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Design of job rotation schedules managing the exposure to age-related risk factors

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Abstract: Repetitive work involving manual handling of low loads at high frequency frequently leads to deteriorated posture and movement co-ordination, causing occupational diseases as the most common work-related musculoskeletal disorders (WMSD). Older workers are more predisposed to develop WMSD than younger workers because of their decreased functional capacity. The susceptibility for developing WMSD or injury is related to the difference between the demands of work and the worker's ability to perform a demanded activity.

Current law requires the adoption of risk control measures to eliminate or reduce the exposure of workers to health and safety risk factors. When repetitive handling is unavoidable, job rotation is an effective risk control method to minimize the exposure of workers to the risks of repetitive movements and awkward postures.

This paper presents a mathematical model for the design of activity schedules for aged workers exposed to the risk of repetitive work. The aim is to define the scheduling of the work activities for each worker from a bi-objective perspective. The first objective is to reduce the ergonomic risk of repetitive work by varying the required movements and their intensity during the work shift. The second objective charges the workers with the activities that better fit their skills and abilities. Finally, the proposed model includes the ergonomic risk assessment of each scheduling solution, ensuring an acceptable exposure of the workers to the risk of repetitive work.

Keywords: Job and activity scheduling; Modelling and decision making in complex systems; Intelligent decision support systems in manufacturing.

1. INTRODUCTION

The workforce aging phenomenon and the inverted population pyramid are the cause of important changes to society and industry (Gonzalez & Morer 2016). These changes comprise the inclusion of older workers in industrial processes and the challenge to adapt the work environment accordingly to their needs and capacities. The greater involvement of older workers is one of the main pillar of the Europe 2020 Strategy (European Commission, 2010).

The daily management should consider age related factors in work organization and define individual work tasks, so that everybody, regardless of age, feels empowered and motivated in reaching personal and corporate goals (Čiutienė, R., & Railaitė 2014). As a consequence, the productivity of various age groups is related to the ability of the management to provide proper working conditions and include workers' age management practices.

Older workers are more predisposed to develop work-related musculoskeletal disorders (WMSD) than younger workers because of their decreased abilities and functional capacity (McDonald & Harder, 2004). Furthermore, age is not an independent risk factor for WMSD. Repetitive activities including manual material handling at high frequency involve a significant stress of the upper-limbs, mainly affecting hand and wrist, but even shoulders and low back. Consequently, the workers are exposed to high ergonomic risk, which frequently results in WMSDs, e.g. the most common tendonitis, low back pain and carpal tunnel syndrome. Previous studies have shown that working activities involving repetitive movements of the upper-limbs and frequent manual handling operations increase the boredom of workers while reducing their performance, satisfaction and safety level (Fonseca, Loureiro, & Arezes, 2013). Thus, WMSDs lead to significant loss of productivity due to higher absenteeism and injures rates. Work-related MSDs are the most popular occupational health problem in the European Union (Fonseca, Loureiro, & Arezes, 2013). Such diseases cause more than 30% of the total annual lost-time and are considered one of the most expensive occupational issue (Xu, Ko, Cochran, & Jung, 2012).

Recent researches have investigated the potential age-related changes to consider during the design of workplaces (Boenzi et al., 2015; Cardoso, Keates, & Clarkson, 2005; Gonzalez & Morer, 2016; Hitchcock et al., 2001)

This paper introduces a mathematical model for the design of activity schedules for aged workers exposed to the risk of repetitive work. The aim is to reduce the risk of MSDs due to manual handling activities of low loads at high frequency, from a bi-objective perspective. The first goal is to enhance the ergonomic benefits of job rotation by varying the intensity of movements. The second goal is to design job rotation schedules improving the person-job fit, i.e. assigning the workers to the tasks that better fit their skills and capacities. Each scheduling solution ensures acceptable exposure of workers to the risk of repetitive movement, as required by current law and international standards (ISO 11228-3).

The following Section 2 introduces the methods adopted to address the job rotation scheduling problem. Section 3 briefly explains the expected results of the application of the proposed bi-objective mathematical model to a real case study. Finally, conclusions and future developments of this research are in Section 4.

2. METHOD

This Section introduces the person-job fit problem and the adopted assumptions for the mathematical model. The methods and the model in this paper include and improve the previous research by Botti et al. (2014) on the design of job rotation schedules for repetitive tasks in assembly lines. While the previous research was based on a generic working population, this paper focuses on the integration of an aged workforce and the related risk factors during the design of job rotation schedules. In particular, the mathematical model includes the investigation of age-related risk factors, as visual acuity, responsiveness and muscular tone.

