Journal of Ambient Intelligence and Humanized Computing
https://doi.org/10.1007/s12652-018-0814-3

ORIGINAL RESEARCH

# Application of genetic algorithm to job scheduling under ergonomic constraints in manufacturing industry

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Received: 31 January 2018 / Accepted: 28 April 2018


**Abstract**

This research proposes a mathematical model of the problem of job rotation considering ergonomic aspects in repetitive works, lifting tasks and awkward postures in manufacturing environments with high variability. The mathematical model is formulated as a multi-objective optimization problem integrating the ergonomic constraints and is solved using improved non-dominated sorting genetic algorithm. The proposed algorithm allows the generation of diversified results and a greater search convergence on the Pareto front. The algorithm avoids the loss of convergence in each border by means of change and replacement of similar solutions. In this strategy, a single similar result is preserved and the best solution of the previous generation is included. If the outcomes are similar, new randomly generated individuals are proposed to encourage diversity. The obtained results improve the conditions of 69% of the workers. The results show that if the worker rotates starting from a high risk, his variation in risk always decreases in his next assignment. Within the job rotation scheme, no worker is exposed simultaneously to high ergonomic risk thresholds. The model and the algorithm provide good results while considering ergonomic risks. The proposed algorithm shows the potentiality to generate a set of quality of response (Pareto Frontier) in a combinatorial optimization problem in an efficient computational time.

**Keywords** Job rotation · Genetic algorithm · Manufacturing · Ergonomic constraints

## 1 Introduction

The workers are prone to musculoskeletal disorders due to unfavorable conditions in the operations of jobs. The illness, disability, absenteeism and illness show the presence of muscular-skeletal disorders which threatens the health and quality of life of the workers. In 2016, 570,420 cases of musculoskeletal injuries were reported in the United States, where workers required 892,270 days-away-from-work for recovery (Bureau of Labor Statistics 2017, November 15). The presence of disorders in the muscular system can be generated by various causes that are part of the production systems, workload and working environment. Job rotation is an inexpensive and easy to perform the administrative control which is carried in an organized way and can achieve very encouraging results in muscle disorders for the welfare of workers and the efficiency of companies (Kogi et al. 2003; Jorgensen et al. 2005). Designing of the work rotation schedules in a problem schedules and sequencing is not a simple activity. The rotation systems must analyze aspects such as the physical load, exposure, duration and frequency of various risk factors as well as items related to individual, social and psychological aspects to obtain practical results for the organizations.

The job rotation is an organizational strategy that adds variability in activities where workers develop forces and efforts and can increase muscular activity variability (Rodriguez and Barrero 2017). The diversification of tasks contributes to the implementation of various muscle movements during the working day and reduction of physical load and energy expenditure (Kuijer et al. 1999). The design of job

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Published online: 12 May 2018

schedules is a complex activity with respect to physical demand, the exposure level, duration and frequency in the risk incurred in the allocation of workstation (David 2005; Frazer et al. 2003). Job rotation generates skills and competencies in workers (Huang 1999), because workers are one of the most important factors in which every company possesses and their performance is related to productivity (Eriksson and Ortega 2006). A design of job rotation is to plan and schedule the assignment and sequencing workstations between workers. An optimal program depends on the variability in the assignment and balancing workload and tasks among operations, which does not protect a particular employee, but rather reduces the risk exposure of all workers (Aptel et al. 2008). Musculoskeletal disorders are attributed to the activities which contain repeatability of movements, a constant load handling, and the adoption of uncomfortable or awkward postures (Rissen et al. 2002). This set of activities promotes the generation of illnesses and ailments, disabilities those bring high costs for organizations (Kuijer et al. 1999). There are several advantages and benefits of job rotation for organizations and workers, such as convenience and speed of implementation, low cost of deployment, increased productivity, development of skills, experience and expertise of workers, training, advancement and promotion of employees, generating motivation and innovation, reducing conditions in the musculoskeletal system, decreased rate of hiring and firing, reduced boredom and monotony, absenteeism, ability to change, improve work environment, and a reduction in psychological burden (Davis et al. 2005; Hsieh and Chao 2004; Lodree et al. 2009; Rissen et al. 2002). Moreover, stress management (Ho et al. 2009), perception of work and psychosocial aspects of work (Aptel et al. 2008), information between workstations, knowledge management (Arya 2004) and intellectual capital (Brunold and Durst 2012) are noteworthy works in this direction. Other researchers measure the rotation as a strategy for the inclusion of disabled people in conditions, while in the process of introducing rehabilitation of the workers in organizational processes. In the design of job rotation schedules, there are several researches that show the importance and effectiveness in organizational management. For example, Hazzard and Mautz (1992) implement the rotation barriers in differentiating levels of risk tasks and the lack of training by the worker to perform a new role in a television industry. Henderson and Kumar (1992) suggest job rotation at a poultry industry by sorting activities with labor demand. Kuijer et al. (1999) study responsibility of workers for garbage collection, ensuring that rotation has an impact on the level of fatigue and effort of workers with a significant effect on energy expenditure and duration of activities. Rissen et al. (2002) assess the rotation of a supermarket cashiers under physical and psychological aspects of stress and work-related musculoskeletal disorders. The results conclude that moderately rotation improves perception and workload. Frazer et al. (2003) study the effect of the rotation that causes the generation of column conditions within an assembly line.

The job rotation within the group of time tabling and scheduling problems belongs to the category of combinatorial optimization problems. The design of efficient rotation schedules is a complex problem due to many criteria to be considered for the assignment of workers to jobs in each rotation. In previous works, this problem is solved using integer programming techniques (Azizi et al. 2010; Tharmmaphornphilas et al. 2003; Coronado-Hernández and Ospina-Mateus 2013). Other authors have explored the use of heuristics and metaheuristics (Carnahan et al. 1999; Michalos et al. 2010; Sekiner and Kurt 2007, 2008), as an alternative to solve such problems, where a very large solution space exists. The works developed by Carnahan et al. (2000) have been generally accepted as a pioneering study focused on the problem of job rotation applied to the prevention of musculoskeletal disorders. Carnahan et al. (1999) implement a genetic algorithm and Integer Programming for the design of rotation schedules to prevent back injuries. The algorithm calculates the risk level for lifting tasks in each workstation by means of the job severity index (JSI) ergonomic method and then applies a clustering method to determine a general set of rules governing task exposure for each group of workers. Bhadury and Radovilsky (2006) raise a multi-objective integer programming model to minimize the cost of assigning tasks and boredom of workers. Filus and Okimorto (2011) generate two heuristics to reduce daily exposure as an occupational risk factor. Öztürk et al. (2006) discussed an integrated and optimized product design framework to support the design optimization applications based on neural networks, Taguchi's method and GA in concurrent engineering. Azizi et al. (2010) present a mathematical programming model for job rotation in manufacturing system those aims are to reduce boredom and variation of knowledge (learning and forgetting) of workers. Application of simulated annealing algorithm (Sekiner and Kurt 2007) and the ant colony algorithm (Seckiner and Kurt 2008), proved a new application to generate rotation schedules to reduce the workload. The use of an intelligent algorithm by Michalos et al. (2010) and the design of a web tool (Michalos et al. 2011) allow to print a dynamic flexibility in obtaining rotation schedules in multiple criteria such as skills, the accumulation of fatigue, repeatability, the distance between jobs, and cost. Ham et al. (2011) formulated binary integer programming (BIP) based real-time scheduling (RTS) heuristic model for time scheduling of a multi-stage flexible job shop floor with machine compatibility. Ezeukwu et al. (2011) determine the prevalence of work-related musculoskeletal pain among timber workers in Enugu Metropolis. Tella et al. (2013) study the prevalence of LBP, associated risk factors and impacts on farmers in South-West Nigeria. Cardenas-Barron and Taleizadeh (2012) apply hybrid metaheuristic algorithms (HMHAs) to solve difficult problems in different fields of inventory theory. Kuah et al. (2012) evaluates knowledge management (KM) performance using Monte Carlo data envelopment analysis with genetic algorithm. Moreira and Costa (2013) generate a hybrid algorithm and a mixed integer programming model for selecting and balancing, job rotation assembly line workers with heterogeneous workstations protected disabilities. Cardenas-Barron (2010) solves a well known inventory lot-sizing problem by the adaptive genetic algorithm. Yildiz (2012) introduced a hybrid technique based on differential evolution algorithm to solve multi-pass turning optimization problems in manufacturing industry for removing unwanted sections of a part to obtain the final product. Santosa et al. (2016) discuss an inventory ship routing problem and obtain optimal solution for a case study in Indonesia using a hybrid cross entropy-genetic algorithm. In general terms, the application of heuristics and metaheuristics in the field of engineering opens the possibility of efficiently solving problems in low computational time (Yildiz 2012, 2013, 2017; Yildiz and Saitou 2011; Yildiz and Solanki 2012; Yildiz et al. 2016a, b; Yildiz and Lekesiz 2017; Yildiz and Yildiz 2017; Karagöz et al. 2017; Pholdeeet al. 2017; Kiani and Yildiz 2016). Relevant research such as Asensio-Cuesta et al. (2012a, b) and Diego-Mas et al. (2009) have demonstrated the application of job rotation related to ergonomic variables and competencies of workers applying genetic algorithms. Researches are also rescued that demonstrate the applicability of job rotation in real environments such as those developed by Mossa et al. (2016), Otto and Scholl (2013), and Ayough et al. (2012).

Generally speaking, job rotation reduces musculoskeletal disorders generated from work activities, ensuring that the workload is equitably distributed among the workers. The ergonomic risks are present simultaneously in the development of repetitive activities, load manipulation and forced postures which carry variability and diversity in the exposure of the individuals, and thus contribute to the well-being of the workers (Mathiassen 2006; Wells et al. 2010). The proposed research project focuses on the design and creation of job rotation schedules that allow the addition of diversity in the activities carried out by the workers through the application of multiobjective genetic algorithms, in order to simultaneously minimize the ergonomic risks through the use of techniques of evaluation of NIOSH equation (Waters et al. 2007), OCRA method (Colombini et al. 2002), and RULA method (McAtamney and Nigel Corlett 1993).The novelty is given in the application of a second-generation algorithm in a multi-objective problem correlated with simultaneous ergonomic conditions of a worker in a job. We convert the mathematical model for testing goodness or adjustment problem agile, considering aspects such as variability, and fatigue for each target present in the problem.

The remainder of the paper is organized as follows. The ergonomic job rotation scheduling problem, fundamental assumptions and notations are provided in Sect. 2. Section 3 presents the ergonomic evaluation methods. Section 4 describes the NSGA II (non-dominated sorting genetic algorithm). Computational study with numerical data is given in Sect. 5. Section 6 discusses the impact of GA and guidelines for practitioners. Conclusions with novelty of our proposed model and suggestions of future research are presented in Sect. 7.

## 2 Problem formulation, assumptions and notation

### 2.1 Assumption

1. The number of workstations equals the number of operators as a job is assigned to each operator in each period. Without loss of generality, we assume dummy jobs or workers with zero assignment costs when number of jobs and number of workstations are unequal.
2. A working day is divided into periods of work with known duration. The number of periods is known in advance.
3. Each job requires only one worker to perform within one work period.
4. Each worker can perform at most one job within one work period.
5. Each workstation is dedicated to a particular operation.
6. The number of workstations and operators is constant and cannot be changed during the planning horizon.
7. Job rotation is allowed only at the end of a work period.
8. Workers are trained for each of the assignments and know the list of jobs they are able to perform.
9. All workers are identical in terms of their skill flexibility and work efficiency.
10. All employees have same qualifications.
11. Ergonomic level of risk is related to the operations in the workstations.
12. The maximum, minimum, upper bound, and lower bound level of ergonomic risk are identical for all operations and all workers.
13. Information pertaining to the ergonomic risks to workers is available or can be estimated.
14. Deterministic workloads and deterministic ergonomic risks for each worker at each workplace are uniformly distributed with different ranges during each time period.

15. Workers are assumed to have sufficient rest at the end of each day to relieve all stress, so that workers return to a normal condition at the beginning of each day.
16. The job rotation scheme must contain variability and diversity in labor demand that workers assume.
17. The model is implemented with the OCRA methodology to evaluate the repeatability of tasks, RULA method to assess awkward postures, and the NIOSH equation to assess load handling.

## 2.2 Notation

The following indices, variables and parameters are used in this paper:

### 2.2.1 Indices

$I$ = Set of workers, $i \in \{1, \ldots, n\}$.

$J$, $Q$ = Set of jobs and workstations, $j, q \in \{1, \ldots, n\}$. Here, one job is assigned in one workstation, i.e., each workstation represents a job.

$T$ = Set periods (rotation), $t \in \{1, \ldots, m\}$.

### 2.2.2 Parameters

$SLI_{jq}$ = Sequential level of risk index lifting of the tasks j and q performed in a period.

$\mathrm{LI_j}$ = The rate of load handling of the tasks j performed by the worker.

$\mathrm{LIMAX_j}$ = Maximum load handling index of the tasks j performed by the worker.

$L_q$ = Weight of the object lifted (kg)in the workstation q.

$LC_q$ = Load Constant (kg) in the workstation q.

$HM_q$ = Horizontal multiplier factor in the workstation q.

$VM_q$ = Vertical multiplier factor in the workstation q.

$DM_q$ = Distance multiplier factor in the workstation q.

$AM_q$ = Asymmetric multiplier factor in the workstation q.

$FM_q$ = Frequency multiplier factor in the workstation q.

$CM_q$ = Coupling multiplier factor in the workstation q.

$FMAX_q$ = maximum frequency factor in the workstation q.

TF = Factor duration of the tasks in blocks (proportion).

$\mathrm{OCRA_j}$ = Risk level repeatability sequential movements of tasks performed by the worker j in the whole scheme of rotation.

$ATA_q$ = the number of technical actions performed by the worker in the workstation q.

$RTA_q$ = the number of reference technical action performed by the worker in the workstation q.

$\mathrm{Var_{jq}}$ = Risk variation between task in the workstation j and workstation q.

$D_t$ = Length of period $t$ (hours).

$DW$ = Length of Working Time (hours).

$DA_t$ = Task duration accumulated in the rotation period t (hours).

$Dp_{t,t+1}$ = Length of rest period between rotation $t$ and $t+1$ (hours).

$FA_q$ = The number of actions per minute required by the workstation q.

$KF$= The constant of frequency of technical actions.

$FS_q$ = The factor of strength risk in the workstation q.

$PM_q$ = The factor of posture risk in the workstation q.

$RE_q$= The factor of repeatability risk in the workstation q.

$AF_q$ = The factor of additional risks in the workstation q.

$RCM$ = The risk factor about lack of recovery periods referred to all throughout the day.

$DM$ = The factor for total length of repetitive tasks in a day.

$\mathrm{LP_j}$ = Level of postural risk assessment scale RULA method for the task in the Workstation j.

$\mathrm{Fat_{jqt}}$ = Postural fatigue between tasks in the workstation j and workstation q during time period t.

$\alpha$ = Reduction Factor postural.

