A new methodological framework to schedule job assignments by considering human factors and workers' individual needs

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Abstract: One of the biggest management challenges for companies consists in including workers' features during production process decisions to obtain more realistic planning and scheduling outcomes. The increasing percentage of ageing operators in manufacturing areas, due to the postponement of retirement age, contributes to enhance the level of both physical and cognitive disparity among workers. Moreover, workers could present physical limitations that restrict the execution of certain tasks. Strong seasonality and the current spread of e-commerce lead companies to face sudden high peaks of market demand through constant operators' turnover. Consequently, workers are not equally skilled and work-related injuries can arise whether tasks are not performed correctly by an ergonomic viewpoint. In such a context, Industry 4.0 tools and real-time monitoring systems have gained higher attention since they can be adopted for training purpose and also such as data collector for every single worker in order to propose ad hoc job rotation solutions. In this paper, we propose a new methodological framework that integrates anthropometric and ergonomics measures during the scheduling decision process and defines all steps needed to define a worker-oriented and flexible scheduling of assembly tasks or job assignment. Each task is categorized in the framework according to three drivers: physical stress, ergonomic risk and execution time. According to the variability of each of them among workers, we propose a step-by-step procedure that can help practitioners to select the most suitable worker in executing each task aiming to reach flexible scheduling by an inclusive workforce.

Keywords: Methodological framework, Ergonomics, Operator 4.0, Mocap system, Occupational Safety

1. Introduction

In this particular period, as the world grapples with COVID-19, it is paramount to consider how the pandemic situation is going to change the market scenario for companies. Numerous enterprises, that previously were not used to cope with unpredictable peaks of demands, have been challenged to satisfy market needs with different volumes or additional services. Several specific business models found some benefits from the pandemic and their market area has increased. Moreover, several companies have experienced an increment in labor turnover and the need to fast train new and not expert workers, also by using virtual training sessions and fast methods to re-scheduling the jobs according to different scenarios. As a consequence, companies need to modify their level of flexibility by rapidly increasing the staffing level, to take the opportunities that derive from unpredictable events. On one hand, the human workforce remains the most flexible resource that allows pursuing this aim, but on the other hand, fast workforce turnover might lead to unwanted work-related consequences due to scarce attention to the initial training phase. According to the European Agency for Safety and Health at Work (EU-OSHA) and the International Labour Organization (ILO), workers musculoskeletal disorders (MSDs) impact 15% of all the work-related causes of years of life lost or lived with disabilities (DALY) both for the European countries and worldwide. Work-related injuries and illnesses produce a loss of 3.9% of all work-years globally and 3.3% of those in the EU, which correspond to 476 billion costs for EU countries (EU-OSHA, 2017a). In addition, according to EC 2017, the working-age population is expected to rise by 9.4% in the following 40 years. The ageing workforce phenomenon is causing significant production system changes since older employees are more exposed to MSDs and cognitive decline (Gonzalez and Morer, 2016). The new forthcoming ISO 314 on Ageing Society will soon support EU companies to provide inclusive working environments, able to support an active ageing involvement by developing flexible and individualized working plans.

The lack of knowledge about workforce characteristics, especially whenever workforce turnover is high, may lead to suboptimal job assignment, and consecutively to high probability to incur in health-related injuries and musculoskeletal disorders.

In this context, a high workforce's diversity needs to be managed within manufacturing fields, in terms of experience level, individual qualifications, age-related personal physical limitations and personal risk propensity. For this reason, just some practitioners and academics have started to include anthropometric and workers' physical and cognitive features during operational processes (Sgarbossa et al., 2020). The main reason is due to some practical limitations that exist. In fact, data must be properly collected and workers must be completely involved before the task assignment phase.

For this reason, in this work, a new methodological framework aims to integrate various aspects of employees that need to be considered in managerial decisions when job assignment is performed. In particular: Section 2 provides a literature review on job rotation scheduling problem (JRSP) analysing how previous works measured and integrated diversity aspects of the workforce in their model or approaches; Section 3 introduces the new step by step methodological framework with a complete description of the diversity aspects it considers. Finally, Section 4 and Section 5 explain the possible limitations of the implementation of the methodological framework and describes the benefits and their relevance to the industry, also providing some further research development.

