,31	14,26
4	3071	496,41	32,17	9,87
5	8276	492,83	32,09	12,32
6	5363	492,83	31,09	11,19
7	1397	494,37	31,62	10,39
8	1888	492,83	31,69	11,74
9	6777	494,37	31,43	9,73
10	1479	493,65	32,34	11,68
Mean Values	3643	493,577	31,871	11,193

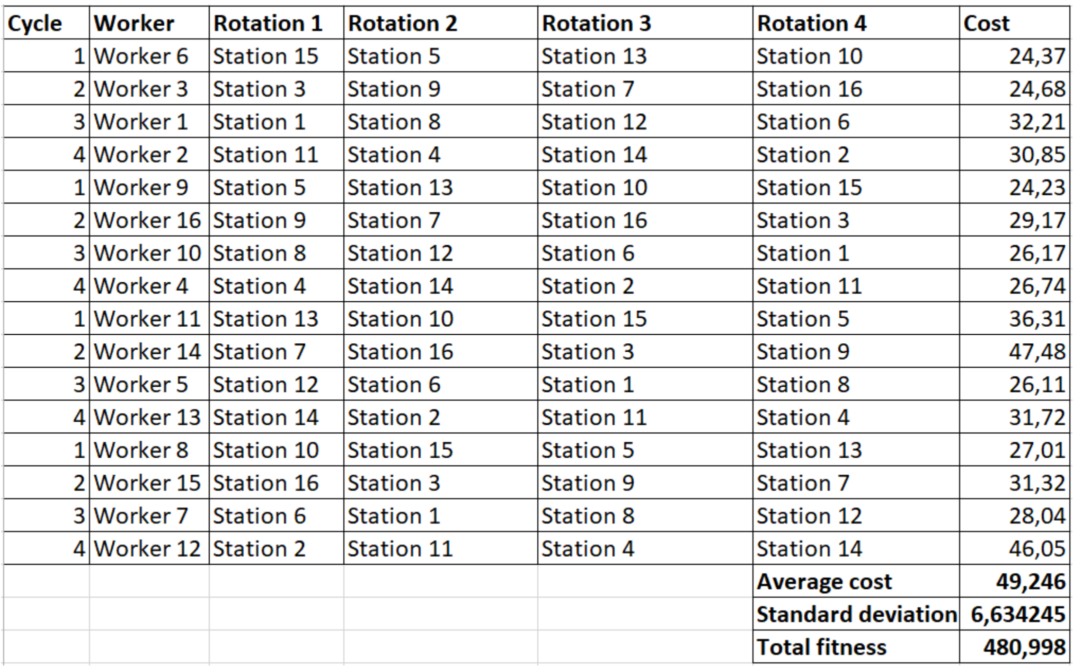
Table 6 - Results of the RGAm algorithm.



Run	Itaration	Best Fitness	Work Mean value	Standard Deviation
1	3142	477,71	29,86	8,01
2	6153	478,32	29,92	7,87
3	3228	480,68	30,85	7,95
4	7069	495,28	29,89	7,42
5	2542	479,86	30,05	7,82
6	6341	478,48	29,87	7,13
7	8694	479,64	29,89	6,67
8	4465	479,07	30,04	7,51
9	5319	480,92	30,03	6,29
10	1532	480,02	29,96	7,56
Mean Values	4848,5	480,998	30,036	7,423

RGA found the best schedule in Run 3 (Table 7). The first rotation group was formed by the workstations 15, 5, 13, and 10 and the workers 6, 9, 11, and 8. The group 2 consisted of workstations 3, 9, 7, 16 and workers 3, 16, 14, and 15. Group 3 included workstations 1, 8, 12, and 6 and workers 1, 10, 5, and 7. Finally, group 4 consisted of workstations 2, 4, 13, and 12 and workers 2, 4, 13, and 12.

Table 7 - Best solution generated by RGA.