2.1 The person-job fit problem

The optimal assignment of the workers to the workstations is accomplished by considering the different competencies and physical characteristics of the working population. Each worker w is characterized by a set of personal skills and ability competencies, besides each workstation s requires different abilities to perform the required task. The person-job fit is defined as the compatibility between individuals and the job or tasks that they perform (Schyns, 2007). The higher the person-job fit, the higher the task performance is. The aim is to assign the workers to the workstation that better fit their skills and competencies to improve the productivity of the whole system.

In the following, 43 items define each workstation and the requirements to perform the demanded tasks. Such items belong to five categories, similarly to the sets defined by Diego-Mas et al. (2009). Table 1 shows the reference items for the considered tasks.

Table 1. Items to define the person-job fit

Category	Item
Movements	Arm abduction, Arm extension, Arm flexion, Elbow flexion, Neck extension, Neck flexion, Neck turning, Neck lateralization, Pinching with the fingers, Trunk extension, Trunk flexion, Trunk rotation.
Functional capacities and senses	Lifting power, Push power, Pull power, Standing, Walking, Sitting, Exerting force while standing, Exerting force in movement, Visual acuity at long distances, Visual acuity at short distances, Hearing, Ability to perform precision work, Flexibility and reaching, Grasping and holding, Bending, Balance, Responsiveness (reaction time), Aerobic capacity, Touch and sensitivity perception.
Competencies and technical skills	Computing capacity, Using assembly tools, Driving forklift truck, Writing, Using keyboard, Using mouse, Previous experiences in the same task.
Relational skills and mental capacities	Reasoning, Responsibility, Taking complex decisions, Initiative/autonomy, Previous contacts with experts.

The first category encompasses each muscular movement, m, of the upper limbs and trunk to perform the required task, while category "Functional capacities and senses" refers to physical capacities and senses, f, as standing and sitting or hearing and touch. The last two sets of items assess the desired technical skills, c , together with the relational requirements, r, demanded by the workstation.

The content of each activity is analyzed according to the scoring system for the workstation assessment in Table 2.

Table 2. Workstation assessment: scores for the items of each category

Movements		Physical skills, competencies and technical skills, relational skills	
Frequency of movements / minute	*Score*	*Skill requirement to perform the task*	*Score*
Very high (>30)	6	Highly required	6
High (15-30)	3	Required with limitations	3
Low (5-15)	2	Very limited	2

Very low (0-5)	1	Not necessary	1

Scores range from 1 to 6, increasing when both the frequency of movements and the skill requirements are high.

The same categories used for the workstation assessment describe the capacity of the worker to perform movements, the functional capacities, competences and relational skills. Table 3 describes the scoring system adopted for the worker assessment.

Table 3. Worker assessment: scores for the items of each category

Movements		Physical skills, competencies and technical skills, relational skills	
Frequency of movements / minute	*Score*	*Skill requirement to perform the task*	*Score*
Very high (>30)	6	Normal	6
High (15-30)	3	Low limitation	3
Low (5-15)	2	High limitation	2
Very low (0-5)	1	Almost unable	1

For the worker assessment, scores range from 1 to 8, increasing when capacity and skill requirements are high. The threshold limit value of 30 movements/minute refers to the constant of frequency, k_f , from the ISO 11228-3. Specifically, when the job activity meets all the ergonomic requirements in terms of applied force, posture, recovery, duration of the task and environmental conditions, the worker performing 30 actions per minute is not exposed to the risk of biomechanical overload of the upper limbs due to repetitive movements.

The introduced scoring systems allow the assessment of the compatibility between workers and workstations requiring specific tasks. Furthermore, the productivity is ensured when the workstation requirements are not over the worker's capacities. The following Equation (1) introduces the worker efficiency, E_{ws}, to perform the task required in workstation s.

$$E_{ws} = \sum_m \left|\frac{\alpha_{mw}}{\alpha'_{ms}}-1\right| \cdot A + \sum_f \left|\frac{\beta_{fw}}{\beta'_{fs}}-1\right| \cdot B + \sum_c \left|\frac{\gamma_{cw}}{\gamma'_{cs}}-1\right| \cdot \Gamma + \sum_r \left|\frac{\delta_{rw}}{\delta'_{rs}}-1\right| \cdot \Delta \quad (1)$$

E_{ws} is the ratio between the worker w capacity to the demand level of workstation s, considering each category of items. Particularly, α_{ms}, β_{fs}, γ_{cs}, δ_{rs} are the workstation scores and α'_{mw}, β'_{fw}, γ'_{cw}, δ'_{rw} are the worker scores, for each item. A set of category coefficients, A , B , Γ , Δ , weights the importance of each group of items to the accomplishment of the task.

