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A RULA-Based Optimization Model for Workers' Assignment to an Assembly Line

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Abstract

Performance of assembly lines require meeting conflictual goals: a high production rate and a high level of flexibility. Flexibility is often provided by human dexterity and the cognitive capabilities of the workforce. In the case of repetitive manual tasks, workers are exposed to the risk of musculoskeletal disorders (MSDs). In these contexts, a high production rate leads to high physical workload, and job rotation is adopted in order to reduce the ergonomic risk. The problem is of particular interest in the view of the workforce aging, a social European phenomenon which is also affecting production systems performance.
Designing and scheduling of human-based assembly systems require a joint evaluation of production system performance and a good balancing of MSDs risk among workers.
The authors propose a mixed integer non linear programming model allowing for the balancing of MSDs risk while meeting production rate of an assembly line. Risk and its acceptability are evaluated using the RULA method (Rapid Upper Limb Assessment), widely recognized as an effective tool for the risk assessment of Upper Limb Work related MSDs (UL-WMSDs). Different workers' performance due to their respective training levels / skills and age is considered in the problem formulation.
Results show the model's capacity to identify optimal job rotation schedules jointly achieving productivity and ergonomic risk goals. Performances of the solutions obtained improve as workforce flexibility increases.

Key words: *Human Workload Balancing; Mathematical Programming; RULA; UL-WMSDs*

1. INTRODUCTION

In a context where the market paradigms radically change in order to meet competition on global markets and to ensure long-term success, the companies need to adapt to shorter delivery times, increasing product variability and high market volatility. One of the major cornerstones to meet these challenges is the implementation of models based on the digital information and the communication technologies in order to introduce a dynamic production environment allowing to ensure competitiveness and overall well being of workers.

Currently there is a digital transformation in progress that covers crosscutting aspects of the industrial activities under economical, technological, social, and well being perspective. A technological development to fit into the so-called Fourth Industrial Revolution finalized to improving the performance of the process and of the product ensuring the psychophysical wellbeing of worker.

The main goal of Industry 4.0 is to "rethink" factories through the use of digital, to reconsider the design approach and to monitor the production process in real time. In particular in assembly system, the application of Digital Manufacturing leads to a series of steps forward, especially for the ergonomic aspect in relation to the work areas and equipment used by a worker.

Work-related musculoskeletal disorders (WMSDs) cover a broad range of health problems associated with ergonomic aspects due to repetitive and strenuous tasks. These health problems include discomfort, minor aches and pains, and more serious medical conditions that, in many cases, can lead even to permanent disability.

Despite the variety of efforts to control them, based on engineering design changes, organizational modifications and working methods training programs, the work-related musculoskeletal disorders represent one of the most common occupational diseases [1]. According the European Agency for Safety and Health at Work, in European countries there are 44 million workers with musculoskeletal disorder. Considering the five important disturbances to the recognized occupational disease in Europe, (fig. 1) the highest occurrence is identified for the diagnostic group of musculoskeletal problems [2]. Consistently with the large number of workers involved, the WMSDs are a central concern in Europe.

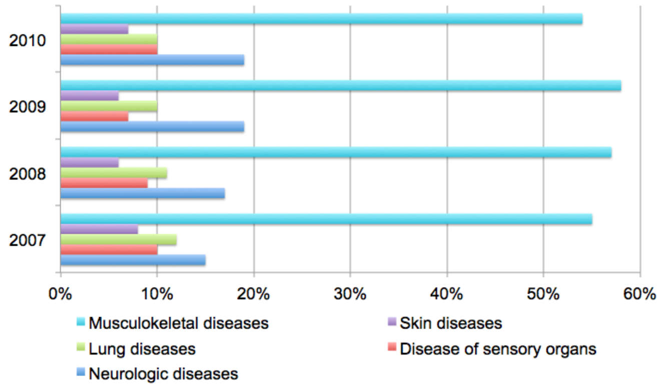

Figure 1. European most common diseases statistics on work environment from year 2007 to 2010

The Fifth European Working Conditions Survey (EWCS), covering 34 EU countries and a time period of twenty years, classifies risk factors for WMSDs. It is very interesting note that for one third of the workers (33%) the WMSDs are due to carry heavy loads at least a quarter of their working time, while almost one in four (23%) are exposed to vibration. Most cause of WMSDs is related to repetitive hand or arm movements (44%) [3]. In particular, the manufacturing industry registered one of the highest incidences of workers taking days away from work due to work-related injuries. It is estimated that employers spend as much as $20 billion a year on direct costs for WMSDs-related workers' compensation [4].