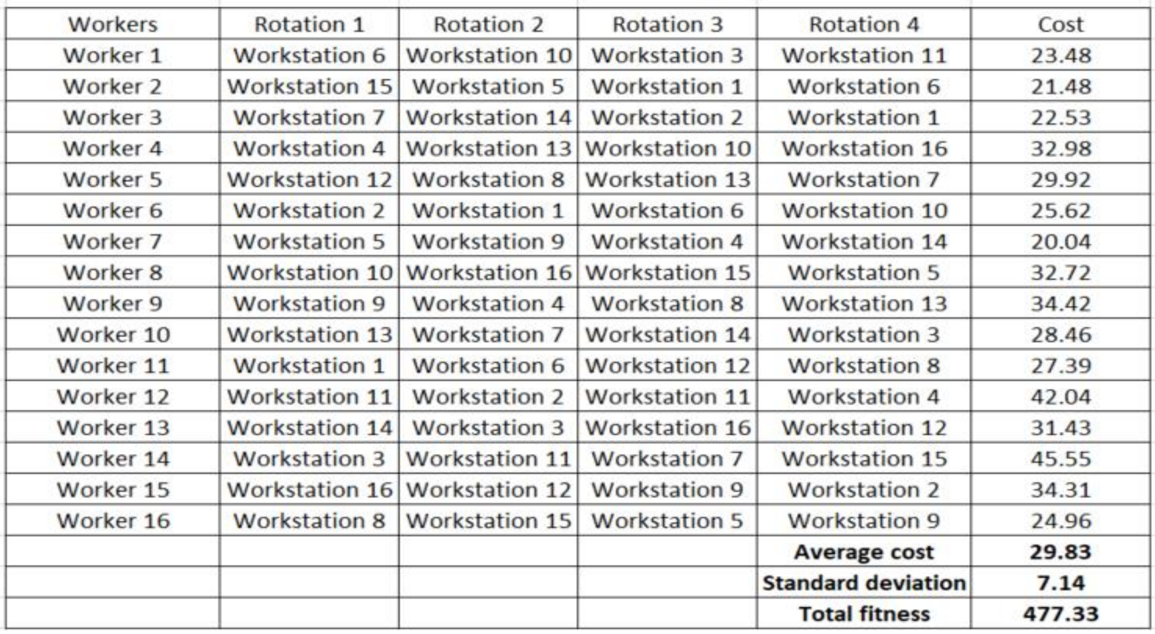


Cycle	Worker	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Cost
1	Worker 6	Station 15	Station 5	Station 13	Station 10	24,37
2	Worker 3	Station 3	Station 9	Station 7	Station 16	24,68
3	Worker 1	Station 1	Station 8	Station 12	Station 6	32,21
4	Worker 2	Station 11	Station 4	Station 14	Station 2	30,85
1	Worker 9	Station 5	Station 13	Station 10	Station 15	24,23
2	Worker 16	Station 9	Station 7	Station 16	Station 3	29,17
3	Worker 10	Station 8	Station 12	Station 6	Station 1	26,17
4	Worker 4	Station 4	Station 14	Station 2	Station 11	26,74
1	Worker 11	Station 13	Station 10	Station 15	Station 5	36,31
2	Worker 14	Station 7	Station 16	Station 3	Station 9	47,48
3	Worker 5	Station 12	Station 6	Station 1	Station 8	26,11
4	Worker 13	Station 14	Station 2	Station 11	Station 4	31,72
1	Worker 8	Station 10	Station 15	Station 5	Station 13	27,01
2	Worker 15	Station 16	Station 3	Station 9	Station 7	31,32
3	Worker 7	Station 6	Station 1	Station 8	Station 12	28,04
4	Worker 12	Station 2	Station 11	Station 4	Station 14	46,05
					Average cost	**49,246**
					Standard deviation	**6,634245**
					Total fitness	**480,998**

This solution met the restrictions imposed on the problem and workers were allocated to different jobs at each rotation, even when a worker identified with a disability or limitation to perform various movements or activities was observed. On the contrary, in the best solution generated by RGAm (Table 8), worker 12 was allocated to the same job in two non-consecutive rotations (rotation 1 and 3).

The last column of Table 7 and Table 8 indicates the contribution of each worker's attributions to the total suitability of the solution. The balance in workers' assignments was very similar in the best solution found by both RGA and RGAm. The best RGA solution was slightly more balanced than the best RGAm solution. In the best RGA solution, the biggest imbalance was between worker 9, with an average cost of 24.23, and worker 14, with an average cost of 47.49. In the best RGAm solution, the biggest difference was found between worker 7, with an average cost of 20.04, and worker 14, with an average cost of 45.55. Worker 14 was the worker with the highest cost in both solutions. Worker 14 had limitations in some movements and skills and was unable to occupy several jobs, which meant less possibilities for both algorithms in an attempt to achieve more favorable and less unbalanced assignments in relation to the other workers. The same happened with worker 12, whose cost was 46 in the best RGA solution and 42.04 in the best RGAm solution.

Table 8 - Best solution generated by RGAm.



Workers	Rotation 1	Rotation 2	Rotation 3	Rotation 4	Cost
Worker 1	Workstation 6	Workstation 10	Workstation 3	Workstation 11	23.48
Worker 2	Workstation 15	Workstation 5	Workstation 1	Workstation 6	21.48
Worker 3	Workstation 7	Workstation 14	Workstation 2	Workstation 1	22.53
Worker 4	Workstation 4	Workstation 13	Workstation 10	Workstation 16	32.98
Worker 5	Workstation 12	Workstation 8	Workstation 13	Workstation 7	29.92
Worker 6	Workstation 2	Workstation 1	Workstation 6	Workstation 10	25.62
Worker 7	Workstation 5	Workstation 9	Workstation 4	Workstation 14	20.04
Worker 8	Workstation 10	Workstation 16	Workstation 15	Workstation 5	32.72
Worker 9	Workstation 9	Workstation 4	Workstation 8	Workstation 13	34.42
Worker 10	Workstation 13	Workstation 7	Workstation 14	Workstation 3	28.46
Worker 11	Workstation 1	Workstation 6	Workstation 12	Workstation 8	27.39
Worker 12	Workstation 11	Workstation 2	Workstation 11	Workstation 4	42.04
Worker 13	Workstation 14	Workstation 3	Workstation 16	Workstation 12	31.43
Worker 14	Workstation 3	Workstation 11	Workstation 7	Workstation 15	45.55
Worker 15	Workstation 16	Workstation 12	Workstation 9	Workstation 2	34.31
Worker 16	Workstation 8	Workstation 15	Workstation 5	Workstation 9	24.96
				Average cost	**29.83**
				Standard deviation	**7.14**
				Total fitness	**477.33**