2. Literature review

Amongst all the studies of the existing literature that propose solutions both for workload balancing and risk prevention, assembly line balancing and job rotation scheduling problem are the strategies of most interest. The first approach deals with task-to-station assignment in assembly lines while the second one defines worker-to-station assignment. An exhaustive survey about different algorithms and models adopted in literature, aiming to reduce and balance physical ergonomic risks by considering ergonomic aspects, is performed by Otto and Battaïa (2017). Concerning the studies that adopt a job rotation strategy, two macro-categories can be outlined: field studies and line-balancing studies. In particular, field studies focus their attention on the effectiveness of job rotation as an intervention strategy for worker MSDs risk management, in various workplaces (Yoon et al, 2016). Of the existing literature on this subject, the present study reviewed only works regarding ergonomic risks reduction generated by flexible work plans through job rotation strategies adoption, by including workforce diversity aspects. The research has been performed in the Scopus database comprising papers until the end of March 2021. The keywords adopted for the research are "job rotation" and "ergonomic" which results into 141 hits. The query considered only "Title, abstract and keywords" and has been limited to papers written in English and published in Journals or Conference proceedings.

2.1. Workforce diversity in job rotation scheduling

The adoption of job rotation programs started at the beginning of the 1980s such as a strategy to reduce costs and time and, in the meanwhile, mitigate continuous exposure to the same risk factors due to repetitive mansions (Padula et al., 2017). According to the survey proposed by Otto and Battaïa (2017), physical ergonomic risks are much more integrated into present mathematical models and algorithms in comparison to psychological and psychosocial ergonomic risk factors, which are mostly absent in the ergonomic measurement methods currently adopted by companies. Job rotation strategies aim to prevent the arise of possible injuries or diseases for workers that repetitively perform the same actions during the entire work shift, involving the same group of muscles and joints of the body. In literature, the problem that most suits this goal is called the ergonomic job rotation scheduling problem (EJRSP) and was firstly introduced by Carnahan et al. (2000). Its main goal is to balance ergonomic risks between operators by minimizing the workload of the worker most exposed to ergonomic risks.

Carnahan et al. (2000) presented a basic model to assign jobs, each one characterised by period-specific ergonomic risk points measured through the Job severity Index (JSI), to the workforce to mitigate ergonomic risks. Otto and Scholl, (2013) extended previous works on EJRSP by considering the possibility to include individual aspects for each worker, replacing general ergonomic points with dynamic and individual values (EJRSP-Ind). Workforce's individuality is considered in the research of Asensio-Cuesta et al. (2012) which defined a set of "vetoed assignments" to avoid incompatibilities between workers' capabilities and physical, mental and/or communication demand of jobs. The identification of the physical limit of the workforce is often carried out by the Occupational Health and Safety Department of each company, in charge of capturing and preventing the possible onset of accidents and occupational diseases. Recently, Diego-Mas (2020) includes medical advice in the developed algorithm to progress job rotation considering individual limitations.

Much more attention to the workforce profiling phase should be paid in the case of aged operators' presence in the manufacturing system. For this purpose, Boenzi et al. (2015) developed an age-related model for JRSP where age-performance profiles of operators are considered during job assignment for overall system performance maximization with an ergonomic perspective. Finally, Finco et al. (2019) investigated the effect of gender and age on threshold limits of fatigue exposure for heterogeneous workers and they considered the individual physical threshold limit in a job rotation model (Finco et al. 2020). Recently, Berti et al. (2021) proposed a new Dual-resource-Constrained Job Shop scheduling problem including ageing and fatigue.

2.2. Estimation of ergonomic risks

The analysis of workload and physical ergonomic risks depends both on job and workplace characteristics. The intensity, frequency and duration of the exertion can strongly impact the workload risk estimation. In the case of job rotation strategy, the most frequent adopted risk assessment methods are reported in Table 1. Amongst all of them, the Occupational Repetitive Action tool (OCRA) (Occhipinti, 1998) is adopted to evaluate jobs with a large number of repetitive actions. Such as example, Asensio-Cuesta et al. (2012) propose a genetic algorithm to balance the level of risk generated by high repetitive manual tasks with the OCRA ergonomic assessment method, to obtain job rotation schedules to prevent work-related injuries.