Section 2.3 introduces the mathematical model for the design of ergonomic job rotation schedules, according to the introduced score systems (Table 2 and Table 3). The higher the value of E_{ws}, the more worker w fits the requirements of workstation s. Before presenting the model, the following Section 2.2 introduces the adopted assumptions.

2.2 Operation assumptions

The ILP model for the design of job rotation schedules is subject to the following assumptions:

- each worker is able to perform all the demanded movement, at different ability levels. Furthermore, no additional training is required to perform each task;
- the workstations admit all the workers. No additional time or interruptions are necessary for the set up of the workspaces;
- the rotation between the different workstations causes no interruptions in the working process since workspaces are located in the same area.

Such conditions define the operation assumptions used within the following ILP model.

2.3 The mathematical model

The ILP model looks for optimal ergonomic job rotation schedules. The model goal is to maximize the worker efficiency levels, ensuring the ergonomic requirements of manual handling of low loads at high frequency. Each schedule solution includes the ergonomic risk assessment through OCRA method to meet the requirements of the Italian occupational health and safety law in force (Ministero del Lavoro e delle Politiche Sociali, 2008). Consequently, each scheduling solution ensures an acceptable level of exposure to the risk of repetitive movements.

The model inputs deal with the characteristics of both workers and workstations. The following Table 4 resumes the notations for the model formulation.

Table 4. Indices and parameters for the ILP model

Indices	
w	Worker index, $w = 1, \dots, W$
s	Workstation index, $s = 1, \dots, S$
t	Time slot index, $t = 1, \dots, T$
m	Movement index, $m = 1, \dots, M$
f	Functional capacity and sense index, $f = 1, \dots, F$
c	Competences and technical skill index, $c = 1, \dots, C$
r	Relational skill index, $r = 1, \dots, R$
l	Upper limb index, $l = 1, 2$
Parameters	
α_{ms}	Movement m score for workstation s
α'_{mw}	Worker w capacity score to accomplish movement m
A	Movements coefficient [%]
β_{fs}	Functional capacity f score for workstation s
β'_{fw}	Functional capacity and sense f score for worker w
B	Functional capacities coefficient [%]
γ_{cs}	Competence and technical skill c score for workstation s
γ'_{cw}	Competence and technical skill c score for worker w

Γ	Competence and technical skills coefficient [%]
δ_{rs}	Relational skill and mental capacity r score for workstation s
δ'_{rw}	Relational skill and mental capacity r score for worker w
Δ	Relational skills and mental capacities coefficient [%]
d	Duration of the rotation [min]
n	Minimum number of workers for each workstation s

The parameters for the ILP model in Table 4 stem from the analysis of both worker and workstations. The following Table 5 shows the OCRA parameters for the ergonomic risk assessment (ISO 11228-3, 2007).

Table 5. OCRA parameters for the ILP model (ISO 11228-3, 2007)

OCRA Parameters	
$n_{TC,w,l}$	Number of technical actions in a cycle, for the upper limb l of worker w
t_C	Cycle time [s]
k_f	Constant of frequency of technical actions per minute
$F_{M,w,l}$	Force multiplier, for the upper limb l of worker w
$P_{M,w,l}$	Posture multiplier, for the upper limb l of worker w
$R_{eM,w,l}$	Repetitiveness multiplier, for the upper limb l of worker w
$A_{M,w,l}$	Additional multiplier, for the upper limb l of worker w
R_{cM}	Recovery period multiplier
t_M	Duration multiplier

The work system is characterized by a set of w workers who rotate between s workstations, for $T-1$ times. Each possible position of a worker within the work system, during a defined time slot, is identified by the (w, t, s) codification.