$\mathrm{PENA}_{iq}$ = Penalties of workers i in the workstation q table with values of 1 and 0.

### 2.2.3 Variables

$\mathrm{X_{ijt}}$ = 1 If worker i performs task j during period t; otherwise, $\mathrm{X_{ijt}}$ = 0.

$\mathrm{R_{ijqt}}$ = 1 If worker i develops the task j before the task q during period t; otherwise, $\mathrm{R_{ijqt}}$ = 0.

Risk(Load) = Maximum level of risk for manual lifting.

$SLIW_{ih}$ = Risk level sequential manual lifting of the tasks performed by the worker i in block work h.

*Risk*(*Repetition*) = Maximum level of risk for repeatability movement.

$OCRAW_i$=Risk level task repeatability of the worker i in the whole scheme of rotation.

$VW_{it}$ = Risk factor variation of the worker I during period t.

$RVL_{\mathrm{i}}$ = Level of variability in risk repeatability Sequential Movements of tasks performed by the worker i in the whole scheme of rotation.

*Risk*(*Posture*) = Maximum level of risk for awkward postures.

$B_i$ = Maximum number of Tasks developed by the worker i.

$\mathrm{E}_i$ = Postural Risk Level of the worker i.

$VR_{it}$: Variability accumulated fatigue postural of the worker i during period t.

$\mathrm{RVRULA_i}$ = Cumulative Fatigue Factor general worker i.

$BT_{ij}$ = Number of tasks j performed by the worker i.

## 2.3 Problem formulation

This paper proposes a methodology for developing job rotation schedules considering simultaneously ergonomic constraints in repetitive works, lifting tasks and awkward postures. We formulate mathematical programming of the problem. The first mathematical models are developed by Carnahan et al. (2000). The susceptible events cause the generation of musculoskeletal disorders which are repetitive movements, load handling and adoption of forced or awkward postures. This fact encourages formulating a multi-objective model for job rotation, that would be considered simultaneously. This set of occupational hazards in which workers are exposed proposed schedules and find job rotation within workstations in order to infuse variability and diversity in developing the tasks to minimize the maximum risk. The NIOSH method permits properly to assess and quantify the load level perceived by workers, which seeks to reduce and balance the risk of lumbar conditions for handling and lifting of materials development. The OCRA method helps to properly quantify the level of repeatability of the tasks performed by workers, which seeks to reduce and balance the risk of musculoskeletal disorders due to development of stereotyped movements. The RULA method to measure and quantify the level of fatigue perceived by workers seeks to reduce and balance the risk by taking static and awkward postures. The multi-objective model of job rotation is given as follows:

$$Minf_1 = \mathrm{Risk(Load)} \tag{1}$$

$$Minf_2 = Risk(Repetition) \tag{2}$$

$$Minf_3 = Risk(Posture) + B \tag{3}$$

Subject to the following constraints:

$$\sum_{i=1}^{n} \mathrm{X_{ijt}} = 1, \quad \forall \mathrm{j,t} \tag{4}$$

$$\sum_{j=1}^{n} \mathrm{X_{ijt}} = 1, \quad \forall \mathrm{i,\ t} \tag{5}$$

$$SLIW_{it} = \sum_{j:1}^{n} \sum_{q:1}^{n} \mathrm{SLI_{jq}} * R_{ijqt}, \quad \forall \mathrm{i, t = 1,\ t = 3} \tag{6}$$

$$SLIW_{it} \le \mathrm{Risk(Load)} \quad \forall \mathrm{i,t} \tag{7}$$

$$OCRAW_i = \sum_{j:1}^{n} \sum_{t=1}^{m} OCRA_j * \mathrm{X_{ijt}}, \quad \forall \mathrm{i} \tag{8}$$

$$VW_{it} = \sum_{j=1}^{n} \sum_{q=1}^{n} \mathrm{Var_{jq}} * R_{ijqt}, \quad \forall \mathrm{i,t} \tag{9}$$

$$RVL_i = \sum_{t=1}^{m} \left[ VW_{it} * \frac{(D_t + D_{t+1})}{DW} - Dp_{t,t+1} \right], \quad \forall \mathrm{i} \tag{10}$$

$$OCRAW_i + RVL_i \le Risk(Repetition), \quad \forall \mathrm{i} \tag{11}$$

$$\sum_{j=1}^{n} \sum_{t=1}^{m} \mathrm{LP_j} \times \mathrm{X_{ijt}} = \mathrm{E}_i, \quad \forall \mathrm{i} \tag{12}$$

$$VR_{it} = \sum_{j=1}^{n} \sum_{q=1}^{n} \mathrm{Fat_{jqt}} \times R_{ijqt}, \quad \forall \mathrm{i,\ t} \tag{13}$$

$$RVRULA_i = \sum_{t=1}^{m} VR_{it}, \quad \forall \mathrm{i} \tag{14}$$

$$E_i + RVRULA_i \le Risk(Posture), \quad \forall \mathrm{i} \tag{15}$$

$$\sum_{t=1}^{m} \mathrm{X_{ijt}} = BT_{ij}, \quad \forall \mathrm{i,j} \tag{16}$$

$$BT_{ij} \le B_i, \quad \forall \mathrm{i,j} \tag{17}$$

$$\mathrm{X_{ijt}} + \mathrm{X_{ij(t+1)}} - R_{ijqt} \le 1, \quad \forall \mathrm{i,j,q,t} < m \tag{18}$$

$$-\mathrm{X_{ijt}} + R_{ijqt} \le 0, \quad \forall \mathrm{i,j,q,t} \tag{19}$$

$$-\mathrm{X_{ij(t+1)}} + R_{ijqt} \le 0, \quad \forall \mathrm{i,j,q,\ t} < m \tag{20}$$

$$\mathrm{X_{ijt}} \le \mathrm{PENA}_{ij}, \quad \forall \mathrm{i,j\ ,t} \tag{21}$$

where $\mathrm{X_{ijt}} \in (0,1)$, $\mathrm{R_{ijqt}} \in (0,1)$, $\mathrm{SLIW_{ih}} \in \mathfrak{R}^+$, $OCRAW_i \in \mathfrak{R}^+$, $VW_{it} \in \mathfrak{R}^+$, $\mathrm{RVL_i} \in \mathfrak{R}^+$ , $\mathrm{E_I} \in \mathfrak{R}^+$ , $VR_{it} \in \mathfrak{R}^+$ , $\mathrm{RVLUA_i} \in \mathfrak{R}^+$, $BT_{ij} \in \mathfrak{R}^+$, $B_i \in \mathfrak{R}^+$;$\forall i \in I$, $\forall j \in J$, $\forall t \in T$, $\forall h \in H$.

The objective of the model is to minimize the maximum level of ergonomic material handling risk (Eq. 1), the maximum level of ergonomic risk repeatability of actions (Eq. 2) and the maximum level of risk fatigue ergonomic posture (Eq. 3), considering the number of times that is assigned to a worker on the same task in the job rotation. Here, the Eq. (4) ensures that each task is manned by a single worker during each time period. The Eq. (5) ensures that each worker performs only one task in each time period. The Eqs. (6) and (7) calculate the level of ergonomic risk perceived a worker in a working block (SLI) by the NIOSH method. Here, $SLIW_{ih}$ is calculated for worker iin block h of 4 consecutive hours where $h \in H = \{1, 2\}$. Each period t is of 2 h. First and second period comprise block $1(h = 1)$ and third and fourth period comprise block $2(h = 2)$. The Eq. (8) estimates the level of risk accumulated by a worker through the OCRA method in each task and each period. The Eq. (9) defines the variability of perceived risk for each worker in each period. The Eq. (10) defines the perceived end variability per worker in all periods, considering the sizes of the periods and recovery periods, as defined. In Eq. (11), the level of risk finally combined for a total repeatability together with the perceived variability worker is to be minimized. The Eq. (12) calculates the level of risk of postural worker for the RULA method after visiting each workstation per period. The Eqs. (13) and (14) define the fatigue that accumulates variability in risk postural tasks. The Eq. (15) estimates the total risk posture with the cumulative risk and variability per worker's fatigue which is to be minimized. The Eqs. (16) and (17) refer to the number of times of a worker who visits a job, and with the aim to minimize the development of workers in the same job for a working day. The Eqs. (18), (19) and (20) are used to calculate the precedence between the activities of the workers. The Eq. (21) presents the blocking assignments those are penalized.

Here, the risks of load handling, repeatability of tasks and forced postures and fatigue are considered. In each of the risk, in addition, related to a validated ergonomic method and conditions are added those are as detailed below:

1. *Load handling or manual lifting* It is applied through the NIOSH equation, updated for the development of multitasking tasks, which considers fatigue in the duration of tasks.
2. *Repeatability of tasks* For repetitiveness, OCRA is applied, considering the variability between repetitive tasks with the objective of penalizing or benefiting the worker when he has fatigue or rest periods accumulated.
3. *Forced postures and fatigue* The RULA method is applied for the calculation of forced posture, and the fatigue caused by the variability between positions is calculated where the value obtained by the method plus sustained postures penalizes this risk. The objective function for postural also includes repetitiveness of tasks in order to give diversity in rotation schedules, making it possible for all workers to rotate but not to remain in the same station for a long time.

## 3 Ergonomic evaluation methods

Recently, there are several ergonomic evaluation methods for determining the level of risk associated with the development of occupational activities. Among these methods, there are noteworthy methods related to the adoption of awkward postures (RULA method: McAtamney and Nigel Corlett 1993), OWAS (OvakoWorking Posture Assessment System) method (Karhu et al. 1977), manual lifting (NIOSH Method: Waters et al. 2007) and Snook and Ciriello tables (Snook and Ciriello 1991), and performing repetitive movements JSI (Job Strain Index) method (Moore and Garg 1995), OCRA Method (Colombini et al. 2002). This article present a methodology for developing job rotation schedules considering simultaneously ergonomic constraints in repetitive works, lifting tasks and awkward postures. The proposed algorithm evaluates the level of exposure to the risk using the NIOSH equation, the RULA method and the OCRA method. In this section, emphasis is given on the most known methods for quantifying ergonomic prone to the development of musculoskeletal disorders and more coverage in various exposure to risk factors (see Table 1), as shown in the studies (David 2005; Chiasson et al. 2012).

### 3.1 The NIOSH equation

The NIOSH equation (Waters et al. 2007) provides the basic for evaluation of the three criteria (biomechanics, physiological and psychophysical). The method describes the lifting index (LI), an index of relative physical stress that can be used to identify hazardous lifting tasks. The lifting equation is widely used by occupational health practitioners because it provides a method for computing a weight limits for manual lifting. The recommended weight limits are useful to identify certain lifting jobs that pose a risk to musculoskeletal system for developing lifting-related low back pain. The ergonomic risk levels for load handling, are calculated by the NIOSH equation through the enlarged sequentially lifting index (SLI) methodology (Waters et al. 2007). The NIOSH method gives the lifting index (LI), which is calculated by the ratio of the weight of the load lifted and the

**Table 1** Exposure factors assessed by different methods, adapted by de David (2005)

| Ergonomic constraints | Method | Posture | Force/load | Movements | Duration | Recovery/rest | Vibration | Others* |
|---|---|---|---|---|---|---|---|---|
| *Manual lifting* | *NIOSH* | √ | √ | √ | √ | √ | | √ |
| *Repetitive* | *JSI* | √ | √ | √ | √ | | | √ |
| *Repetitive* | *OCRA* | √ | √ | √ | √ | √ | √ | √ |
| *Awkward postures* | *RULA* | √ | √ | √ | | | | |
| *Awkward postures* | *OWAS* | √ | √ | | | | | |

*Includes psychosocial mechanical compression, gloves, ambient conditions, tools, grip, teamwork, visual demand, and individual factors recommended weight limit, and (LIMAX) is calculated by the maximum frequency handling as follows:

$$LI_q = \frac{\text{Load weight}}{\text{Recommended weight limit}} = \frac{L_q}{LC_q \times HM_q \times VM_q \times DM_q \times AM_q \times FM_q \times CM_q} \forall q$$

$$LIMAX_q = \frac{\text{Load weight}}{\text{Recommended weight limit}} = \frac{L_q}{LC_q \times HM_q \times VM_q \times DM_q \times AM_q \times FMAX_q \times CM_q} \forall q$$

where, SLI is sequentially lifting index, $SLI_{jq}$ to the workstation j and workstation q, is calculated as follows:

$$SLI_{jq} = \begin{cases} LI_j + \left(LIMAX_j - LI_j\right) \times \frac{(LIMAX_j + LIMAX_q)TF}{LIMAX_j} & \text{If } (j \neq qandLIMAX_j > LIMAX_q) \\ \mathrm{LI}_q + \left(\mathrm{LIMAX}_q - \mathrm{LI}_q\right) \times \frac{(\mathrm{LIMAX_j} + \mathrm{LIMAX}_q)\,\mathrm{TF}}{\mathrm{LIMAX}_q} & \text{If } (j \neq qandLIMAX_j < LIMAX_q) \ \forall \mathrm{j, q} \\ \mathrm{LIMAX_j} & \text{If } (j = q) \end{cases}$$

## 3.2 RULA method (rapid upper limb assessment)

RULA (McAtamney and Nigel Corlett 1993) is a survey method developed for use in ergonomics investigations of work places where work-related upper limb disorders are reported. This tool requires no special equipment in providing a quick assessment of the postures of the neck, trunk and upper limbs along with muscle function and the external loads experienced by the body. The development of RULA is occurred in three phases. The first is the development of the method for recording the working posture, the second is the development of the scoring system, and the third is the development of the scale of action levels which provide a guide to the level of risk and need for action to conduct more detailed assessments. The ergonomic risk levels by awkward postures are calculated by the RULA method to calculate the level of postural fatigue as follows:

$$\mathrm{Fat_{jqt}} = 1 + \left[\alpha \times \frac{LPj \cdot D_t}{DA_t} + \frac{LPq \cdot D_{t+1}}{DA_{t+1}}\right] \forall \mathrm{j, q, t}$$

## 3.3 The OCRA method (occupational repetitive actions)

The OCRA method is a useful tool to calculate the workers' exposure when they are assigned to different workstations for certain periods of time, following a job rotation scheduler. The method evaluates the main collective risk factors as well, repetitiveness, force, awkward postures and movements, lack of recovery periods, based on their respective duration. Other factors such as mechanical, environmental, and organizational factors are considered providing evidence of causal relationship with work-related musculoskeletal disorders and it's growing popularity and value in the field of ergonomic (Occhipinti and Colombini 2007). Finally, it has to be added that the current OCRA method forms the basis for two technical standards currently being developed by ISO (ISO-11228-3 2007). The ergonomic risk levels for repetition of activities are calculated using OCRA method as follows:

$$OCRA_q = \frac{ATA_q}{RTA_q} = \frac{FA_q}{KF \times FS_q \times PM_q \times RE_q \times AF_q \times RCM \times DM} \forall q$$

The values of above variables depend on the risk evidence in the workstation j and qthose are given in Table 2 as follows.

The effect of ergonomic risks on human body is provided in Table 3 as follows.