Rapid posture assessment methods perform faster evaluations of working posture. Recently, Digiesi et al. (2018) recognised that literature concerning JRSP presents a lack of studies that incorporate Rapid Upper Limb Assessment (RULA) (McAtamney & Corlett, 1993). For this reason, the authors proposed a mixed-integer programming approach to balance ergonomic risks in JRSP with RULA-based ergonomic constraints.

Furthermore, such as an extension of the upper body assessment, the Rapid Entire Body Assessment, (REBA) (Hignett and McAtamney, 2000) incorporates also legs risk evaluation. REBA method is adopted in Yoon et al. (2016) for the classification of each job, considering the average risk value performed by individual worker. In the presence of jobs where particular attention must be paid to lifting activities, the NIOSH lifting equation (Waters et al., 1993) is adopted to evaluate trunk risk assessment. Finally, with a particular focus on the automotive sector, the Ergonomic Assessment Work Sheet (EAWS) (Schaub et al., 2013) provides separated ergonomic risk assessment on the whole-body posture and awkward hand movements.

The novelty of our approach, in comparison to the existing literature, is related to the progression of a step-by-step framework that can evidence singular deficiency regarding risk tendency. In some prior works, job risk indexes were defined starting from the average score progressed by a group of workers. This approach is surely faster, but it can also penalize less skilled operators, from an ergonomic viewpoint, due to the scarce or absent training phase or by neglecting individual risk propensity for certain activities. On the other hand, with our approach, the main obstacle is related to the need of an accurate ergonomic risk assessment for each operator, which can be considered as much time and cost consuming. Moreover, another main problem of workforce diversity integration in mathematical models and methods consists in the difficulty to evaluate the differences among the workers involved in the manufacturing system.

For this reason, we aim to propose a new framework to involve workforce's perspectives and healthcare maintenance through ergonomic risk prevention.

Reference	Measurement of ergonomic risks	Values of ergonomic risk index determined with	Individual qualification profile	Individual physical limitations
Carnahan et al. (2000)	JSI-Diff	Randomly generated from task characteristic	-	✓
Asensio-Cuesta et al. (2012)	OCRA	On field observations and ergonomic analysis	-	✓
Otto and Scholl (2013)	EAWS	2 Random data sets, uniform distribution	-	✓
Mossa et al. (2016)	OCRA	On field observations, ergonomic risk analysis	✓	-
Yoon et al. (2016)	REBA	Ergonomic analysis, 2 video camcorders report	-	-
Song et al. (2016)	NIOSH	Job ergonomic assessment with NIOSH Lifting Equation	-	✓
Hochdörffer et al. (2018)	EAWS	Colour scheme ergonomic risk assessment per each workstation	✓	✓
Digiesi et al. (2018)	RULA	Ergonomic risk assessment and experts' evaluation of obtained results	✓	-
Sana et al. (2019)	NIOSH OCRA RULA	Ergonomic risks scores are available or can be estimated by author's assumption	✓	✓
Botti et al. (2020)	OCRA	Videotaping analysis, ergonomic specialists' risk assessment	✓	✓

Table 1: Ergonomic risks methods adopted in job rotation models

3. Method

3.1. New Methodological framework

The trend that can be outlined from the proposed literature review highlights that workers' diversity and heterogeneity aspects are currently a source of interest in studies on mathematical models and approaches that cope with ergonomic risks exposure in JRSP. The procedure proposed by this framework consists of the integration of different inputs derived from three main analyses: 1) Job analysis defines the characteristics of each job and the common risks related to its execution, also related to workstation design; 2) Workforce profiling analysis involves workers' perception and health state. It also considers the operator-job fitness according to individual preference and aptitude; 3) Ergo-time analysis is progressed with the inertial Motion Capture (MOCAP) system to assess ergonomic postural risk and also physical effort from heart rate monitoring device. This analysis also provides job execution time and helps to determine the experience level of each operator.