The ILP model decisional variables define the position of each worker within the work system, during the work shift. Analytically,

$$Z_{s,t}^{w} = \begin{cases} 1, & \text{if worker w is assigned to workstation s during time period t} \\ 0, & \text{otherwise} \end{cases} \quad \forall\, w, t, s \qquad (2)$$

The model objective functions are as follows (see Equations 3 and 4).

$$\varphi = -\left(\sum_m \left|\frac{\alpha_{mw}}{\alpha'_{ms}} - 1\right| \cdot A + \sum_f \left|\frac{\beta_{fw}}{\beta'_{fs}} - 1\right| \cdot B + \sum_c \left|\frac{\gamma_{cw}}{\gamma'_{cs}} - 1\right| \cdot \Gamma + \sum_r \left|\frac{\delta_{rw}}{\delta'_{rs}} - 1\right| \cdot \Delta\right)$$
(3)

$$\chi = \sum_{w=1}^{W} \sum_{t=2}^{T} \sum_{m=1}^{M} \left| \sum_{s=1}^{S} \alpha_{ms} \cdot Z_{s,t}^{w} - \sum_{s=1}^{S} \alpha_{ms} \cdot Z_{s,t-1}^{w} \right| \qquad (4)$$

The first objective function, φ, is from the previous Equation (1). φ computes the overall efficiency of the work system. Particularly, Equation (3) is the sum of the worker efficiencies during the time shift. Given the score system in Section 2.1, the higher such a φ, the higher the overall efficiency level is.

The second objective function, χ, analyzes the job rotation schedules from an ergonomic perspective. The succession of high and low demand activities supports the recovery of the workers, i.e. χ is a measure of the movement turnover of the work system. Such an objective function includes the absolute difference of movement demands between two consecutive time slots, for each worker, w, and time slot, t. Specifically, χ is the sum of such absolute differences. The higher the objective function χ, the higher the ergonomic benefits for workers are.

In the following the proposed ILP model formulation.

$$\max\{\varphi, \chi\} \qquad (5)$$

$$\sum_{s=1}^{S} Z_{s,t}^{w} = 1 \qquad \forall\, w, t \qquad (6)$$

$$\sum_{w=1}^{W} Z_{s,t}^{w} \geq n \qquad \forall\, s, t \qquad (7)$$

$$\sum_{s=1}^{S} \alpha \cdot Z_{s,t}^{w} + \sum_{s=1}^{S} \alpha \cdot Z_{s,t-1}^{w} < 12 \qquad \forall\, w, t, m \qquad (8)$$

$$\frac{\sum_{s=1}^{S}\left[\frac{n_{TC} \cdot 60}{t_C} \cdot \sum_{t=1}^{T}\left(Z_{s,t}^{w} \cdot d\right)\right]}{\sum_{s=1}^{S}\sum_{t=1}^{T}\left[Z_{s,t}^{w} \cdot \left(k_f \cdot F_{M,w,l} \cdot P_{M,w,l} \cdot R_{eM,w,l} \cdot A_{M,w,l} \cdot d\right)\right] \cdot R_{cM} \cdot t_M} \leq 2.2 \qquad \forall w, l \qquad (9)$$

$$A + B + \Gamma + \Delta = 1 \qquad (10)$$

$$Z_{s,t}^{w} \text{ binary} \qquad \forall w, t, s \qquad (11)$$

Equation (5) maximizes the introduced objective functions, while Equation (6) limits each worker to be occupied in one workstation at a time slot. Equation (7) ensures the minimum number of workers for each workstation and time slot, while Equation (8) ensures the alternation between two high demanding tasks, aiming to reduce the prolonged exposure to the risk of strenuous tasks for aged workers.

Equation (9) stems from the International Standard ISO 1122-3 and restricts the OCRA index value to a threshold limit value for each worker and limb (ISO 11228-3, 2007). Equation (10) ensures the proper distribution of the weighting coefficients for movements and capacities. Finally Equation (11) gives consistence to binary variables. The proposed model size is of $W \cdot T \cdot S$ binary variables and $W \cdot T \cdot (1 + M + S) + S \cdot T + W \cdot L$ constraints.

3. EXPECTED RESULTS

The proposed mathematical model has not been tested on a real case study yet. The bi-objective structure suggests that different solutions of the model will represent good scheduling alternatives in a bi-objective perspective. Two solutions will lead to the optimum values for the objective functions. Then, solutions leading to objective function values between such two optimum will be good scheduling alternatives. The choice of the preferred scheduling solution will be up to practitioners, depending on the predominant desired objective.

Each scheduling solution will ensure that the OCRA index value for each worker is lower than the threshold limit value defined by the ISO 11228-3.

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

Demographic aging trends will have impact on the composition of the upcoming workforce. The aging workforce phenomenon and the need to satisfy the requirements of the increasing number of older workers are challenges for employers and companies.