# 4 Solution method

The level of complexity of the multi-objective model of job rotation falls into the category of combinatorial optimization problem, specifically in the group scheduling and timetabling. In evolutionary computation, Genetic algorithms (GA) is an efficient method for solving combinatorial optimization problems and multi-objective problems. GA provides reasonable solutions without excessive computation time. In particular, multi-objective evolutionary

**Table 2** Variable factors versus the risk evidence in the workstations

| $\mathrm{Var_{jq}}$ | $OCRA_q < 2.3$ | $2.3 \le OCRA_q < 3.5$ | $OCRA_q \ge 3.5$ |
|---|---|---|---|
| $OCRA_j < 2.3$ | 0 | 0 | 0 |
| $2.3 \le OCRA_j < 3.5$ | 0 | 2 | 3 |
| $OCRA_j \ge 3.5$ | 0 | 2 | 4 |

**Table 3** Effects of ergonomic risks on limbs of a human body

|  | Ergonomic risks | Description | Method | Neck area | Shoulder | Elbow | Hand -wrist | Back | Legs | Arm |
|---|---|---|---|---|---|---|---|---|---|---|
|  | Repetition | Repetitive movement | OCRA | Ordinary | Ordinary | Mild | Strong | Strong | Ordinary | Strong |
| | Load handling | Cargo movement and involves making force | NIOSH | Ordinary | Mild | Ordinary | Strong | Strong | Ordinary | Strong |
| | Awkward postures | Posture uncomfortable and static | RULA | Strong | Ordinary | Mild | Mild | Ordinary | Strong | Mild |

algorithms (MOEA) allow multi-objective problem (MOP) solving approach, finding a complete set of Pareto-solutions in a single run, making them a natural choice to solve job rotation problems. The technique used to solve the problem of multi-objective job rotation is an elitist non-dominated sorting genetic algorithm (NSGA-II). This methodology has two important features: it ensures diversity in the process of solution and is further characterized by being elitist.

This paper proposes an improved NSGA II that intensifies the diversity of the population and guarantees a convergence oriented within the Pareto fronts. The algorithm avoids the loss of convergence in each border, by means of change and replacement of similar solutions. In this strategy, a single similar result is preserved and the best solution of the previous generation is included. In the case of similar results, new randomly generated individuals are proposed to encourage the diversity. In this research, a novel application of NSGA II is presented to reduce the complexity of the procedure of quick order without dominance while each individual represents an agenda of job rotation to determine the jobs assignment to each worker in each rotation. The procedure begins with the random generation of individuals in the population (initial population) where classification of the population is made by fronts. Each individual is assigned a level equivalent to their non-dominance rank. The best individuals are those with lower ranks. Also, it calculates a crowding distance, as the operator uses to maintain population diversity. The new generation are guided by some genetic operators (crossover and mutation) which combine or modify chromosomes representing individuals. For each generation, the fitness of individuals in the population is estimated by an objective function. The fittest individuals are selected to form the next generation. This process repeats for several cycles (generations) individuals to provide better solutions to the problem. This section proposes a methodology for developing job rotation schedules considering simultaneously ergonomic constraints in repetitive works, lifting tasks and awkward postures. Next, the proposed MOEA is described by using a multi-objective NSGA-II.

### 4.1 Generation the initial population of solutions

The algorithm initiates a set of solutions with a matrix scheme, where the size of the array is determined by the number of workers involved in the rotation (J) and the span of rotation is considered by intervals (T). A workstation is assigned at random to each cell of this matrix, avoiding repetition of the workstations within the same row, and thus ensures the generation of feasible individuals. Each cell in the array contains a value that indicates the position assigned to a worker J on a rotation T. In the example given in Fig. 1, it explains the scheme of individuals. The number of individuals that makes up the population (p) depend on the characteristics of the problem and it is examined experimentally. The population is coded through a vector of p individuals.

### 4.2 Fitness assessment

We shall explain each of the fitness functions of the multi-objective feature of job rotation. The following subsections explain the fitness functions for each of the objective functions discussed above.

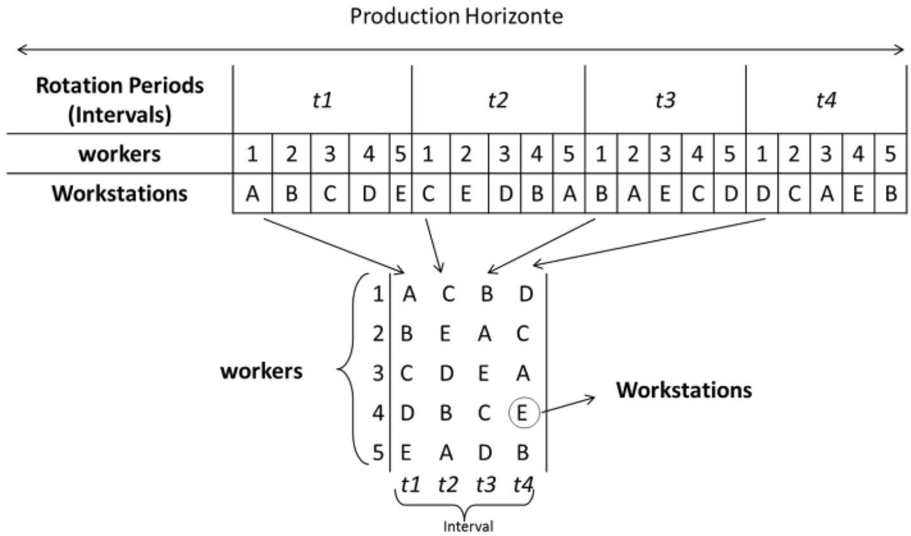
#### 4.2.1 Fitness function of load lifting

The evaluation function for each of the workers lifting load is related to the sequence lifting index (SLI), which is as follows.

$$Fitness\_NIOSH\_Worker\ (i) = SLI_{ih}$$

The fitness calculated by the NIOSH method for an employee refers to the level of risk for manual manipulation of sequential loading of the tasks performed by a worker i

**Fig. 1** Representation of a job rotation scheme




working in block h. The final assessment that determines the level of fitness of individuals in respect of the population is calculated with the highest level of ergonomic risk of NIOSH through its sequence lifting index (SLI), which can be assumed by a worker when it develops its rotation. Here,

$$\begin{aligned} &Total\ Fitness\ Load\ Lifting\ of\ the\ Individual \\ &\quad = Fitness\_NIOSH\_Worker\ (i) \end{aligned}$$

#### 4.2.2 Fitness function by repetition of movements

This function evaluates the level of risk of a worker involved with jobs that require repetition in the development of movements. The evaluation function for each of the workers in repetitive activities is formulated as follows:

$$Fitness\_OCRA\_Worker(i) = OCRA_i + RVL_i$$

$OCRA_i$ is related to the level of risk by repeatability of movements which are then exposed to rotate a worker i, and $RVL_i$refers to the level of variability that exists in the repetitiveness of sequential movements of the tasks developed by the worker x. The formulation and development of ergonomic risk level of the OCRA method is applied as a tool to quantify the repeatability of movement of worker. In the calculation, it takes into account the variability in the assignment of tasks of worker which helps to define the changes in the level of risk of workers, explained in the previous session. Then,

$$\begin{aligned} &Total\ Fitness\ for\ repeatability\ of\ the\ Individual \\ &\quad = Fitness\_OCRA\_Worker(i) \end{aligned}$$

#### 4.2.3 Fitness function of awkward postures

This function measures the charge level of postural workers. For this level of ergonomic assessment, it is required for each of the tasks involved in job rotation through RULA method. The expected RULA risk level (Ei) by RULA is initial parameter. The evaluated function for each of the workers is constituted as follows:

$$Fitness\_RULA\_Worker(i) = ERULA_i + RVRULA_i + Nrep$$

$ERULA_i$ is the level of risk that a worker i accumulates, established by the sum of postural risk by the RULA method to the task j developed by the worker during the journey in different rotations. $RVRULA_i$ is the factor of fatigue accumulated by the worker i within the job rotation.Nrep consists of the maximum number of jobs which are repeated by a worker during rotation scheme. Now,

$$\begin{aligned} &Total\ Fitness\ for\ Awkward\ Postures\ of\ the\ Individual \\ &\quad = Fitness\_RULA\_Worker(i) \end{aligned}$$

#### 4.2.4 Total fitness evaluation function (multi-objective)

Knowing each fitness by awkward postures, load handling and repetitive activities, individuals with lower fitness value are considered for better quality over the entire population. Because, the proposed genetic algorithm seeks to minimize the maximum ergonomic risk in which workers are exposed. To define a fitness value that represents the best compromise between the goals, we proceed to determine the level of dominance of each of the individuals and thus know the set of Pareto Optimum and its image in the target space is known as Pareto Front. The first non-dominated front requires comparison with each of the individuals in the population with the rest of it to determine whether it is non-dominated strongly. For calculating the fitness of the initial individuals, it considers the allocation of hierarchy based on Pareto dominance of the population and thus we have the following algorithm.

**Algorithm 1: Management Approach for fast non-dominated (P), (NSGA-II)**

```
for(int p=0;p<Population ;p++){
for(int pp=0;pp<Population ;pp++){
if(p != pp){
        if( (Total Fitness of Load Lifting [p] <=  Total Fitness of Load Lifting [pp]) &
                (Total Fitness for Awkward Postures [p]  <=  Total Fitness for Awkward Postures [pp]) &
                        (Total Fitness for repeatability [p]  <=  Total Fitness for repeatability [pp]) ){
                        FitnessFinal [p] = 1  +FitnessDominant [p];
                    }
                }
        }
}
```

This population is ordered based on the principle of non-domination. Each solution is assigned to a value of goodness (or hierarchy), equal to the level of its domination (Level 1 is the best, 2 is the next best and so on). In the same way, ordering of the population in different layers or fronts comprises FPc individuals where FPc is a percent of the population.

Following the above phase, in charge of maintaining diversity in the population is described. The best individuals are those with lesser charges. Also, it calculates a crowding distance. The process of find out the crowding-distance requires ordering of the population according to the value of each objective function in ascending order of magnitudes. Then, for each objective function, infinite distance values are assigned to individuals who are at the ends (individuals with the lowest and highest value).

All other solutions (individuals) are assigned a distance value equal to the absolute value of the difference (normalized) of the value of the functions corresponding to adjacent points. These calculations are done with all objective functions. The total value of crowding-distance is calculated as the sum of the values of all distances of the corresponding elements to each objective. The following procedure is used to calculate the distance in a non-dominated set (i), which is described in the equation as follows:

$$d_i = \sum_{m=1}^{M} \left| \frac{f_m^{(I_{i+1}^m)} - f_m^{(I_{i-1}^m)}}{f_m^{(\max)} - f_m^{(\min)}} \right|$$

where I (m) is the vector indicating the neighboring alternative solution to the alternative i, $f_m^{(max)}$ and $f_m^{(min)}$ are the maximum and minimum values on the entire solution space of the objective function m and M is the number of objective function to be optimized.

### 4.3 Application of penalties

The job rotation is considered as an option to infuse variability of tasks carried out in production systems. The constraint that must be considered is the inclusion of disabled people in conditions, during the process of introducing rehabilitation workers within organizational processes. In addition, one must consider the skills, abilities, skills and limitations that the workers have to face the challenges of the job, considering key aspects such as preparation, training, experience and even remuneration. Then, it seeks to penalize the assignment of workers in certain job positions from planning in the rotation. All undesirable work assignments form the groups are blocked assignments. The algorithm evaluates each individual in the population and penalizes those containing these assignments. The penalties of individuals are valued at a level of dominance to the people by zero (0), by leaving them outside the Pareto frontier.

### 4.4 Selection and replacement of individuals within the population

We consider the technique of roulette as a form of selection, because it allows individuals with greater capacity that possess more likely to survive, without denying the possibility for individuals to lower fitness, thereby ensuring the diversity of the population in future generations. Roulette is implemented taking into account the cumulative probability in fitness of individuals within the population. The algorithm uses a technique for direct inclusion, where the new generation among new parents and offspring is selected. When the parents improve descendants, it replaces these entirely by the parents. Otherwise, the descendants are taken within the next generation, adding the best parents to complete the population.

### 4.5 Reproduction

The crossover probability ($T_c$) determines the number of individuals in the next generation. Figure 2 shows the reproduction process. The crossover point is chosen at random by crossing point size content of rotations, and to share information between two parents' individuals to generate two descendants that represent feasible solutions.

### 4.6 Mutation

The mutation probability (Tm) is related to the number of individuals which would be modified. The process consists of selecting at random one rotation and two workers, and exchanging the jobs assigned to the workers in that rotation (Fig. 3). The mutation intensity (Im) is the number of modification on an individual who has been selected at random within the population.

### 4.7 Parameterization algorithm

The technical solution used to solve the problem of planning is the algorithm multi-objective NSGA-II. This methodology has two important features which ensure diversity during

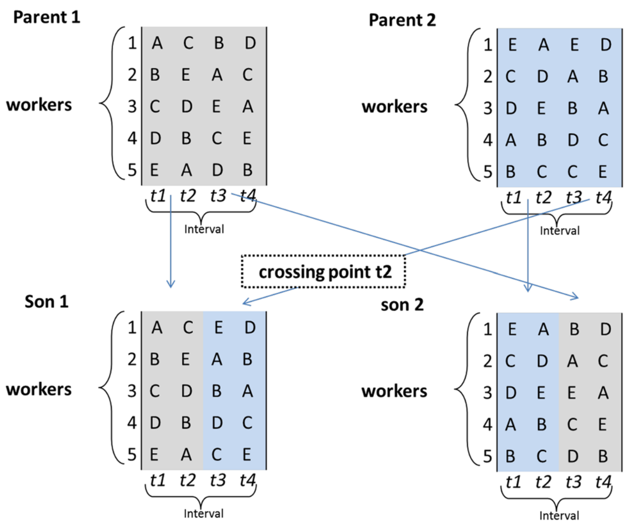



**Fig. 2** Crossover points of job rotation

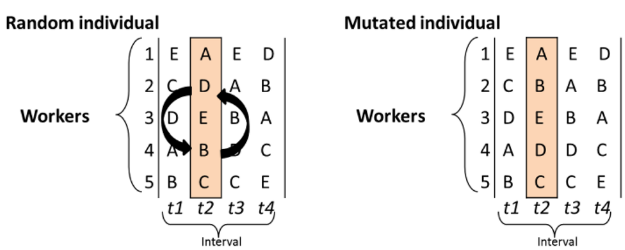



**Fig. 3** Mutation strategy for job rotation

the solution process. Individuals belonging to the first front are not dominated. Those belonging to the second front are not nominated in the absence of the previous front, and so on. Each individual is assigned to a level equivalent to its non-dominance rank.

Before finalizing a generation algorithm, pre-selection process and preservation of elite solutions are involved by getting the set of solutions of Parents and descendants obtained by operator's selection, crossover and mutation. Thus the current population increases at twice individuals of the initial population. This requires sorting of the complete set in their respective front's dominance and preserves individuals belonging to the fronts of better quality. If it is not possible to enter all the alternatives of a particular front, then those individuals are eliminated with a smaller crowding distance. The sequence of algorithm 2 of improved NSGA-II is schematized in Fig. 4.