The main objective of this framework concerns the individualisation of the different quantifiable aspects related to the personal profile of the workforce to perform job scheduling and workload balancing decision in several workplaces. This new methodology aims to describe data integration process, starting from initial data acquisition phase followed by the ergonomic risks quantification and concluding with managerial insight coming from EJRSP solution approach. The procedure consists of 8 steps to

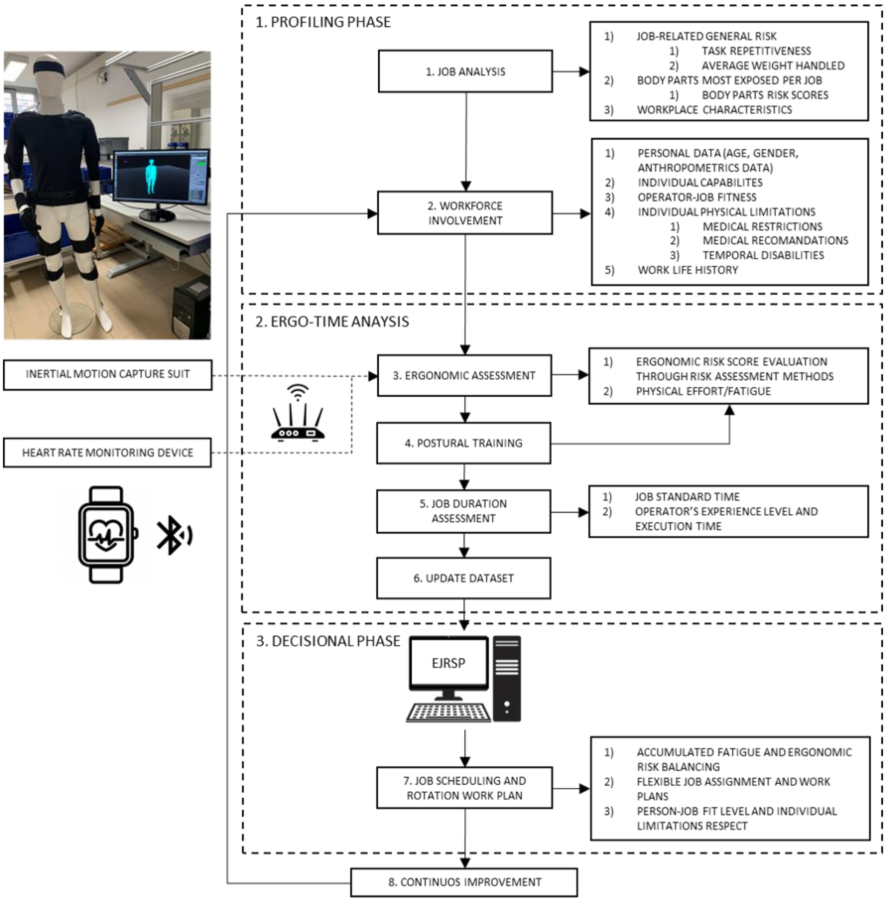

Figure 1: Methodological framework for assessing a worker-oriented ergonomic job rotation scheduling problem

be executed some in parallel and some in sequence to finally obtain an effective worker-oriented job rotation and job assignment solution.

3.2. Profiling phase (Step 1 and Step 2)

The profiling phase deals with the initial workforce data collection. In this phase, workers are involved to collect, for each job, some insights about the job description and physical attitude. Moreover, this phase aims to create updated profiles of each job and operator. Step 1 reports an exhaustive description of the job depending on its characteristics, like the repetitiveness of actions or the part of the body that are more exposed to musculoskeletal risk. Furthermore, Step 2 involves the operator's opinion and perception about the personal health condition and job assignment preference (e.g., which work plan fits most operator's capabilities in terms of competence, skills and attitude). Another important aspect is related to the workforce's developed abilities. For this reason, skills are collected in the matrix where a binary parameter specifies whether a worker can perform a particular job or not. In phase 2, the subjective workload assessment is measured according to the NASA Task Load Index (Hart and Staveland, 1988). In this way, also the mental demand is measured as well as the frustration in performing such kind of tasks. Moreover, starting from the workforce's viewpoint, it is also possible to highlight shared opinion and evaluation on part of the body, involved in job completion, most exposed to risk. Workers can provide subjective feedback according to the Borg C10 scale and is such a way they are able to also provide a quick measure of the physical and muscular fatigue (Morishita et al., 2013). However, in this case, scores assigned to each task are influenced both by workstation design and also by the sequence of activities to be performed in job execution and for this reason different scenario are created.