In the last decade there have been more than 270 papers published in major refereed international journals about the WMSDs and the loss of efficiency issue in human based production systems [5]. In order to smooth the workload and the related ergonomic risk among employees, to cross-train them at a low cost, and to increase productivity, job rotation is the most widespread labour flexibility instruments in the case of repetitive assembly tasks [6].

The problem of assigning jobs or tasks to workers is known as Job Rotation Scheduling Problem (JRSP). Many models have been developed in order to identify the optimal solution for minimizing the risk exposure of the worker and for achieving a global balancing of the workload, using Integer Programming (IP), Mixed Integer Linear Programming (MILP), Mixed Integer Non Linear Programming (MINLP) model, Genetic Algorithm (GA), and many other approaches. Ayough et al. [7] developed a multi-period IP model with the objective to minimize the total cost given by assignment and boring cost function. Two search algorithms GA and Imperialist Competitive Algorithm (ICA), are designed and adopted in order to solve and validate the algorithmic complexity in some industrial real cases and in different randomly produced test problems. Otto and Scholl [8] illustrated the JRSP in general terms and compared, by means of computational experiments, the performance of some heuristic procedures, under different aspects. In this way, the authors identified a fast and effective smoothing heuristic method that allows a good integration with computing devices and/or can be adopted as a local re-optimization procedure.

Boenzi et al. [9] presents the OCcupational Repetitive Action (OCRA) score method for the ergonomic assessment in case of infrequent job rotations. The model allows to minimize the exposure risk of a single worker, adopting an algorithm for identifies, among all the feasible job rotations, the best solution in presence of a sub-group of operators with different ergonomic requirements. In [10] a MINLP is proposed aiming to find optimal job rotation schedules with differently skilled workers, under ergonomic and productivity constraints.

Mossa et. al [11] developed a model which aims to find the optimal job rotation schedules in work environment characterized by low load manual tasks with a high frequency of repetition. The model, based on the mixed integer programming, jointly allows maximizing the production rate, reducing and balancing human workloads and ergonomic risk within acceptable limits. Risk and its acceptability are evaluated using the OCRA score method.

Many others JRSP solved by means of a direct observation of the worker during his work shift are widely applied in industry case study. A detailed review of the most common observational methods is proposed by Roman-Liu [12] where OWAS, revised NIOSH, OCRA, REBA, LUBA, and EAWS are compared. Among the simplified methods for rapid analysis of mainly static tasks, the RULA, acronym of Rapid Upper Limb Assessment, is one of the most popular [14]. Details are in section 3.

In a smart factory the well-being of the workers, in both the short and the long term, is one of the most important principles. Therefore an "ergonomic 4.0" approach requires the assessment of repetitive tasks by means of an automated and continuous monitoring of the body position assumed by employs during the work shift. Manghisi et al. [15] suggest a Real time RULA assessment using Kinect v2 sensor, in this case a RULA ergonomic assessment is carried out by means of a computer processing and a skeleton tracking systems. The optical motion capture system adopted (Kinect v2 sensor) allows estimating, in real time, the ergonomic risk of the executed tasks. The evaluation proposed not requires expensive devices and allows ensuring in real time the psychophysical wellbeing of worker consistently with paradigms introduced by the Fourth Industrial Revolution.

Currently in scientific literature there is a lack of studies providing solutions of the JRSP according to the adoption of the RULA method. Therefore, the aim of this paper is to present a model developed for minimizing the exposure risk of a workers involved in repetitive manual tasks. The model is based on the mixed integer programming, and jointly allows reducing and balancing human workloads and ergonomic risk within acceptable limits, even in case of workers with different ergonomic requirements. Risk and its acceptability are evaluated using the RULA method.