Now, the improved process is being described in the new NSGA- II, where the diversification of the population is sought, after the conformation of the Pareto fronts and to relate the crowding distance. The algorithm develops a search on the entire population and on each of the fronts avoiding similar results. Thus, results are changed by Pareto front previous generation or random (best complying with the crowding distance) result. This strategy allows a better diversification of the population and avoids the premature convergence of the algorithm. The improved pseudo code is presented below.

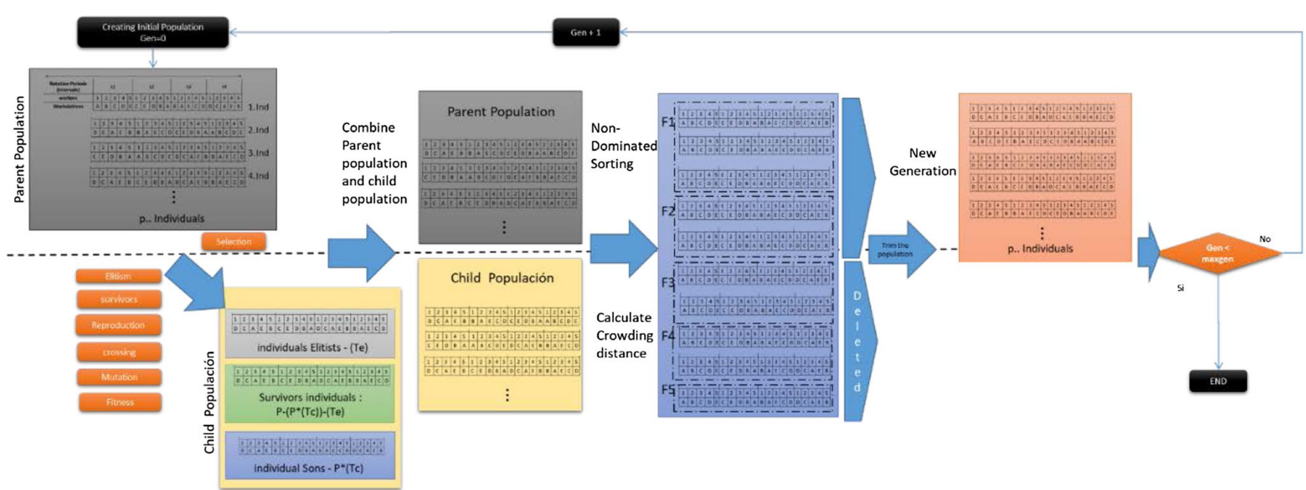



**Fig. 4** General flow of the proposed algorithm for multiobjective NSGA-II

**Algorithm 2. Pseudo code improved NSGA II:**

Initiation:
Generate population randomly P of size N
Generations (Gen=0)
1. New generation from parents
   a. Elitism (Te)
   b. Reproduction and crossing (Tc)
   c. Mutation (Tm and Im)
   d. Survivors.
2. Global Population compiled (2N)
   a. Calculation of the level of dominance of each individual
   b. Identify fronts dominance
   c. Evaluate the crowding distance in each front.
3. Compare two situations which have two attributes:
   a. A range of non-domination R (i) according to the Pareto front.
   b. A crowding distance d(i)
4. The selection provides the winning solution i, based on two fundamental criteria:
   a. If it has better range: r(i) < r(j)
   b. If it has the same range but (i) has better crowding distance: d (i) > d(j)
5. Compare duplicate or similar individuals on the front.
   a. Remove duplicate individuals
   b. Select from the Elite Group from the front of the population of the previous generation.
   c. Compare the random solution with elitist, and calculate crowding distance and range.
6. Parents and children collect in a set of size 2N and sort fronts dominance.

5. Determine the final descent fronts set
   a. If the limit exceeds population N, remove solutions with less crowding distance in the last selected front.
7. If the convergence criterion occurs or generations, End of process is satisfied.

END (Maxgen)

Its application to the problem of job rotation contributes to the agenda of rotation dynamic and diverse converging to good results within the possibilities, restrictions and penalties of the problem without falling into convergences or bad results.

## 5 Computational study

The GA is an effective tool to assist the planning committee in finding job rotation schemes offering the benefits to the technique with an ergonomic approach. In the algorithm, there are many factors and parameters which are highly configurable. The algorithm is implemented in software using java programming language with the aim of obtaining the maximum flexibility in the introduction of data and visualization of results. The rotations of production scheduling in 32 workstations with 32 employees with 22 jobs (Table 4) are selected in a plastic industry. The workers employed in the job rotation have sufficient training and the workstations are located in the same area and each rotation causes no interruptions in the process.

The 32 job workstations involved in the rotation are analyzed and assigned a score for each of the items considered in the lifting task evaluated by the NIOSH equation (Table 5), the repetitive works evaluated by the OCRA method (Table 6), and the awkward postures evaluated by the RULA method (Table 7). A suitable rotation of jobs should influence variability and diversity of roles that workers can take without incurring injuries or conditions on the stability and health.

**Table 4** Job assignments in workstations

| Job | Workstation | Job profiles |
|---|---|---|
| 1 | A | Polyethylene extrusion operator leader |
| 1 | B | Mixtures of polyethylene extrusion operator |
| 2 | C (1C, 2C) | Extrusion operator monitoring polyethylene |
| 2 | D (1D, 2D) | Weighing and labeling operator polyethylene extrusion |
| 1 | E | Polyethylene leader operator conversion |
| 2 | F (1F, 2F) | Conversion operator (1) |
| 2 | G (1G, 2G) | Conversion operator (2) |
| 1 | H | Conversion operator (3) |
| 4 | I (1I, 2I, 3I, 4I) | Conversion operator (4) |
| 2 | J (1J, 2J) | Conversion operator (5) |
| 3 | K (1K, 2K, 3K) | Conversion operator (6) |
| 1 | L | Drilling operator assistant |
| 1 | M | Packaging conversion operator (4) |
| 1 | N | Packaging conversion operator (6) |
| 1 | O | Packaging conversion operator (3) |
| 1 | P | Packaging conversion operator (2) |
| 1 | Q | Extrusion operator leader polypropylene |
| 1 | R | Mixtures of polypropylene extrusion operator |
| 1 | S | Twister extrusion operator polypropylene |
| 1 | T | Weighing and labeling operator extrusion polypropylene |
| 1 | U | Extrusion operator support polypropylene |
| 1 | V | Polypropylene extrusion operator hoop |

**Table 5** Results of the NIOSH ergonomic assessment method

| Number of job | Workstation | LC | HM | VM | DM | AM | FM | CM | FMAX | LW | RWL | LI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | 25 | 1 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 25.00 | 0.0 |
| 1 | B | 25 | 1 | 0.87 | 0.88 | 0.86 | 0.60 | 1.00 | 0.35 | 25 | 9.73 | 2.6 |
| 2 | C | 25 | 1 | 0.99 | 0.87 | 0.86 | 0.88 | 1.00 | 0.75 | 25 | 16.05 | 1.6 |
| 2 | D | 25 | 1 | 0.90 | 0.93 | 1.00 | 0.92 | 1.00 | 0.81 | 50 | 19.20 | 2.6 |
| 1 | E | 25 | 1 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 25.00 | 0.0 |
| 2 | F | 25 | 1 | 0.96 | 0.93 | 0.86 | 0.95 | 0.95 | 0.85 | 50 | 17.20 | 2.9 |
| 2 | G | 25 | 1 | 0.96 | 0.93 | 0.86 | 0.95 | 1.00 | 0.85 | 50 | 18.10 | 2.8 |
| 1 | H | 25 | 1 | 0.93 | 0.91 | 1.00 | 0.95 | 0.90 | 0.85 | 50 | 17.99 | 2.8 |
| 4 | I | 25 | 1 | 0.96 | 1.05 | 0.86 | 0.95 | 0.95 | 0.85 | 50 | 19.27 | 2.6 |
| 2 | J | 25 | 1 | 0.87 | 0.91 | 0.86 | 0.95 | 0.90 | 0.85 | 50 | 14.40 | 3.5 |
| 3 | K | 25 | 1 | 0.99 | 1.05 | 0.86 | 0.95 | 0.90 | 0.85 | 50 | 18.83 | 2.7 |
| 1 | L | 25 | 1 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 25.00 | 0.0 |
| 1 | M | 25 | 1 | 0.99 | 0.88 | 0.86 | 0.75 | 0.90 | 0.75 | 20 | 12.58 | 1.6 |
| 1 | N | 25 | 1 | 0.99 | 0.88 | 0.86 | 0.75 | 0.90 | 0.75 | 30 | 12.58 | 2.4 |
| 1 | O | 25 | 1 | 0.99 | 0.88 | 0.86 | 0.75 | 0.90 | 0.75 | 15 | 12.58 | 1.2 |
| 1 | P | 25 | 1 | 0.96 | 0.88 | 0.86 | 0.95 | 1.00 | 0.85 | 50 | 17.17 | 2.9 |
| 1 | Q | 25 | 1 | 0.93 | 0.91 | 0.86 | 0.95 | 0.90 | 0.85 | 50 | 15.40 | 3.2 |
| 1 | R | 25 | 1 | 0.93 | 0.91 | 0.86 | 0.60 | 1.00 | 0.35 | 25 | 10.81 | 2.3 |
| 1 | S | 25 | 1 | 0.96 | 0.87 | 0.86 | 0.95 | 0.90 | 0.85 | 5.00 | 15.11 | 0.3 |
| 1 | T | 25 | 1 | 0.93 | 0.87 | 0.86 | 0.75 | 0.90 | 0.75 | 20 | 11.56 | 1.7 |
| 1 | U | 25 | 1 | 0.93 | 0.91 | 0.86 | 0.95 | 0.90 | 0.85 | 40 | 15.40 | 2.6 |
| 1 | V | 25 | 1 | 0.93 | 0.91 | 0.86 | 0.85 | 0.90 | 0.85 | 30 | 13.78 | 2.2 |

Here, works (I = 32; i:1,2,3,4….), workstation (q = 32; q:1A,1B,1C,2C,1D,2D, 1E,1F,2F,1G,2G,1H,1I, 2I, 3I, 4I, 1J, 2J, 1K, 2K, 3K, L, M, N, O, P, Q, R, S, T, U, V),LC: Load Constant (kg); HM: Horizontal multiplier factor; VM: Vertical multiplier factor; DM: Distance multiplier factor; AM: Asymmetric multiplier factor; FM: Frequency multiplier factor; CM: Coupling multiplier factor; FMAX: maximum frequency factor; LW: Weight of the object (kg); LI: Lifting index; RWL Recommended weight limit.

It is assumed to develop intervals rotation after every 2 h as a strategic period that infuses diversity, considering a suitable interval to decrease of muscle fatigue. The working day is 8 h (480 min) with an hour break for lunch. For organizational reasons, it is scheduled four rotations of 2 h, placing the break after the second rotation. The penalized allocations are shown in Table 8.

The different parameters of the algorithm have been described in previous sections. The values assigned to these parameters for solving the problem are based on experimental design of works where the most appropriate values are determined as a function of the number of workers, rotation, workstations and penalties. In Appendix 1, the experimental design is shown for the definition of appropriate parameters. Table 9 shows the values for each parameter which is chosen for solving the problem.

Multi-objective genetic algorithm is set up and evaluated on an Intel Core i5-2430M 2.40 GHz and 4 GB memory RAM. The algorithm is executed 5 times with the aim of giving greater coverage to the results generated under the parameters considered. In Table 10, values are given the fitness of the best individual obtained in relation to the objectives for load handling (NIOSH), repeatability (OCRA) and awkward postures (RULA). The average fitness for the Risk RULA is 32.34, for the risk NIOSH is 3.64 and 5.74 is for the risk OCRA. The algorithm takes 4 min to reach a solution after running 10,000 generations.

Figure 5 provides the evolution of the value of the target function of the best individual during execution 5 and it reflects the capacity of the algorithm to generate better solutions by employing simulated evolution techniques. The graph shows a constantly decreasing evolution. This is due to the implement of elitist strategy that prevents the algorithm from becoming disorientation. The Tables 11 and 12 show the behavior on the level of risk of the workers in job rotation in each of the goals. The results show that workers can obtain variability and diversity in the development of the working day, where no worker is exposed simultaneously to high risks. Importantly, risk level NIOSH through sequential calculation tasks (SLI) and the levels of risk do not keep the same proportions as the LI indicator. That is why a level of risk is assumed to be moderate 3.5 high (Waters et al.

**Table 6** Results of the RULA ergonomic assessment method

| Number of job | Workstation | A | | | | | | B | | | | | Grand score | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Arm | Forearm | wrist | Twist wrist | Muscle | Force | Neck | Trunk | Leg | Muscle | Force | Pre A | Score A | Pre B | Score B | LP |
| 1 | A | 2 | 2 | 2 | 1 | 0 | 1 | 3 | 2 | 1 | 0 | 1 | 3 | 4 | 3 | 4 | 4 |
| 1 | B | 2 | 2 | 3 | 2 | 0 | 3 | 3 | 3 | 1 | 0 | 1 | 4 | 7 | 4 | 5 | 7 |
| 2 | C | 4 | 2 | 3 | 1 | 0 | 0 | 1 | 2 | 1 | 0 | 0 | 4 | 4 | 2 | 2 | 3 |
| 2 | D | 3 | 2 | 3 | 2 | 0 | 3 | 3 | 3 | 1 | 0 | 3 | 4 | 7 | 4 | 7 | 7 |
| 1 | E | 1 | 1 | 3 | 1 | 0 | 1 | 3 | 1 | 1 | 0 | 0 | 2 | 3 | 3 | 3 | 3 |
| 2 | F | 2 | 2 | 3 | 1 | 0 | 2 | 3 | 3 | 1 | 0 | 0 | 3 | 5 | 4 | 4 | 5 |
| 2 | G | 2 | 2 | 3 | 1 | 0 | 2 | 2 | 3 | 1 | 0 | 0 | 3 | 5 | 4 | 4 | 5 |
| 1 | H | 3 | 2 | 3 | 1 | 0 | 2 | 3 | 3 | 1 | 0 | 3 | 4 | 6 | 4 | 7 | 7 |
| 4 | I | 3 | 2 | 3 | 2 | 0 | 1 | 3 | 2 | 1 | 0 | 1 | 4 | 5 | 3 | 4 | 5 |
| 2 | J | 2 | 2 | 3 | 2 | 0 | 1 | 3 | 3 | 1 | 0 | 1 | 4 | 5 | 4 | 5 | 6 |
| 3 | K | 2 | 1 | 3 | 1 | 0 | 1 | 3 | 4 | 2 | 0 | 1 | 3 | 4 | 6 | 7 | 6 |
| 1 | L | 3 | 2 | 3 | 2 | 0 | 2 | 3 | 3 | 2 | 0 | 2 | 4 | 6 | 5 | 7 | 7 |
| 1 | M | 2 | 2 | 3 | 2 | 0 | 1 | 3 | 4 | 2 | 0 | 1 | 4 | 5 | 7 | 8 | 7 |
| 1 | N | 2 | 1 | 3 | 2 | 0 | 1 | 3 | 4 | 2 | 0 | 1 | 4 | 5 | 7 | 8 | 7 |
| 1 | O | 3 | 1 | 3 | 2 | 0 | 2 | 3 | 3 | 1 | 0 | 3 | 3 | 5 | 4 | 7 | 7 |
| 1 | P | 2 | 2 | 3 | 1 | 0 | 2 | 2 | 3 | 1 | 0 | 3 | 3 | 5 | 4 | 7 | 7 |
| 1 | Q | 2 | 2 | 3 | 1 | 0 | 2 | 3 | 3 | 1 | 0 | 0 | 3 | 5 | 4 | 4 | 5 |
| 1 | R | 2 | 2 | 3 | 2 | 0 | 3 | 3 | 3 | 1 | 0 | 3 | 4 | 7 | 4 | 7 | 7 |
| 1 | S | 2 | 1 | 3 | 1 | 0 | 1 | 3 | 3 | 1 | 0 | 0 | 4 | 5 | 4 | 4 | 5 |
| 1 | T | 2 | 1 | 3 | 2 | 0 | 2 | 3 | 4 | 2 | 0 | 2 | 4 | 6 | 7 | 9 | 7 |
| 1 | U | 2 | 2 | 3 | 1 | 0 | 2 | 3 | 3 | 1 | 0 | 0 | 3 | 5 | 4 | 4 | 5 |
| 1 | V | 2 | 2 | 3 | 1 | 0 | 1 | 3 | 3 | 1 | 0 | 0 | 3 | 4 | 4 | 4 | 4 |