The most innovative aspect about the profiling phase concerns the collection of past, temporary or permanent physical limitations of workers and operators' perceptions to perform improved values of job-operator fitness (Botti et al., 2020). In fact, it has been demonstrated that each worker's life history has certainly impact on future work ability, in particular for older workers (Fischer and Martinez, 2013). In such a way, job rotation can better fit the worker's physical and cognitive level. For this reason, the integration of data coming from workforce's involvement phase and quantitative and qualitative information collected in this framework, represent our novelty and it is useful in completing the dataset with all data necessary as input for the model to solve EJRSP and to find optimal solutions, depending on company objectives and desired performance.

In addition to the job-operator fitness score, physical restrictions and possible chronic diseases for each part of the body of each worker must be collected. These data are collected from occupational medicine practitioners, but also directly from the workforce's opinions through questionnaire and self-evaluation approaches, developed to capture in advance possible incoming musculoskeletal disorders or to avoid an aggravation of the global health status. These methods can help the company to judge the actual health condition of the workforce and the proneness to permanent or temporal injuries. This information becomes useful to avoid job assignment that can foster consequences such as workforce absenteeism and the relative arising costs.

3.3. Ergo-time analysis (from Step 3 to Step 6)

Thanks to the quick technology advancement fostered by the fourth industrial revolution, which bases its principles on data collection, new devices are continuously introduced in the market at accessible and more affordable prices. To perform a precise evaluation of working posture and to define relative postural risks during work progression, smart technologies like MOCAP systems are currently adopted also in the manufacturing field. The integration of these technologies allows us to save time and costs during posture assessment during the worker's training phase. The amount of data needed to perform ergonomic risks evaluation for each operator are collected during the initial postural assessment. The execution of each job is performed wearing a MOCAP system which consist in several IMUs placed in the whole body. Data are collected and processed by a software platform able to calculate in real-time the ergonomic risks through the most suitable international indicator for the job analysed. Moreover, direct feedbacks to worker are given since they can see the monitor in front of their working place and easily understand which part of body is majorly stressed by an ergonomic point of view.

The ergo-time analysis starts with an ergonomic assessment (Step 3) to evaluate the initial level of ergonomic experience of each worker. In fact, due to the strong turnover effect, new employees can perform the same job in several manners, depending on their attitude and experience level. This step assesses whether the worker needs to perform postural training with real-time feedback intervention and some practitioners' suggestions, aiming to educate the operator to behave with proper movements to reduce postural ergonomic risk. We assume that after the postural training session (Step 4) job risk score is reduced to the lowest level, thanks to the training activity performed. Furthermore, in this phase, the amount of accumulated physical fatigue and stress for each worker can be monitored for further analysis (e.g., in the form of energy expenditure consumption, heart rate, oxygen consumption). Heart rate monitoring systems are nowadays easily affordable and reliable devices to monitor the worker's heart rate. For example, they can be adopted to calculate energy expenditure for individuals (Li, Deurenberg, and Hautvast, 1993). In such a way, postural risk can be smothered together with physical effort in job scheduling activity. This information reflects the fact that different operators can process the same job progressing different amount of fatigue, based on the age and the physical condition of the worker. In this phase, ergonomic data are collected for each task, each worker and each part of the body involved. Since threshold limit on the postures changes according to the type of activity they are performing, in this phase ergonomic experts are involved. Step 4 does not collect data about performances. For this reason, Step 5 carries out a job duration assessment to provide information about the experience level of every worker in comparison to the standard time of job completion. This information can be displayed both such as the real job duration per each operator or by the incidence of experience and worker's ability in comparison to the standard time of job completion. Once the workforce's experience level, job duration, postural risk score and physical effort values have been collected, the workforce dataset is updated (Step 6) with all the information coming from the profiling phase (Step 1 and Step 2) and from the ergo-time analysis (from Step 3 to Step 5).

3.4. Decisional phase and continuous improvement (Step 7 and Step 8)

Once the data acquisition process is completed and ergonomic indicators, attesting the work-related risk proneness for each worker, are finally progressed, the integration phase (Step 7) in the EJRSP can be initialised. In our case, the proposed EJRSP model is bi-objective, where productivity must be maximized by minimizing the ergonomic risk of each worker. According to the type of activity the appropriate ergonomic index is selected, for example, in picking activities NIOSH is selected. Moreover, additional constraints are included in the model aiming to consider physical and cognitive limits of each worker. In particular, the constraint related to the fatigue, as well as that one related the mental demand, are always included.