The rest of the paper is structured as follows: in Section 2 the rapid evaluation of the ergonomic risk is introduced; in Section 3 the proposed model is described; results obtained in case of a full scale numerical experiment are in Section 4; finally, conclusion of this work are in Section 5.

2. RAPID EVALUATION OF THE ERGONOMIC RISK

A lot of methods and tools have been developed to help the managers and practitioners in estimating the incorrect postures and related activities for several industrial contexts.

The set of the most popular ergonomics evaluation methods includes OWAS, NIOSH lifting equation, RULA, REBA, and OCRA. Each of these observational methods has different features and adopts different key factors for ergonomics evaluations as reported in table 1.

Regardless to the specific method, the assessment results are typically defined as evaluation indices which are compared to threshold values. The tools are widely used in very different contexts and industries but they are very time consuming and the scoring system is questionable, too [16]. Moreover, the observational methods, even if supported by multiple depth cameras, still require a heavy intervention by a field expert to estimate the required parameters (e.g. forces, loads, static/repetitive muscular activity etc.). Therefore, the ISO standard 11228-3:2007(E) [13] suggests the use of a simplified method in the early stage of the analysis and, only in case of critical conditions detected, standard suggests the adoption of the OCRA method for additional investigation.
The RULA (Rapid Upper Limb Assessment) method evaluates the exposure of individual workers to ergonomic risk factors associated with upper extremity MSD. The RULA ergonomic assessment tool considers biomechanical and postural load requirements of job on the neck, trunk and upper extremities. Usually several key risk factors must be considered when the risk is assessed for a given task, including force, posture, repetition (or frequency), duration of the task, and of the working day. So there are some factors that are not fully considered in the RULA method. Nevertheless these limits, it immediately gained a following because ergonomics practitioners were looking for a method that is fast, observational, able to perform the assessment in real time with not expensive equipment, and reliable. At the same time it needs trained skill in ergonomics in the evaluation phase of the results.

The RULA method adopts a single page worksheet to evaluate the ergonomic risk [14]. It consists of two sections: section A for the arm and wrist, and section B for the neck and trunk. After the data on posture, force, and repetition for each body region are collected and scored, a synthetic score representing the global level of MSD risk is calculated.

In table 2 are showed the range limits of the RULA scores representing the different levels of MSD risk and the resulting requirements for action.

Table 1. Ergonomic risk evaluation methods, features and factors considered

Method	Features	Posture	Force	Frequen.	Recovery	Dynamic	Body
OWAS (Ovako Working Analysis System). Karhu et al. (1977)	Work-related disorders on body portion. No detail on upper limb.	Y		Y		Y	Y
NIOSH National Institute of Occupational Safety and Health	Lifting equation. RWL: Recommended Weight Limit		Y	Y			
RULA (Rapid Upper Limb Assessment). McAtamney and Corlett (1993)	Rapid evaluation of upper body members constraints	Y	Y				
REBA (Rapid Entire Body Assessment). Hignett and McAtamney (2000)	Rapid evaluation of the whole body	Y	Y				Y
OCRA (Occupational Repetitive Action). Colombini et al. (2002)	Upper limb repetitive movements evaluation check list	Y	Y	Y	Y		

Table 2. RULA score, corresponding level of MSD risk, and requirements for action.

Score	Level of risk and Requirements for Action
1 or 2	Negligible risk, no action required
3 or 4	Low risk, changes may be required
5 or 6	Medium risk, investigation and changes are required
7	Very high risk, changes are required immediately.

3. THE MODEL

The model is a mixed integer nonlinear programming model. Hypothesis, symbols and assumptions adopted as well as numerical formulations are in the following.

3.1 Hypothesis

A single product manual assembly line is operated by differently aged and skilled workers. Workers are exposed to musculoskeletal disorders (MSDs) risk due to high frequency of repetition of manual tasks. Workstations differ in the ergonomic risk evaluated by the RULA method (Rapid Upper Limb Assessment).