*Pre-A* postural score in group A; *Score A* postural score with muscle use, force/load; *Pre-B* postural score in group B; *Score B* postural score with muscle use, force/load; *LP* level of postural risk assessment scale of RULA

**Table 7** Results of the OCRA Ergonomic assessment method

| Number of job | Label | KJ | FA | FS | PM | RE | AF | DM | RCM | Nata | RTA | OCRA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A | 30 | 10 | 1 | 1 | 1 | 0.95 | 1 | 0.6 | 80 | 136.8 | 0.58 |
| 1 | B | 30 | 20 | 0.85 | 0.6 | 0.7 | 0.9 | 1 | 0.6 | 160 | 46.3 | 3.46 |
| 2 | C | 30 | 40 | 1 | 0.7 | 1 | 0.9 | 1 | 0.6 | 320 | 90.7 | 3.53 |
| 2 | D | 30 | 15 | 0.85 | 0.5 | 0.7 | 0.8 | 1 | 0.6 | 120 | 34.3 | 3.50 |
| 1 | E | 30 | 10 | 1 | 0.7 | 1 | 0.95 | 1 | 0.6 | 80 | 95.8 | 0.84 |
| 2 | F | 30 | 35 | 1 | 1 | 0.7 | 0.8 | 1 | 0.6 | 280 | 80.6 | 3.47 |
| 2 | G | 30 | 35 | 1 | 1 | 0.7 | 0.8 | 1 | 0.6 | 280 | 80.6 | 3.47 |
| 1 | H | 30 | 35 | 1 | 0.7 | 0.7 | 0.9 | 1 | 0.6 | 280 | 63.5 | 4.41 |
| 4 | I | 30 | 35 | 1 | 1 | 0.7 | 0.8 | 1 | 0.6 | 280 | 80.6 | 3.47 |
| 2 | J | 30 | 25 | 1 | 0.7 | 0.7 | 0.8 | 1 | 0.6 | 200 | 56.4 | 3.54 |
| 3 | K | 30 | 35 | 1 | 0.7 | 0.7 | 0.9 | 1 | 0.6 | 280 | 63.5 | 4.41 |
| 1 | L | 30 | 30 | 1 | 0.6 | 1 | 0.8 | 1 | 0.6 | 240 | 69.1 | 3.47 |
| 1 | M | 30 | 20 | 0.85 | 0.6 | 0.7 | 0.9 | 1 | 0.6 | 160 | 46.3 | 3.46 |
| 1 | N | 30 | 20 | 0.85 | 0.6 | 0.7 | 0.9 | 1 | 0.6 | 160 | 46.3 | 3.46 |
| 1 | O | 30 | 20 | 0.85 | 0.6 | 0.7 | 0.9 | 1 | 0.6 | 160 | 46.3 | 3.46 |
| 1 | P | 30 | 35 | 1 | 1 | 0.7 | 0.8 | 1 | 0.6 | 280 | 80.6 | 3.47 |
| 1 | Q | 30 | 10 | 0.65 | 0.7 | 0.7 | 0.8 | 1 | 0.6 | 80 | 36.7 | 2.18 |
| 1 | R | 30 | 20 | 1 | 0.6 | 1 | 0.8 | 1 | 0.6 | 160 | 69.1 | 2.31 |
| 1 | S | 30 | 18 | 0.85 | 0.6 | 0.7 | 0.8 | 1 | 0.6 | 144 | 41.1 | 3.50 |
| 1 | T | 30 | 20 | 0.85 | 0.6 | 0.7 | 0.8 | 1 | 0.6 | 160 | 41.1 | 3.89 |
| 1 | U | 30 | 10 | 0.65 | 0.7 | 0.7 | 0.8 | 1 | 0.6 | 80 | 36.7 | 2.18 |
| 1 | V | 30 | 35 | 0.85 | 1 | 1 | 0.9 | 1 | 0.6 | 280 | 110.2 | 2.54 |

*KJ* the constant of frequency of technical actions. (Movement), *FA* the number of actions per minute, *FS* the factor of strength risk, *PM* The factor of posture risk, *RE* the factor of repeatability risk, *AF* the factor of additional risks, *DM* the factor for total length of repetitive tasks, *RCM* the risk factor about lack of recovery periods, *Nata* number of technical actions, *RTA* number of reference technical actions, *OCRA* risk level repeatability sequential movements of tasks performed by the worker

**Table 8** Penalized allocations

| Penalization | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Worker | A | B | 1C | 2C | 1D | 2D | E | 1F | 2F | 1G | 2G | H | 1I | 2I | 3I | 4I | 1J | 2J | 1K | 2K | 3K | L | M | N | O | P | Q | R | S | T | U | V |
| W29 | √ | O | O | O | O | O | √ | O | O | O | O | O | O | O | O | O | O | O | O | O | O | √ | O | O | O | O | √ | √ | √ | √ | √ | √ |
| W30 | O | √ | O | O | √ | O | O | √ | √ | O | O | O | O | O | O | O | √ | √ | O | O | O | O | O | O | O | √ | √ | √ | O | O | O | O |
| W31 | √ | √ | √ | √ | √ | √ | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O |
| W32 | √ | √ | √ | √ | √ | √ | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O | O |

√indicates the jobs that can be worked by the worker. The worker W29 is penalized by assigning at distance stations with high level of load handling. The W30 is new worker in the company, so only limited stations are assigned to him. The W31 and W32 are the workers having only working experience in the stations A–D

2007). Moreover, the 3.5 index OCRA method assumes as a medium high risk. Finally, RULA with index 7indicates a high risk.

Only three workers are at a moderately high-level load handling. Five workers are on average high by repetitiveness, while the postural risk means all workers. In each of the objectives whenever high risks presented in rotation schemes is accompanied by a rotation, the risk decreases. Within the job rotation scheme, no worker is exposed simultaneously in the high ergonomic risk thresholds. From the Tables 11 and 12, the optimal job assignments among 32 workers are W1 ∈{(T1,B); (T2, 4I); (T3, 1G); (T4, 2F)}, W2 ∈{(T1,U); (T2,H); (T3, 2I); (T4, S)}, W3 ∈{(T1, 1G); (T2, 2I); (T3, V); (T4, 2D)},W4 ∈{(T1, 2K); (T2,U); (T3, 2J); (T4, 1J)}, W5 ∈{(T1, 2J); (T2, 1J); (T3,Q); (T4,O)},W6 ∈{(T1,L); (T2,A); (T3, S); (T4, 3K)}, W7 ∈{(T1, S); (T2, 2F); (T 3,M); (T4, 2L)},W8 ∈{(T1,N); (T2, 2K); (T3,E); (T4,L)}, W9 ∈{(T1,H); (T2, 1K); (T3,U); (T4, 1F)},W10 ∈{(T1,M);

**Table 9** Values of the parameters used in the case

| | Parameter | Definition | Value |
|---|---|---|---|
| Genetic algorithm | *J* | Number of workers. Number of rotations | 32 |
| | *P* | Population size | 400 |
| | *Tc* | Probability of crossing (roulette) | 0.3 |
| | *Tm* | Probability of mutation | 0.3 |
| | *Im* | Intensity of mutation | 1 |
| | *Te* | Intensity of the elitism | 1 |
| | *maxgen* | Number of generations | 10,000 |
| Problem data | *T* | Number of rotation intervals | 4 |
| | *P-ND* | Individuals set size no dominated | 100 |
| | $FP_c$ | Percentage of population in the c layer. (c:5) | 0.2 |
| | $D_t$ | Duration of rotation t. (4 rotation) | 2 h |
| | $Dp(t,t+1)$ | Duration of rest period between t and t + 1 rotation. ($t_2$) | 1 h |
| | $\alpha$ | Fatigue reduction factor | 0.33 |

**Table 10** Value of the evaluation function for the best solution

| Nos. run | Load lifting | Repeatability | Load lifting |
|---|---|---|---|
| 1 | 32.42 | 3.68 | 5.67 |
| 2 | 32.64 | 3.68 | 5.71 |
| 3 | 31.80 | 3.68 | 5.71 |
| 4 | 32.42 | 3.49 | 5.99 |
| 5 | 32.42 | 3.68 | 5.67 |
| Max | 32.64 | 3.68 | 5.99 |
| Min | 31.80 | 3.49 | 5.67 |
| Average | 32.34 | 3.64 | 5.75 |

(T2,E); (T3,H); (T4, 1K)}, W11 ∈{(T1, 3I); (T2,Q); (T3, 1J); (T4, 2J)}, W12 ∈{(T1, P); (T2, 3I); (T3, 1F); (T4,N)}, W13 ∈{(T1,E); (T2, 1D); (T3, 2D); (T4, 4I)},W14 ∈{(T1, T); (T2, 2C); (T3, 2K); (T4,A)}, W15 ∈{(T1,R); (T2,M); (T3, 1C); (T4, 1G)}, W16 ∈{(T1, 2F); (T2,O); (T3,R); (T4, 2C)}, W17 ∈{(T1, 1K); (T2, 1C); (T3,L); (T4,U)},W18 ∈{(T1, 2D); (T2, 3K); (T3,A); (T4, 2K)}, W19 ∈{(T1, 4I); (T2,B); (T3, 3I); (T4, P)}, W20 ∈{(T1, 2C); (T2, T); (T3,O); (T4,Q)}, W21 ∈{(T1, 2G); (T2, V); (T3, P); (T4, T)},W22 ∈{(T1, 1C); (T2,N); (T3,B); (T4, 3I)}, W23 ∈{(T1,Q); (T2, S); (T3, 1K); (T4, 1I)},W24 ∈{(T1, 1F); (T2,L); (T3, 4I); (T4,M)}, W25 ∈{(T1, 1J); (T2, 2J); (T3, 1D); (T4,E)}, W26 ∈{(T1, 1I); (T2, P); (T3, T); (T4, V)} W27 ∈{(T1,A); (T2, 2D); (T3, 3K); (T4,H)},W28 ∈{(T1, V); (2, 1F); (T3,N); (T4, 1C)}, W29 ∈{(T1, 1D); (T2, 2G); (T3, 2C); (T4,R)}, W30 ∈{(T1,O); (T2, 1G); (T3, 1I); (T4,B)}, W31 ∈{(T1, 2I); (T2,R); (T3, 2G); (T4, 1D)},W32 ∈{(T1, 3K); (T2, 1I); (T3, 2F); (T4, 2G)}where the workloads are balanced according to ergonomic risks. Figures 6, 7 and 8 contrast the implementation of a job rotation model that simultaneously considers ergonomic hazards and the current structure of the production system without rotation.

Comparisons of the current system and the changes that occur during introducing a rotation system indicate that the rotation balances workload of the employees. Allowing workers to perform tasks in a range of controlled risk where the monotony is avoided and skills are developed that minimizes the maximum perceived risk, ensuring optimization of welfare of workers.

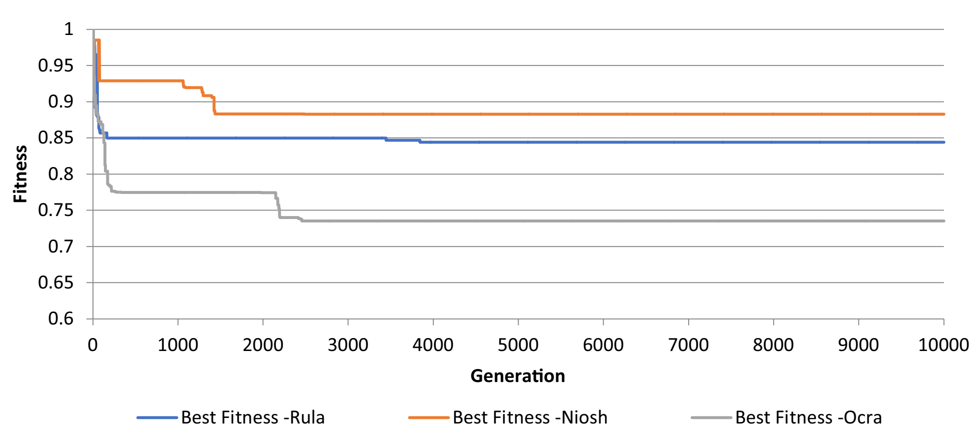



**Fig. 5** Evolution of the fitness of the best individual throughout the generations. (Normalized fitness values)

**Table 11** Results of job rotation

| Worker | Rotation | | | | Fitness | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | Load handling | Repeatability | Posture |
| 1 | B | 4I | 1G | 2F | 3.49 | 5.47 | 30.47 |
| 2 | U | H | 2I | S | 3.10 | 5.03 | 30.47 |
| 3 | 1G | 2I | V | 2D | 2.92 | 5.64 | 28.76 |
| 4 | 2K | U | 2J | 1J | 2.95 | 4.57 | 31.45 |
| 5 | 2J | 1J | Q | O | 3.50 | 4.27 | 32.64 |
| 6 | L | A | S | 3K | 2.82 | 3.40 | 30.23 |
| 7 | S | 2F | M | 2I | 3.10 | 5.47 | 30.25 |
| 8 | N | 2K | E | L | 2.92 | 3.27 | 31.53 |
| 9 | H | 1K | U | 1F | 3.23 | 4.77 | 31.80 |
| 10 | M | E | H | 1K | 3.10 | 3.97 | 31.34 |
| 11 | 3I | Q | 1J | 2J | 3.44 | 4.30 | 30.12 |
| 12 | P | 3I | 1F | N | 3.20 | 5.47 | 32.64 |
| 13 | E | 1D | 2D | 4I | 2.78 | 4.45 | 30.25 |
| 14 | T | 2C | 2K | A | 2.80 | 5.53 | 27.95 |
| 15 | R | M | 1C | 1G | 3.47 | 5.71 | 30.69 |
| 16 | 2F | O | R | 2C | 3.52 | 5.71 | 30.75 |
| 17 | 1K | 1C | L | U | 2.89 | 5.54 | 28.92 |
| 18 | 2D | 3K | A | 2K | 2.96 | 3.55 | 31.67 |
| 19 | 4I | B | 3I | P | 3.49 | 5.47 | 32.64 |
| 20 | 2C | T | O | Q | 3.50 | 5.35 | 30.25 |
| 21 | 2G | V | P | T | 3.18 | 5.70 | 31.09 |
| 22 | 1C | N | B | 3I | 3.49 | 5.49 | 30.25 |
| 23 | Q | S | 1K | 1I | 3.46 | 5.53 | 29.03 |
| 24 | 1F | L | 4I | M | 3.08 | 5.47 | 32.64 |
| 25 | 1J | 2J | 1D | E | 2.78 | 5.47 | 30.75 |
| 26 | 1I | P | T | V | 3.08 | 5.70 | 31.83 |
| 27 | A | 2D | 3K | H | 3.10 | 5.55 | 32.53 |
| 28 | V | 1F | N | 1C | 3.19 | 5.67 | 26.76 |
| 29 | 1D | 2G | 2C | R | 3.52 | 5.70 | 30.20 |
| 30 | O | 1G | 1I | B | 3.49 | 5.47 | 32.64 |
| 31 | 2I | R | 2G | 1D | 3.14 | 5.67 | 32.64 |
| 32 | 3K | 1I | 2F | 2G | 3.24 | 5.67 | 29.14 |
| | | | **Max Fitness** | | **3.52** | **5.71** | **32.64** |
| | | | **Min Fitness** | | **2.78** | **3.27** | **26.76** |
| | | | **Average** | | **3.18** | **5.13** | **30.76** |
| | | | **Deviation** | | **0.25** | **0.74** | **1.48** |