This research focuses on the changes associated with the inclusion of the characteristics of an older workforce in work activity scheduling. The aim is to study the impact of demographic changes on industrial systems. At this stage, a bi-objective mathematical model has been developed to address researchers and practitioners through the design of activity schedules for aged workers exposed to the risk of repetitive work. The first objective was to reduce the ergonomic risk of repetitive work by varying the required movements and their intensity during the work shift. The second objective was to charge the workers with the activities that better fit their capacities, abilities and skills.

The forthcoming step of this research will include the test of the proposed mathematical model with different case studies on assembly lines in manufacturing industry. Specifically, the bi-objective mathematical model will be solved through the bi-objective optimization method by Messac et al. (2003). The resulting Pareto frontier will show different scheduling alternatives. The choice of the optimal job rotation schedule among the alternative solutions of the bi-objective optimization is up to practitioners, based on the most desired objective.

The aim will be to prove the effectiveness of the model and to investigate the overall efficiency of the work system with the rotation of aged workers among different workstations. Finally, a different ergonomic risk assessment method will be included in the model, aiming to compare the results of the model with the previous obtained.

REFERENCES

Boenzi, F., Digiesi, S., Mossa, G., Mummolo, G., & Romano, V. A. (2015). Modelling workforce aging in job rotation problems. *IFAC-PapersOnLine, 48*(3), 604-609. doi:http://dx.doi.org/10.1016/j.ifacol.2015.06.148

Botti, L., Gamberi, M., Manzini, R., Mora, C., & Regattieri, A. (2014). A bi-objective optimization model for work activity scheduling of workers exposed to ergonomic risk. *Proceedings of the XIX Summer School "Francesco Turco",* Senigallia, Italy. *, Proceedings of the XIX Summer School "Francesco Turco".*

Cardoso, C., Keates, S., & Clarkson, P. J. (2005). *Design for inclusivity: Assessing the accessibility of everyday products*. Cambridge: University of Cambridge.

Čiutienė, R., & Railaitė, R. (2014). Challenges of managing an ageing workforce. *Procedia - Social and Behavioral Sciences, 156*, 69-73. doi:http://dx.doi.org/10.1016/j.sbspro.2014.11.121

Diego-Mas, J.A., Asensio-Cuesta, S., Sanchez-Romero, M.A. & Artacho-Ramirez, M.A. (2009). A multi-criteria genetic algorithm for the generation of job rotation schedules, *International Journal of Industrial Ergonomics, 39*(1), 23-33.

European Commission. (2010). *Europe 2020: A strategy for smart, sustainable and inclusive growth* No. 52010DC2020). Brussels: EUR-Lex.

Fonseca, H., Loureiro, I. F., & Arezes, P. (2013). Development of a job rotation scheme to reduce musculoskeletal disorders: A case study. In G. Perestrelo (Ed.), *Occupational safety and hygiene* (pp. 351-356) CRC Press.

Gonzalez, I., & Morer, P. (2016). Ergonomics for the inclusion of older workers in the knowledge workforce and a guidance tool for designers. *Applied Ergonomics, 53, Part A*, 131-142.

Hitchcock, D. R., Lockyer, S., Cook, S., & Quigley, C. (2001). Third age usability and safety—an ergonomics contribution to design. *International Journal of Human-Computer Studies, 55*(4), 635-643. doi:http://dx.doi.org/10.1006/ijhc.2001.0484

ISO 11228-3 2007, *System of standards for labor safety. Ergonomics. Manual handling. Part 3. Handling of low loads at high frequency.*

McDonald, T., & Harder, H. G. (2004). Older workers and disability management. *International Journal of International Disability Research Centre on Social & Economic Innovation. Special Issue on the Ageing Workforce, 3*(3), 1-8.

Messac, A., Ismail Yahaya, A., & Mattson, C. A. (2003). The normalized normal constraint method for generating the pareto frontier. *Structural and Multidisciplinary Optimization, 25*(2), 86-98. doi:10.1007/s00158-002-0276-1

Ministero del Lavoro e delle Politiche Sociali 2008, *D.lgs 9 aprile 2008, n.81 Testo unico sulla salute e sicurezza sul lavoro*.Schyns, B. (2007). In Rogelberg S. (Ed.), *Implicit theory of leadership*. Thousand Oaks, CA: SAGE Publications, Inc.

System of Standards for Labor Safety. Ergonomics. Manual Handling. Part 3. Handling of Low Loads at High Frequency. (2007).

Xu, Z., Ko, J., Cochran, D., & Jung, M. (2012). Design of assembly lines with the concurrent consideration of productivity and upper extremity musculoskeletal disorders using linear models. *Computers & Industrial Engineering, 62*(2), 431-441.