The line operating time consists of a number of predefined time slots. Workers are assigned to workstations in each time slot. Net duration of time spent by a worker at each WS proportionally contributes to the individual ergonomic risk measured by a time-weighted “overall” RULA. Every time a job rotation is performed at a WS during a time slot, a reduction in productivity is observed. The production time loss due to a job rotation of workers between any couple of work stations is considered constant over the work shift.

Standard time of the workstations increases by a worker productivity factor with higher values for low skilled and aged workers. The worker productivity factor is constant over the work shift.

Given the desirable production output, the manual operation times of workers at each WS, and the individual ergonomic risk thresholds, the model identifies one or more optimal job rotation schedules that minimize the variability of the musculoskeletal risk exposure for the workforce assuring a balanced workload among workers.

3.2 The Model Equations

m: number of workstations;

n: number of workers (*n*>=*m*);

K: number of time slots in a work shift;

T_k: duration of the k-th time slot;

$$T = \sum_{k=1}^{K} T_k \text{ : line operation time} \qquad (1)$$

t_j: standard operation time of j-th workstation;

k_{ij}: productivity factor of the i-th worker at the j-th workstation: the factor depends on worker skill and age;

$x_{i,j,k}$: assignment variable of worker (i) to WS (j) during the time slot k, taking value 1 if the assignment is done and 0 otherwise;

t_r: production time loss due to job rotation of a worker between a couple of WSs;

$$q_{i,j,k} = \frac{[T_K - t_r(x_{i,j,k} - x_{i,j,k-1})]}{tj \cdot k_{i,j}} x_{i,j,k} \qquad (2)$$

is the number of items assembled by the i-th worker at the j-th workstation during the k-th time slot with the initial condition (k=0):

$$x_{i,j,0} = 0, \ \forall\ i = 1,..,n; \ \forall\ j = 1,..,m$$

$Q_{i,j}$: production of the *i*-th worker at the *j*-th workstation in a work shift:

$$Q_{i,j} = \sum_{k=1}^{K} q_{i,j,k} \qquad (3)$$

$$P_J = \sum_{i=1}^{n} Q_{i,j} \qquad (4)$$

is the production of the j-th workstation in a work shift

The line production in a work shift will be:

$$P_L = \underset{\{J\}}{Min}\, P_J \qquad (5)$$

P_{LT}: production target of the line in a work shift;

$WT_{i,j}$: working time of the *i*-th worker at the *j*-th workstation:

$$WT_{i,j} = \sum_{k=1}^{K} T_K \cdot x_{i,j,k} \qquad (6)$$

$RULA_J$: RULA index of the j-th workstation;

$RULA_i$: weighted RULA of the i-th worker during the work shift:

$$RULA_i = \sum_{j=1}^{m} RULA_j \cdot \frac{WT_{i,j}}{T} \qquad (7)$$

$RULA_i^{\max}$: maximum admissible RULA value for the i-th operator;

$\overline{R}$: average RULA index of the *n* workers during the work shift;

$$\overline{R} = \sum_{i=1}^{n} \frac{RULA_i}{n} \qquad (8)$$

σ_R: standard deviation of $RULA_i$:

$$\sigma_R = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(RULA_i - \bar{R}\right)^2} \qquad (9)$$

Coefficient of variation of the $RULA_i$:

$$CV_R = \frac{\sigma_R}{\bar{R}} \qquad (10)$$

3.3 Objective Function and Constraints

For an assigned target level of production, the objective is the minimization of the coefficient of variation of the weighted RULA index of the whole workforce:

$$\text{O.F.} = \min_{\{x_{i,j,k}\}} CV_R \quad x_{i,j,k} \in \{0,1\},\ \forall\ i,j,k$$

subject to assignment, ergonomic, and production constraints.