Bold indicates the adjustment and performance of the objective function calculated for the ergonomic restrictions

Observing the dispersion of solutions that contribute to the formation, there are a clear set of nondominated responses and a strong concentration of suboptimal responses dominated objective functions. The finding of the objectives is directed to the minimization of risks. That is why, the outline of the graphics of the Pareto fronts reflect the grouping in the formation of a joint response that satisfies the conditions, being sought within the problem where is diversity in the number of responses that conform to a multi-objective environment (Fig. 9).

Since no study of such cases are found in the literature whose results could be compared with those provided by the algorithm. We proceed to compare the results obtained when the objectives of optimizing are considered simultaneously. We optimize each of the targets individually, using genetic algorithms and integer linear programming models. All test problems have been written in GAMS software and solve CPLEX solver. Additionally, the multiobjective linear programming model of the problem considered the weighted multiobjective method,

**Table 12** Best job rotation schedule

| Worker | Load handling (NIOSH index) | | | | | Repeatability (OCRA index) | | | | | Awkward posture (RULA index) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T4 | SLI | T1 | T2 | T3 | T4 | OCRA | T1 | T2 | T3 | T4 | RULA |
| 1 | 2.6 | 2.6 | 2.8 | 2.9 | 3.49 | 3.46 | 3.47 | 3.47 | 3.47 | 3.47 | 7 | 5 | 5 | 5 | 5.50 |
| 2 | 2.6 | 2.8 | 2.6 | 0.3 | 3.10 | 2.18 | 4.41 | 3.47 | 3.50 | 3.53 | 5 | 7 | 5 | 5 | 5.50 |
| 3 | 2.8 | 2.6 | 2.2 | 2.6 | 2.92 | 3.47 | 3.47 | 2.54 | 3.50 | 3.14 | 5 | 5 | 4 | 7 | 5.25 |
| 4 | 2.7 | 2.6 | 3.5 | 3.5 | 2.95 | 4.41 | 2.18 | 3.54 | 3.54 | 3.57 | 6 | 5 | 6 | 6 | 5.75 |
| 5 | 3.5 | 3.5 | 3.2 | 1.2 | 3.50 | 3.54 | 3.54 | 2.18 | 3.46 | 3.27 | 6 | 6 | 5 | 7 | 6.00 |
| 6 | 0.0 | 0.0 | 0.3 | 2.7 | 2.82 | 3.47 | 0.58 | 3.50 | 4.41 | 2.40 | 7 | 4 | 5 | 6 | 5.50 |
| 7 | 0.3 | 2.9 | 1.6 | 2.6 | 3.10 | 3.50 | 3.47 | 3.46 | 3.47 | 3.47 | 5 | 5 | 7 | 5 | 5.50 |
| 8 | 2.4 | 2.7 | 0.0 | 0.0 | 2.92 | 3.46 | 4.41 | 0.84 | 3.47 | 2.77 | 7 | 6 | 3 | 7 | 5.75 |
| 9 | 2.8 | 2.7 | 2.6 | 2.9 | 3.23 | 4.41 | 4.41 | 2.18 | 3.47 | 3.77 | 7 | 6 | 5 | 5 | 5.75 |
| 10 | 1.6 | 0.0 | 2.8 | 2.7 | 3.10 | 3.46 | 0.84 | 4.41 | 4.41 | 2.97 | 7 | 3 | 7 | 6 | 5.75 |
| 11 | 2.6 | 3.2 | 3.5 | 3.5 | 3.44 | 3.47 | 2.18 | 3.54 | 3.54 | 3.30 | 5 | 5 | 6 | 6 | 5.50 |
| 12 | 2.9 | 2.6 | 2.9 | 2.4 | 3.20 | 3.47 | 3.47 | 3.47 | 3.46 | 3.47 | 7 | 5 | 5 | 7 | 6.00 |
| 13 | 0.0 | 2.6 | 2.6 | 2.6 | 2.78 | 0.84 | 3.50 | 3.50 | 3.47 | 2.45 | 3 | 7 | 7 | 5 | 5.50 |
| 14 | 1.7 | 1.6 | 2.7 | 0.0 | 2.80 | 3.89 | 3.53 | 4.41 | 0.58 | 2.53 | 7 | 3 | 6 | 4 | 5.00 |
| 15 | 2.3 | 1.6 | 1.6 | 2.8 | 3.47 | 2.31 | 3.46 | 3.53 | 3.47 | 3.21 | 7 | 7 | 3 | 5 | 5.50 |
| 16 | 2.9 | 1.2 | 2.3 | 1.6 | 3.52 | 3.47 | 3.46 | 2.31 | 3.53 | 3.21 | 5 | 7 | 7 | 3 | 5.50 |
| 17 | 2.7 | 1.6 | 0.0 | 2.6 | 2.89 | 4.41 | 3.53 | 3.47 | 2.18 | 3.54 | 6 | 3 | 7 | 5 | 5.25 |
| 18 | 2.6 | 2.7 | 0.0 | 2.7 | 2.96 | 3.50 | 4.41 | 0.58 | 4.41 | 2.55 | 7 | 6 | 4 | 6 | 5.75 |
| 19 | 2.6 | 2.6 | 2.6 | 2.9 | 3.49 | 3.47 | 3.46 | 3.47 | 3.47 | 3.47 | 5 | 7 | 5 | 7 | 6.00 |
| 20 | 1.6 | 1.7 | 1.2 | 3.2 | 3.50 | 3.53 | 3.89 | 3.46 | 2.18 | 3.35 | 3 | 7 | 7 | 5 | 5.50 |
| 21 | 2.8 | 2.2 | 2.9 | 1.7 | 3.18 | 3.47 | 2.54 | 3.47 | 3.89 | 3.20 | 5 | 4 | 7 | 7 | 5.75 |
| 22 | 1.6 | 2.4 | 2.6 | 2.6 | 3.49 | 3.53 | 3.46 | 3.46 | 3.47 | 3.49 | 3 | 7 | 7 | 5 | 5.50 |
| 23 | 3.2 | 0.3 | 2.7 | 2.6 | 3.46 | 2.18 | 3.50 | 4.41 | 3.47 | 3.53 | 5 | 5 | 6 | 5 | 5.25 |
| 24 | 2.9 | 0.0 | 2.6 | 1.6 | 3.08 | 3.47 | 3.47 | 3.47 | 3.46 | 3.47 | 5 | 7 | 5 | 7 | 6.00 |
| 25 | 3.5 | 3.5 | 2.6 | 0.0 | 2.78 | 3.54 | 3.54 | 3.50 | 0.84 | 2.47 | 6 | 6 | 7 | 3 | 5.50 |
| 26 | 2.6 | 2.9 | 1.7 | 2.2 | 3.08 | 3.47 | 3.47 | 3.89 | 2.54 | 3.20 | 5 | 7 | 7 | 4 | 5.75 |
| 27 | 0.0 | 2.6 | 2.7 | 2.8 | 3.10 | 0.58 | 3.50 | 4.41 | 4.41 | 2.55 | 4 | 7 | 6 | 7 | 6.00 |
| 28 | 2.2 | 2.9 | 2.4 | 1.6 | 3.19 | 2.54 | 3.47 | 3.46 | 3.53 | 3.17 | 4 | 5 | 7 | 3 | 4.75 |
| 29 | 2.6 | 2.8 | 1.6 | 2.3 | 3.52 | 3.50 | 3.47 | 3.53 | 2.31 | 3.20 | 7 | 5 | 3 | 7 | 5.50 |
| 30 | 1.2 | 2.8 | 2.6 | 2.6 | 3.49 | 3.46 | 3.47 | 3.47 | 3.46 | 3.47 | 7 | 5 | 5 | 7 | 6.00 |
| 31 | 2.6 | 2.3 | 2.8 | 2.6 | 3.14 | 3.47 | 2.31 | 3.47 | 3.50 | 3.17 | 5 | 7 | 5 | 7 | 6.00 |
| 32 | 2.7 | 2.6 | 2.9 | 2.8 | 3.24 | 4.41 | 3.47 | 3.47 | 3.47 | 3.67 | 6 | 5 | 5 | 5 | 5.25 |

High risk XX medium risk  low risk XX T1. T2. T3 and T4 refer to the four intervals of rotation

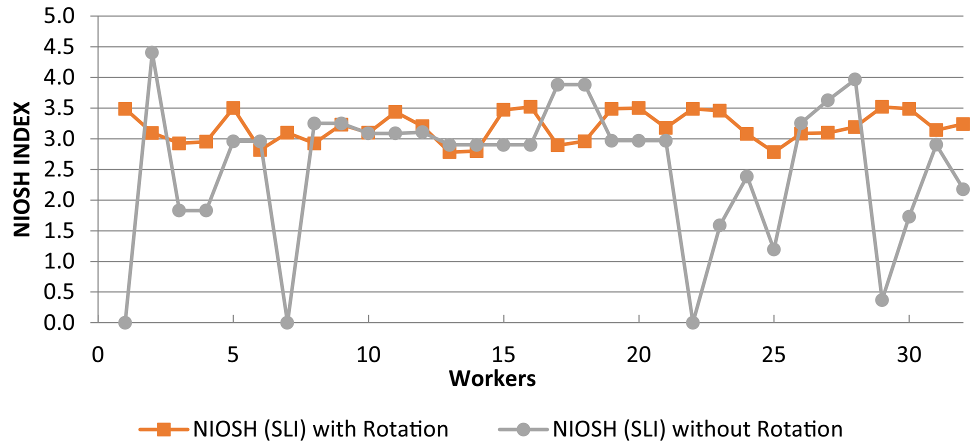



**Fig. 6** Contrast risk load handling, with and without job rotation

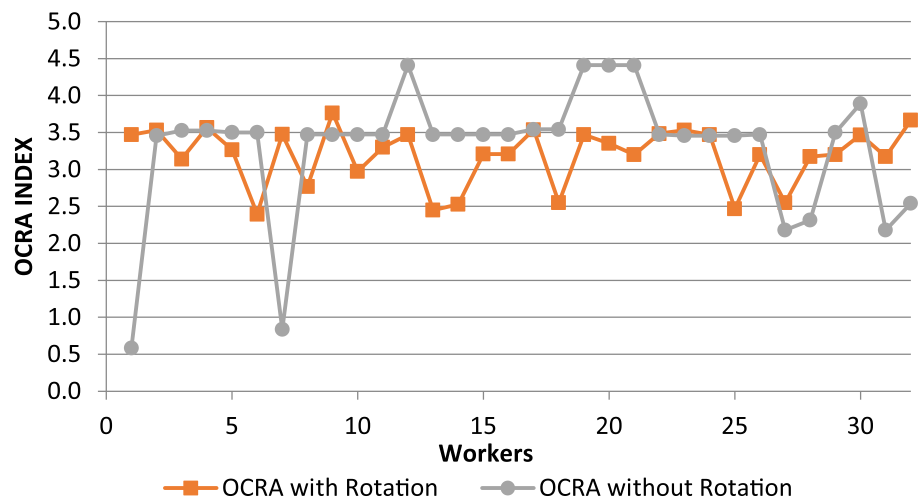



**Fig. 7** Contrast risk repeatability of activities, with and without job rotation

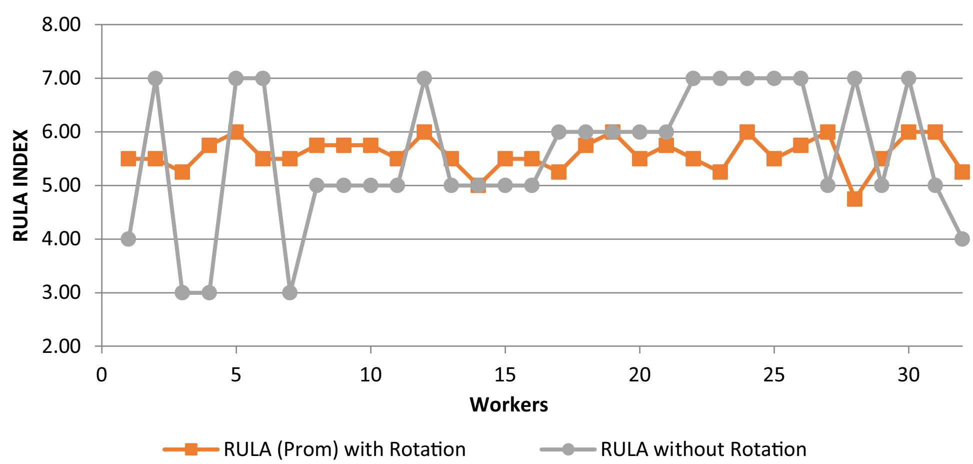
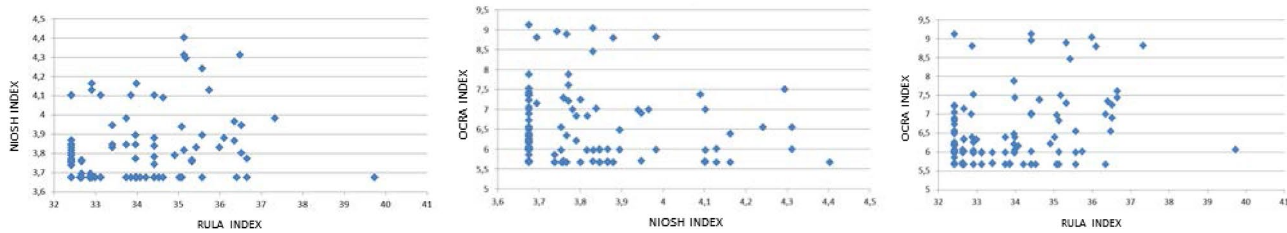



**Fig. 8** Contrast risk awkward postures, with and without job rotation

Multiobjective goal programming and the ε-constraint method will be validated. In the weighting method, the weighted sum of the objective functions is optimized and equivalent weight is considered for each of the objectives. Also, indicators are normalized to generate results on the same solution space. In the multiobjective solution for goals, the hierarchy is given by order of objectives. In the ε-constraint method we optimize one of the objective functions using the other objective functions as constraints (Ehrgott and Ruzika 2004). The application of the




**(a)** RULA Vs NIOSH **(b)** NIOSH Vs OCRA **(c)** RULA Vs OCRA

**Fig. 9** Formation of Pareto Frontier (contrast by objectives)

restricted method is supported by the ε-constraint method library of the Gams optimizer for multiobjective linear programming problems (Mavrotas 2009). The problem is adjusted by the authors on the sequencing restrictions for its combinatorial condition.The search for the optimal solution has been limited to 86,400 CPUs. IP formulation has not found optimal solutions for all test problems. At the end of time limit, a near optimal solution is obtained. This is used for comparing with proposed algorithm.