3.1. Discussion

The RGA algorithm generates rotation schemes by grouping the jobs to be included in the rotation plan so that a set of workers rotates cyclically over a small number of jobs. The model defined for him was to determine the grouping of workstations, indicate which workers are best suited for each rotation group, and the sequence of rotation.

The solutions obtained with the RGA can reduce the risk of musculoskeletal injuries, increase the diversification of tasks to be performed throughout the working day, and consider the possible disabilities of employees. Furthermore, RGA simplifies changeovers between rotations, avoiding delays in the production process, while facilitating monitoring tasks. Computational experiments show the ability of the RGA algorithm to solve the problem of generating rotation schemes while simultaneously considering multiple criteria and constraints, creating rotation groups. Under these conditions, the algorithm provides good results with a small computation time. In the case under study, the model was able to obtain solutions in which workers rotate cyclically in four workstations, minimizing the repetitiveness of the movement and being able to balance the cumulative effect of fatigue and stress.

The solution space of the current problem, in which only cyclic schedules are considered valid solutions, is a subset of the solution space of the problem without workstation clustering. This suggests that, necessarily, the fitness function value of the best solution in the RGA solution space will be greater than or equal to the value of the best solution without task clustering. In fact, the RGAm version of the algorithm was able to generate a solution to the test problem with a slightly lower objective function value than the RGA. To verify whether the best solution obtained by RGA is significantly worse from an ergonomic point of view than the one obtained by RGAm, it would be convenient to know the optimal solution of the problem, but it is not possible to obtain this value analytically.

The fitness value of the best rotation schedule obtained using RGA was 492.80 and using RGAm was 477.33. Therefore, the fitness of the best cyclic schedule was 24.09% better than the mean fitness of random schedules, and the fitness of the best no-cyclic schedule was 26.47% better. The difference between both algorithms compared to the random allocation is 2.38%. Therefore, although the best cyclic rotation schedule is slightly worse than the best no-cyclic schedule from the ergonomics point of view, the difference is small, and it is compensated by the benefits of a better work organization.

Workers' paths during a workday were experimented in a cyclical solution and a non-cyclical solution. The non-cyclical solution presents some organizational problems such as the diversity and complexity of the routes followed by workers or the chaotic movement of workers during changes. On the other hand, the best cyclical solution simplifies workers' journeys during the working day. Rotation groups make it possible to know the jobs around which workers will rotate, allowing for better organization and monitoring of work. The problems arising from the implementation of a cyclical solution imply, on many occasions, the abandonment of the rotation plan. Thus, the organizational benefits obtained with the use of the RGA seem to compensate the increase in the value of the fitness function.

The ergonomics criteria considered in this work are mainly intended to reduce the exposure of workers to repetitive movements. However, other criteria can be included in the process to reduce the exposure of the workers to other musculoskeletal disorders risk factors or to prevent musculoskeletal pain or disability. One of the advantages of our proposal is the additive model used in the fitness function of RGA. This additive model gives the possibility of including new factors and criteria to be considered to generate the job rotation schedules. Each new criterion can be included, adding a new term to the fitness function with a weighting coefficient to consider its relative importance with respect to other criteria. In this way, for example, the Nordic Musculoskeletal Questionnaire [43] could be used to consider the workers musculoskeletal pain, the NIOSH lifting equation [44] to take into account the effects of handling loads or the Rapid Entire Body Assessment (REBA) [39] for awkward postures. The results of the application of each of these evaluating tools could be included as items to be considered and added to the evaluating function with their corresponding weighting coefficients.

4. CONCLUSION

In this study, we have presented a new procedure to generate cyclic job rotations schedules. RGA generates rotation schedules that group workstations in rotation groups so that a set of workers rotate cyclically in a small number of jobs. The algorithm determines how to cluster the jobs, which workers are best suited for each group, and the sequence of rotation. The solutions obtained by this procedure minimize movement repetitiveness, diversify the content of the tasks performed by the workers during the workday, take the limitations of workers into consideration, and balance the cumulative effect of fatigue and stress. In addition, job clustering simplifies changeovers between rotations, avoiding delays in the production process, while facilitating the monitoring of the workers.

Although, from an ergonomic point of view, no-cyclic schedules performs better, our results shows that cyclic schedules are only slightly worse than t no-cyclic schedules and that this difference is compensated by the benefits of a better work organization.

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