Assignment constraints: each workstation can be operated by only one worker during each time slot:

$$C_1 : \sum_{i=1}^{n} x_{i,j,k} = 1,\ \forall\ j = 1,..,m;\ \forall\ k = 1,..,K \qquad (11)$$

and each worker can be assigned to one workstation during each time slot:

$$C_2 : \sum_{j=1}^{m} x_{i,j,k} = 1,\ \forall\ i = 1,..,n;\ \forall\ k = 1,..,K \qquad (12)$$

Ergonomic constraints: each worker cannot exceed his ergonomic threshold:

$$C_3 : RULA_i \le RULA_i^{\max},\ \forall\ i = 1,..,n \qquad (13)$$

Production constraint: the line should meet its production target:

$$C_4 : P_L \ge P_{LT} \qquad (14)$$

3.4 Dual problem formulation

The problem can be re-formulated by maximizing the output of the system meanwhile guaranteeing both a reduced musculoskeletal risk for the most exposed categories of employees and a balanced workload:

$$\text{O.F.} = \max_{\{x_{i,j,k}\}} P_L \qquad (15)$$

$$x_{i,j,k} \in \{0,1\},\ \forall\ i,j,k$$

Subject to constraints C_1, C_2, C_3, and to

$$C_5 : CV_R \le CV_R^{\max} \qquad (16)$$

4. NUMERICAL EXPERIMENTS

Numerical experiments are carried out to test the model capability. Experiments refer to a production system of four manual assembly work stations (WSs) (m=4). The assembly line is operated during eight hours shifts by four workers (n=4). Each work shift consists of five working time slots (K=5) (see Figure 2). The net duration of one work shift is 405 [min]. This value is obtained by considering the length of the work shift and planned rests (r1-r4).

k	k=1	r1	k=2	r2	k=3	r3	k=4	r4	k=5
T_k [min]	80	15	80	15	95	30	80	15	70

Figure 2. Operating time, time slots and rests durations [min]

Workers have different age and different skill. Starting from the standard operating time of each WSs (t_j), by adopting different productivity factors (k_{ij}), the performance of each worker at each WS is obtained (Table 3).

Table 3. Standard and workers operating times

	WS			
j	1	2	3	4
t_j [s]	30	30	35	30
$t_j k_{ij}$ [s]	30	30	38.5	33
	30	30	35	30
	36	36	38.5	33
	36	36	42	33

RULA indices of each WS are in Table 4; WS 4 is critical WS from the ergonomic point of view.

Table 4. RULA index of the j-th workstation

	WS			
j	1	2	3	4
RULAj	1	2	1	4

On the basis of numerical data, four scenarios have been developed.

The scenario S1 is characterized by standard operation times with no productivity factor influence (k_{ij}=1; $\forall i$, j=1,…,4) and no job-rotations (assignments of workers to the WSs during the shift are in Table 5).

In the scenario S2, the optimization model provides the workers' assignment by keeping the productivity to the maximum value (k_{ij}=1; $\forall i$, j=1,…, 4) and searching for a balanced ergonomic risk among workers with a maximum admissible RULA value of $RULA_i^{max}$ <3 for the whole workforce. The resulting job assignments are in Table 5. A comparison between S1 and S2 results (Table 6) outlines a more uniform workload (CV_R(S1) = 0,71 vs. CV_R(S2) = 0,07) while causing a slight decrease in the line production P_L (-1,33%).

Table 5. Assignments of workers (i = 1,…, 4) to WSs during the work shift (k = 1,…, 5) - Scenario S1 and S2

i=1	i=2	i=3	i=4

	k	1	2	3	4	5
S1	WS 1	1	1	1	1	1
	WS 2	2	2	2	2	2
	WS 3	3	3	3	3	3
	WS 4	4	4	4	4	4
S2	WS 1	2	4	4	3	3
	WS 2	3	3	2	4	4
	WS 3	1	1	1	2	2
	WS 4	4	2	3	1	1

Table 6. Coefficient of variation of the *RULA*$_i$ (CV_R), Variation (%) of CV_R with reference to S1, Line Production (P_L) [u/shift], Variation (%) of P_L with reference to S1, Average WS Production ($AV\ P_j$) [u/shift], and Variation (%) of $AV\ P_j$ with reference to S1 - Scenario S1-S5

	CV_R	DCV_R%	P_L [u/shift]	DP_L%	AvP_j [u/shift]	$DAvP_j$%
S1	0.71	-	684	-	771	-
S2	0.07	-961%	675	-1.33%	751	-2.6%
S3	0.71	0%	665	-2.86%	719	-7.3%
S4	0.15	-384%	651	-5.07%	707	-9.1%
S5	0.28	-155%	651	-5.07%	701	-10.1%

The effects of productivity factors have been tested in scenario S3, where no job-rotations have been considered. The expected reduction in line production is of around 2,86% if compared with the initial reference case S1. No effects are observed to RULA values as no job rotation are considered.