In Table 13, the results of each of the experiments are obtained, where experiment 1 belongs to multi-objective proposed model. Experiments 2 consists of a basic multiobjective genetic algorithm (MOEA). Experiments 3, 4 and 5 correspond to the other multi-objective optimizers. Experiments 6, 7 and 8 corresponds to the genetic algorithm are represented mono-objective, and the experiments 9, 10 and 11 belong to mono-objective through integer linear programming models only for NIOSH. The other results on the experiment 1 is the best result as programming run time is minimum as well as three risk factors are considered simultaneously which is more appropriate healthy strategy for the workers in sustainable management systems.

The integer linear programming is run by the optimization software GAMS for 48 h of computing time. The results are evidence of linear programming beyond the data to implement mono-objective genetic algorithms. The response obtained from independently goals are good if we only want to optimize this, but to compare their impact on others ergonomic indexes, one may conclude that improves it by disregarding its impact on other risk. The results obtained by the proposed method show that the objectives can be improved while simultaneously and be substantially like minimize the risk level independently. In the multi-objective problems, a performance measure was formulated to compare the impact of the results obtained by the different approaches. The measure selected was coverage metric, this measures how many different nondominated solutions are generated and how well they are distributed. The measure is found as the number of non-dominated solutions in an expected global set of 100 responses for a Pareto front.

**Table 13** Results of experiments of job rotation models

| Experiment | Objective | Solution | Time (s) | Risk RULA | Risk NIOSH | Risk OCRA | Coverage |
|---|---|---|---|---|---|---|---|
| 1 | Multi-objective | NSGAII | 232 | 32.418 | 3.676 | 5.670 | 62% |
| 2 | Multi-objective | MOEA | 236 | 32.9125 | 3.738 | 5.99 | 38% |
| 3 | Multi-objective | IP* weighting method | 172,800 | 35.572 | 4.090 | 6.189 | 8% |
| 4 | Multi-objective | IP* goal programming | 172,800 | 35.125 | 3.983 | 7.747 | 10.2% |
| 5 | Multi-objective | IP* ε-constraint method | 172,800 | 33.745 | 3.755 | 6.160 | 33.4% |
| 6 | NIOSH | GA | 242 | 39.738 | 3.487 | 7.716 | – |
| 7 | OCRA | GA | 230 | 32.418 | 4.242 | 8.968 | – |
| 8 | RULA | GA | 231 | 37.298 | 4.312 | 5.724 | – |
| 9 | NIOSH | IP* | 172,800 | 37.435 | **3.486** | 8.001 | – |
| 10 | OCRA | IP* | 172,800 | 36.243 | 3.847 | **6.667** | **–** |
| 11 | RULA | IP* | 172,800 | **33.368** | 3.940 | 7.316 | – |

Bold indicates the best value found in each assessed objective respectively

*IP* integer programming

*Suboptimal

The results in performance as evidence that the proposed algorithm has greater ability to find quality responses and form a better distributed Pareto frontier. the basic multiobjective algorithm (MOEA) is inferior in generating response capacity for the problem due to its rapid convergence and lack of diversity. The solutions proposed by the integer programming located in better condition to method e-restricter. It emphasizes what theoretically is established with respect to the optimization weighted and by goals, they do not produce good results and they are not easy to converge.

The restricter method by validating the objectives as constraints in their iterations facilitates the exploration of new solution spaces which make it easier to leave a local optimum. However, the proposed algorithm provides the best result.

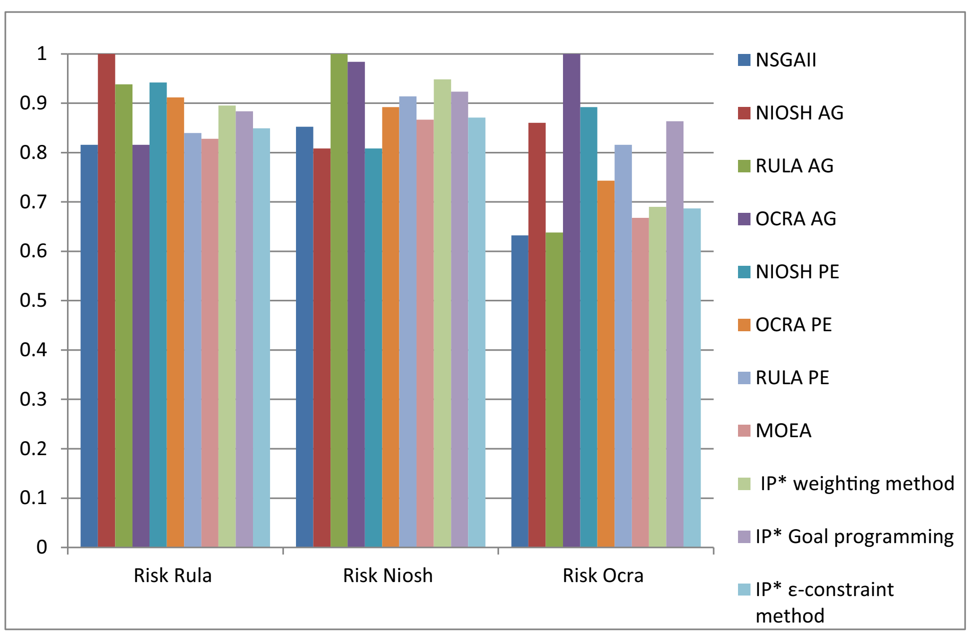
In Fig. 10, the level of impact of multi-objective scheme is plotted independently to minimize ergonomic risks with the normalized data.

## 6 Discussion

The proposed algorithm seems to be an effective tool to obtain solution that infuses diversity and variability in the activities of the workers and to avoid prolonged exposure to ergonomic hazards generators skeletal muscle disorders. It is important to note that the highest perceived risk thresholds depend on the production system, where accurate and representative of the processes evaluated information are required, and thus it has a significant impact on the welfare of workers. The schedules of job rotation improve the conditions of 69% of workers. The agenda of rotation possesses no repetition by the workers in the same workstation during the workday, only where their positions that represent the same job profile are not developed on different workstations. Job rotation improves the motivational part of the workers because it faces new challenges, reducing the monotony, stress and boredom in the workplace. Moreover, it is presented as a learning strategy that can extend the abilities and skills of workers in the workstations, and helps to improve the organizational environment. The part of the direction of the organization establishes fair compensation rates, levels of education and training that facilitate and improve sustainability of the change management.

The proposed multi-objective genetic algorithm for modeling job rotation is proceeded to design under the JAVA language in the Eclipse IDE Java EE Developers Helios -Version Service Release 2. The proposed platform for Web makes a connection of the application in conjunction with a sheet structured data with information from MS EXCEL problem, which, in turn, throws the processes and results in a new sheet.

The Genetic Algorithm is projected as second generation type (Genetic Algorithms by rating not dominated NSGAII), where premature convergence of the Pareto frontier in low quality answers is avoided. The algorithm is oriented in the closed and elitist strategy that avoided the infeasibility operators, without falling into error by the segmentation of the quality of individuals according their




* Note: The results obtained are not the best, but the best answers are found in the computational time.

**Fig. 10** Contrast experiments models of job rotation density within the range of responses from the population. The developed algorithm meets the needs of a new problem comprehensively. There are key factors for the implementation of a system of job rotation. As a result, intervention model for multi-objective implementation is structured with ergonomic approach considering the conditions and guidelines to be carried out as follows:

- *Generation of environment exchange of job rotation scheme* This phase seeks the relevance of rotation schemes of jobs, in which the full participation of the organization is required to deal with changes in scheduling and sequencing of shifts of workers. A proper analysis of the environment influences the convenience of variability and diversity of roles that workers can take without incurring injuries or conditions on the stability and health of these detailed. Furthermore, they should give assurances on the environment by the rotation direction of the organization, where equitable compensation rates, levels of education and training are established to facilitate and improve the change of a management.
- *Determination of labor demand, the exposure level, duration and frequency of occupational hazards* We establish the level of risk to which workers are exposed within workstations, considering the level, exposure duration and frequency. In case of musculoskeletal disorders, it is important to assess how the strength (material handling), the actions and movements (repeatability) and postures (awkward postures) are exercised. When we cannot afford to decrease occupational hazards, the workplace should not be likely to be included in a rotation scheme, but rather we should exclude and involved primarily with ergonomic tools.
- *The number of jobs and workers' rotation* The definition of workers and workstations is critical to the design of job rotation schemes. It will count with workers and jobs where print is feasible diversity and variability in the allocation of tasks and stations, and thus balance—the workload, and allow recovery periods of musculoskeletal system among all workers. Get a very low number of jobs and workers influences a lack of variability, while a large number of workstations, and may hamper the dynamic allocation and order in the internal management of organizations. That is why decisions should be given under consideration of the employment situation and the production system.
- *Ergonomic rating* An ergonomic analysis is input to assess the relevance of improving conditions of a job. Identifying workstations with low demand or workload, but in periods of peak efforts are critical positions where they should consider the need to implement job rotation, because these micro-periods are sufficient to cause aches and pains to workers, which does not benefit a rotation scheme, but quite the opposite. Ergonomic evaluation methods are critical to obtaining relevant information as it finds the working conditions and the time of passage planning and programming in the rotation job.
- *Duration of working time and number of rotation periods of labor (intervals)* Set in planning the rotation intervals and duration are engaged in the design to find the best scheme for compliance and minimize ergonomic risks, which states each change of allocation periods. If risks are diverse in the allocation of jobs in a system of job rotation, the way of rotation intervals are developed that will allow workers to change their status level of risk and complexity of the tasks. Therefore, the range of rotation is a key aspect that influences the variability of risks perceived by workers.
- *Profile of workers and jobs (restrictions and preferences)* It is important to note the level of competence, skills and aptitude of each of the workers involved in job rotation. The definition of constraints in the allocation (limitations), as well as the preferences of workers in rotation schemes, where it is possible strategically engages each of the workers in his new role. The restrictions can signal medical limitations, lack of labor skills, different levels of salary compensation among other things pointing consistency in the allocation of required job skills in contrast to the skills and competencies contained by the worker.
- *Job rotation model using genetic algorithms* It proceeds to configure the Multi-Objective Genetic Algorithm (NSGA) as a tool that collects all the information and allows the planning and programming of the rotation of jobs under an ergonomic scheme. Genetic algorithm has a fully configurable set of information regarding the setup and information of the work environment for the generation of job rotation plan, considering ergonomic aspects (repeatability, load handling and awkward postures). The rotation scheme defines the best allocation schemes where the risks for disorders of skeletal muscle disorders are minimized. The results are obtained through computational tool that deliver a range of solutions with quality and efficiency for analysis and interpretation under the actual conditions of organizations.
- *Implementation* Finally, the job rotation scheme must be validated and implemented, where adjustments and improvement opportunities are evidenced due to the interaction of workers, jobs and rotation intervals, coordination, monitoring and adaptation logistics. In the implementation process, monitoring with ergonomic facts and figures to evaluate the continuity of rotation plan is critical hazards. Implementation of rotation system requires proper coordination in the exchange of workstations, where production criteria are not affected,

and can be an instrument of supporting and monitoring by a supervisor of the operation, to guarantee the adequate coordination. In development, it is important to collect information from the rotation sequences that are assigned, sign up compliance and noncompliance, and the full set of retro feed information to allow a rotation system for the welfare of workers.

## 7 Conclusion

This model integrates the design of ergonomic aspects such as load handling, the repetitiveness of tasks and awkward postures, innovation in schemes for the planning and scheduling of job rotation as multi-objective approach avoiding the generation of skeletal muscle disorders. The implementation of multi-objective work rotation considers restrictive aspects within the production system by workers such as constraints, preferences, and skills. The model presents a multi-objective approach in a novel way for job rotation considering ergonomic risks for load handling, awkward postures and repeatability of tasks simultaneously. The consideration of index sequential activities (SLI) for assessing load handling is another aspect to highlight in model building as it considers the variability in the sequence of activities, and availability of rest time to calculate the level of risk to expose a worker in a rotation system. The inclusion of the variability of activities and repeatability of postural fatigue calculation of workers helps to diversify rotation schemes for workers' integrity. Due to complexity of the proposed model, a multi-objective genetic algorithm (NSGAII) is designed. The model and algorithm provide good results considering integrally ergonomic risks. The Algorithm created to the problem of job rotation shows the potential of meta-heuristics to generate a set of response quality (Pareto Frontier) in an optimization problem as demonstrated inefficient computational time. It has robustness that presents the algorithm in the experimental phase in their own settings. It demonstrates its easy application and guidance to obtain the best responses to the problem.