Since data required in the model can be collected easily and in a faster way, the model can be applied each time new workers are involved as well as new tasks are performed. Our approach can ensure a balanced workload to the workforce depending on the individual physical characteristics and flexible work plans to smooth the fatigue accumulated and the risk exposure. Physical limitations, collected and constantly updated with continuous improvement phase (Step 8), will ensure feasible job rotation schedules by the restrictions imposed to operators that cannot perform some activities, avoiding the arise of physical impairments and musculoskeletal disorders.

4. Relevance to industry

The framework presented in this work should be considered as a starting point for individual and personal flexible and dynamically generated working plans and job rotation schedules. Other operator's features can be further added to the framework, like psychosocial and psychological characteristics of the workforce as well as the learning and forgetting effects. However, as stated in Section 2.1, physical aspects are nowadays much more integrated into the current measurements progressed by companies because data are directly collectable and exploitable. For this reason, this work aims to exploit the initial postural assessment and, eventually, the training phase to collect data and further information on the workforce to obtain the most suitable work plan for everyone depending on physical conditions and job-operation fit.

The information in the system needs to be constantly updated concerning the ergonomic level reached by the workforce with the experience matured in the working field. For this reason, the training process is not only progressed once, at the beginning of operator's work experience but also repeated (Step 8), since the profile of operators can differ in terms of gained experience level or capabilities, but also for health status deterioration or due to high workforce turnover. According to current legislation, occupational medicine carries out medical examinations on an annual basis. This time window can be too wide to pursue risk detection on the workforce on a wide range. For this reason, constant workforce assessment sessions can support risk evaluation and investigation both on operators' viewpoint and on workplace design. The solutions obtained from the EJRSP model, starting with all the information collected in the previous framework steps, must respect all the ergonomic and physical constraints outlined during the framework. From this set of solutions, managers can determine which one fits best the current objectives of the company. Whenever critical or unexpected periods arise, ergonomic aspects can be considered momentarily secondary in comparison to daily production performance.

The strongest weakness of this framework resides in one of its major strength: workforce viewpoint integration. The high reliance on qualitative measurements, collected in the workforce integration phase, provides additional information to perform flexible and individual work plans based on operators' health status. On the other hand, qualitative measurements, as well as ergonomic self-assessments, are subjected to personal evaluation, which could lead to imprecise and precautionary assessments of the self-condition. To mitigate this problem, historical data of past operators' work plans can be considered to avoid the risk of repetitive assignment to jobs that could urge the same parts of the body, allowing to naturally spread the stress in a uniform condition.

Furthermore, data collection in manufacturing fields is highly restricted from privacy rights. Workers' rejection of being profiled trough their personal data might leads the framework to neglect a part of the profiling phase, reducing work plans individualisation effect and benefits. From a practical viewpoint, the implementation of this framework starts with whom most perceives positive benefits from the individualisation of personal work plan and later spread among the rest of workforce. Such as other successful strategies, this framework pursues a bottom-up approach, driven by the forecasted benefits of personal and human-oriented job scheduling activity.

5. Conclusions

There is conflicting evidence about how the workforce's diversity management, in terms of age, gender and personality, can lead to increase workers' commitment or might foster conflicts that can damage the cohesiveness within a group (Bassett-Jones, 2005). Sometimes, the workforce is intentionally assumed homogeneous in terms of efficiency and quality (e.g., concerning operators' gender or capabilities) to respect current regulations and territorial anti-discrimination laws, as reported both in Otto and Scholl, (2013) and in Hochdörffer et al., (2018).

The choice to consider a heterogeneous workforce concerning gender, age and capabilities, represents a challenge to the management that can embrace diversity aspects such as a risky business to enhance overall company performance. Moreover, as defined in Sgarbossa et al. (2020) considering human factors leads to more reliable, efficient and safe workplaces. The novelty of the new methodological framework proposed in this paper is related to the possibility to rapidly profile each worker considering personal features for the execution of jobs dependently on the current level of qualification of each worker and on the health status in which the operator behaves. The integration of ergonomic features together with fatigue workload and job-operator fitness function represents an overall analysis of the health condition that allows monitoring and evaluating the risk related to the operator's wellbeing during job execution.

Future research on this framework will evaluate the feasible job rotation schedules obtained as output from the optimal model or from heuristic approaches adopted to solve EJRSP. The impact that each quantitative and qualitative variable considered in this framework on final results will be evaluated with various scenario analyses based on real-case application.

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