Design job rotation model is fully configurable to the needs of the productive systems, where information may vary according to the specific characteristics of the processes and activities of the plant floor. The results highlight the ability of the proposed methodology in creating job rotation plans, integrating aspects as workers and jobs, ergonomic evaluations of the jobs, the planning of rotation intervals and the working days. Otherwise, a bad design and planning in the assignment and sequencing, can bring harm to the health of employees engaged in the system of job rotation. The effectiveness of implementing job rotation is given in the medium and long term, through figures such as the level of absenteeism, injuries, accidents and incidents, illnesses, levels of productivity, among other things. Finally, the main objective of this research is to design a model of job rotation that helps to address simultaneously ergonomic hazards generators musculoskeletal disorders, helping work activities those are conditional on the skills, physical abilities and mental condition of the human being those are the core and key factors of any production system. In this paper, a novel approach to ergonomic job rotation is proposed in a multi-objective model for an environment of intensive production characterized by manipulation tasks loads, high frequency of repeatability and awkward postures, unlike the multi-criteria approaches defined by other researchers. The proposed model is quite new regarding the following aspects: (1) sequential load index through the NIOSH equation, allowing a better estimation of the cumulative risk for assessment of load handling, common condition rotation schemes are integrated; (2) quantification of risk repeatability is allowed considering the variability in the exchange rate between the tasks and rest periods in the rotation scheme so that the balancing of risk is accepted by the workers who fluctuate from one period forth between high levels of acceptable risk and moderate; (3) it considers the accumulated fatigue and reduce the monotony penalizing by keeping in the same job, as a strategy to reduce the impact of postural risk. Therefore, the proposed model generates an interesting methodology for making decisions in job rotation, by optimizing the duration, intensity and frequency of exposure to risk, thus favoring the welfare of workers in the productive environment. Though nonlinearity complicates incorporating ergonomic aspects in job rotation problem, it is a fundamental (and intuitive) assumption which cannot be omitted as all known methods are based on nonlinear risk estimation functions. Levels of exposure are aggregated in ergonomic risk estimation functions by a nonlinear aggregation function in NIOSH, multiplication in OCRA, mixture of multiplication and addition in RULA. Therefore, a novelty of the model is to consider all these treatment methods that allows include linearity within a linear integer programming model.

Future work in this area can integrate other methodologies, and consideration of other factors at work, information clustering, neural networks for the prediction type of risks in the jobs using different probability distributions for the task demand parameters.

### Compliance with ethical standards

**Conflict of interest** We do hereby declare that we do not have any conflict of interest of other works.

## Appendix 1: Experimental design of the parameters of the genetic algorithm

The adequate definition of the parameters is indispensable to guarantee that the genetic algorithm is oriented and allows to reach answers of quality and computational efficiency. For this reason, we look for the best configuration of the elements of metaheuristics. The following Table 14 summarizes the parameters of the problem, which are part of validation of the case. Experimental design development is executed Taguchi type where six features and three levels factors are handled, as listed below:

**Table 14** Summary of the parameters

| Parameters | Nomenclature | Values |
|---|---|---|
| Number of generations | *maxgen* | 10000, 5000, 500 |
| Size of the initial population | *P* | 100, 250, 400 |
| Probability of crossover | *Tc* | 0.3, 0.6, 0.9 |
| Probability of mutation | *Tm* | 0.1, 0.3, 0.5 |
| Intensity of mutations | *Im* | 1, 2, 4 |
| Elitism | $Te_1$ | On (1,4) |

The proposed experimental design is based on the model proposed by Genichi Taguchi, characterized by being an orthogonal design with a fraction of the possible combinations in contrast to what is executed in a complete experimental design. This reduces the size of experimentation considering the noise and robustness of the experimental process. The result for the experimental design consists of 27 treatments with one replicate. The response variables will be the three objective functions of a non-dominated solution selected from the Pareto front resulting from each experiment. The combinations for the replicas of the experiment determined by means of STATGRAPHICS Centurion XVI and MINITAB® 15.1.30.0 are shown below (Table 15).

The following figures show the results found by means of the Fractional Experimental Design (Orthogonal L27–3 * 13) for means and standard deviations where the most influential factors are evidenced within the case of validation considered in the framework of the design of a scheme of job rotation. The mutation parameter is one

**Table 15** Experimental results consist of 27 treatments

| *maxgen* | *P* | *Tc* | *Tm* | *Im* | $Te_1$ | *RiskRULA* | *RiskNIOSH* | *RiskOCRA* |
|---|---|---|---|---|---|---|---|---|
| 500 | 250 | 30 | 10 | 2 | 4 | 34,6375 | 3,73468587 | 5,98624298 |
| 500 | 400 | 60 | 10 | 2 | 1 | 34,9125 | 3,759526 | 6,18933987 |
| 500 | 100 | 90 | 10 | 2 | 0 | 34,6375 | 3,86680351 | 6,16703337 |
| 500 | 100 | 30 | 30 | 4 | 1 | 32,4175 | 4,1014496 | 6,16979765 |
| 500 | 250 | 60 | 30 | 4 | 0 | 33,4075 | 3,759526 | 6,00287236 |
| 500 | 400 | 90 | 30 | 4 | 4 | 32,6375 | 3,67598922 | 6,18933987 |
| 500 | 400 | 30 | 50 | 1 | 0 | 32,9125 | 3,86709831 | 5,98551073 |
| 500 | 100 | 60 | 50 | 1 | 4 | 32,6375 | 3,67598922 | 5,98491185 |
| 500 | 250 | 90 | 50 | 1 | 1 | 32,6375 | 3,67598922 | 5,98562849 |
| 5000 | 400 | 30 | 10 | 4 | 1 | 32,9125 | 3,67598922 | 5,97366958 |
| 5000 | 100 | 60 | 10 | 4 | 0 | 32,6375 | 3,83829103 | 5,99206349 |
| 5000 | 250 | 90 | 10 | 4 | 4 | 34,6375 | 3,67598922 | 5,97366958 |
| 5000 | 250 | 30 | 30 | 1 | 0 | 32,6375 | 3,67598922 | 5,70288842 |
| 5000 | 400 | 60 | 30 | 1 | 4 | 32,6375 | 3,67598922 | 5,63720728 |
| 5000 | 100 | 90 | 30 | 1 | 1 | 32,6375 | 3,67598922 | 5,70840099 |
| 5000 | 100 | 30 | 50 | 2 | 4 | 32,9125 | 3,67583662 | 5,97366958 |
| 5000 | 250 | 60 | 50 | 2 | 1 | 32,4175 | 3,67598922 | 5,98491185 |
| 5000 | 400 | 90 | 50 | 2 | 0 | 32,4175 | 3,67583662 | 5,82699873 |
| 10000 | 100 | 30 | 10 | 1 | 0 | 32,6375 | 3,67583662 | 5,70840099 |
| 10000 | 250 | 60 | 10 | 1 | 4 | 32,6375 | 3,67598922 | 5,63720728 |
| 10000 | 400 | 90 | 10 | 1 | 1 | 32,6375 | 3,67598922 | 5,66989362 |
| 10000 | 400 | 30 | 30 | 2 | 4 | 31,8025 | 3,67598922 | 5,98491185 |
| 10000 | 100 | 60 | 30 | 2 | 1 | 32,6375 | 3,67583662 | 5,66989362 |
| 10000 | 250 | 90 | 30 | 2 | 0 | 31,5825 | 3,67598922 | 5,98624298 |
| 10000 | 250 | 30 | 50 | 4 | 1 | 32,6375 | 3,67598922 | 5,97443396 |
| 10000 | 400 | 60 | 50 | 4 | 0 | 32,5275 | 3,69529568 | 5,99346088 |
| 10000 | 100 | 90 | 50 | 4 | 4 | 32,9125 | 3,67583662 | 5,66989362 |

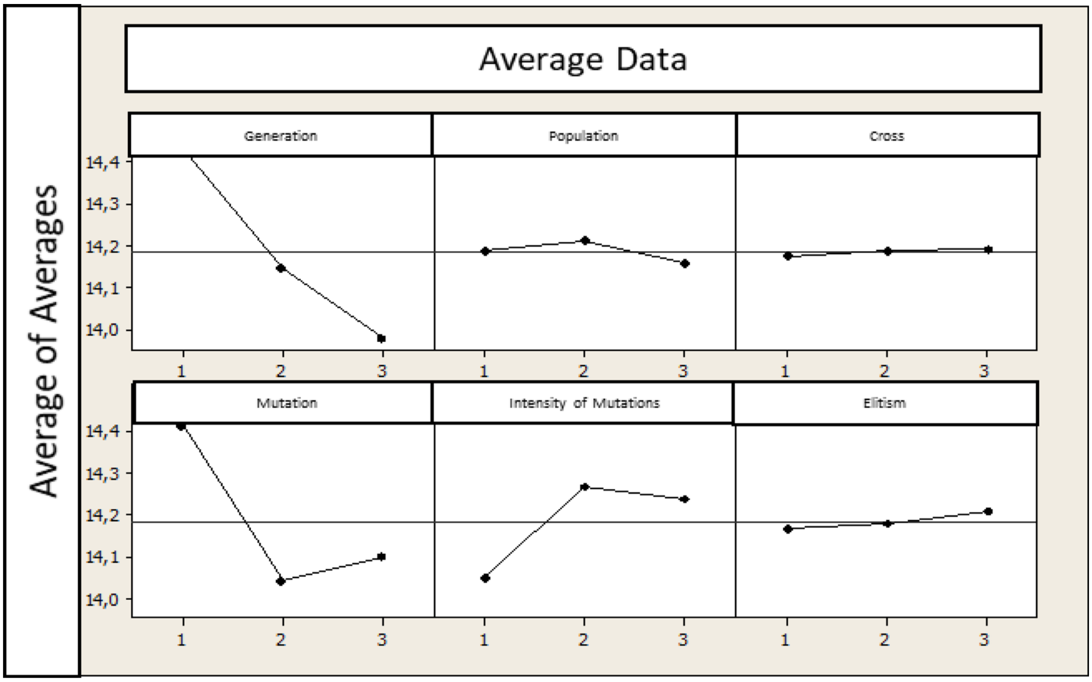
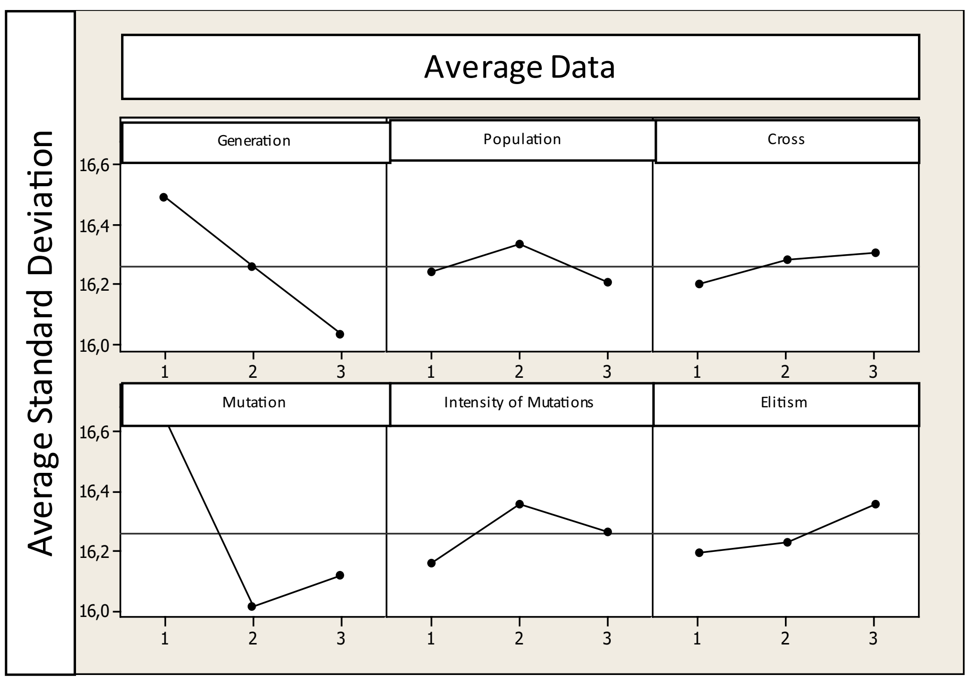



Fig. 11 Main effective graphs for average data

Fig. 12 Main effective graphs for standard deviation of data




of the elements that influences diversity in the development of the algorithm. The experimental design shows a percentage of 30%, which has a significant statistical difference with a rate of 10 and 50%. A rate of 30% indicates lower residual value, as evidenced in Figs. 11 and 12, reaffirming the theoretically proposed parameters.The intensity parameter reflects few positions mutation into the chromosome be modified by individual. In this way, a modification of a single gene is of lower residual value and marks a clear significant difference with the level of 2 and 4 modifications, as can be seen in Figs. 13, 14 and 15. Elitism is a mechanism in the evolutionary algorithms to conserve convergence and a good value avoids falling into local optima and guarantees orientation in the

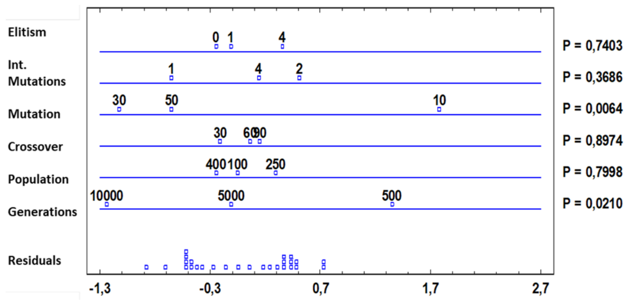



**Fig. 13** Graphical ANOVA for RISK RULA

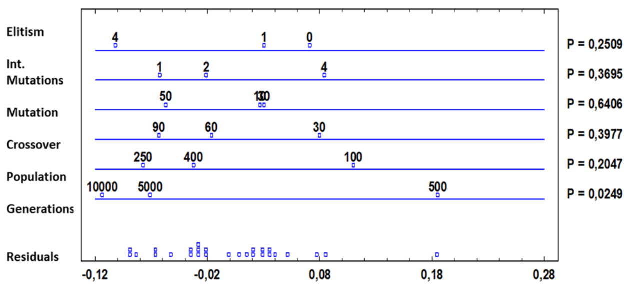



**Fig. 14** Graphical ANOVA for RISK NIOSH

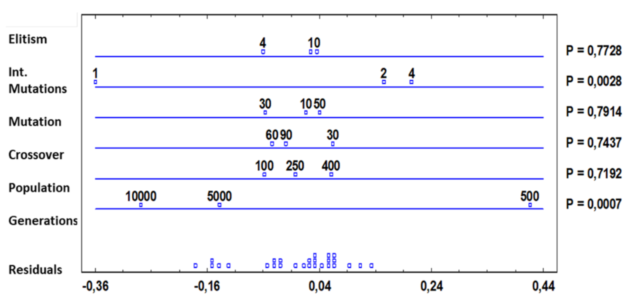



**Fig. 15** Graphical ANOVA for RISK OCRA

results. Under the experimental evidence, it is found that the intensity encourages adequate for the problem above an individual. This best individual is the one who directs the Pareto fronts within the algorithm. Then, the ANOVA chart for each of the objectives is reflected here.

In brief, the following features regarding generation and mutation of the proposed method are observed as follows:

RULA: It is evident that the factors of size of generations and mutation rate have significant effects within the problem.

NIOSH: It is evident that the only relevant factor is the size of the generations.

OCRA: It is evident that the influencing factors are the size of generations and the intensity of the mutations.

In a general context, individual experiments follow the principles of independence, constant variance and normality. Finally, the individual experiments confirm the effect of each of the levels considered within the factors of the experiment when the ergonomic risk variables of the problem are analyzed simultaneously.

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