Finally, by relaxing the hypothesis of no job rotation, scenario S4 provides better ergonomic performance (CV_R(S3)=0,71 vs. CV_R(S4)=0,15) with a small effect on line productivity (-5,07% compared to S1).

Table 7. Assignments of workers (i = 1,…, 4) to WSs during the work shift (k = 1,…, 5) - Scenario S3 and S4

	k	1	2	3	4	5
S3	WS 1	1	1	1	1	1
	WS 2	3	3	3	3	3
	WS 3	2	2	2	2	2
	WS 4	4	4	4	4	4
S4	WS 1	1	4	4	3	3
	WS 2	4	1	1	1	1
	WS 3	3	3	2	2	2
	WS 4	2	2	3	4	4

An additional scenario (S5) is considered for facing with a practical industrial situation: a smaller admissible RULA value has been considered for one worker (j=4) who for age and/or skill consideration requires to be preserved for ergonomic workload ($RULA_4^{max}$ = 1,5). The model provides a new solution which is compliant with all constraints showing a good capability in risk balancing among the workforce (CV_R = 0,28) while keeping unchanged the line production (P_L=651 units/shift).

Table 8. Assignments of workers (i = 1,…, 4) to WSs during the work shift (k = 1,…, 5) - Scenario S5

	k	1	2	3	4	5
S5	WS 1	1	4	4	4	4
	WS 2	4	1	1	1	3
	WS 3	3	3	2	2	2
	WS 4	2	2	3	3	1

5. CONCLUSION

Human dexterity in repetitive manual task with high frequency rises out relevant and conflicting issues: the need of preserving the worker well being while meeting production performance. An effective answer can be provided by a proper job rotation scheduling of workers involved in repetitive manual tasks.

The use of model requires field investigations to assess model data; it is the case of the worker productivity parameter to consider age and skill of each worker. However, the huge number of possible work environment situations limits reasonable hopes to standardize such a complex evaluation. To this concern, the model tool reveals of great usefulness in allowing sensitivity analysis and help production managers in decision making of proper job rotation schedules also in case of no or few field data available.

6. REFERENCES

[1] Nunes, I. L. (2009), "*FAST ERGO_X – a tool for ergonomic auditing and work-related musculoskeletal disorders prevention*", A Journal of Prevention, Assessment, & Rehabilitation, Vol. 34, pp.133-148.

[2] Šteinbuka, I., Clemenceau, A., De Norre, B. (2010), "*Eurostat - Health and safety at work in Europe – A statistical portrait*", available at: http://ec.europa.eu/eurostat/en/web/products-statistical-books/-/KS-31-09-290 (accessed: 15 July 2017).

[3] Ardito, C., d' Errico, A., Leombruni, R., (2012), "*EUROFOUND – European Foundation for the Improvement of Living and Working Conditions, "Fifth European Working Conditions survey - 2010*", available at: https://www.eurofound.europa.eu/sites/default/files/ef_publication/field_ef_document/ef1302en.pdf (accessed: 12 July 2017).

[4] Otto, A., and Armin, S. (2011), "*Incorporating ergonomic risks into assembly line balancing*", European Journal of Operational Research, Vol. 212, pp. 277–286.

[5] Battaia, O., Dolgui, A. (2013), "*A taxonomy of line balancing problems and their solution approaches*", International Journal of Production Economics, Vol. 142, pp. 259–277.

[6] Paul, P., Kuijer, F.M., Visser Bart, K., Han, C.G. (1999), "*Job rotation as a factor in reducing physical workload at a refuse collecting department*", Ergonomics, Vol. 42 (9), pp. 1167–1178.

[7] Ayough, A., Zandieh, M., and Farsijani H. (2012), "*GA and ICA approaches to job rotation scheduling problem: considering employee's boredom*", International Journal of Advanced Manufacturing Technology, Vol. 60 (5), pp. 651–666.

[8] Otto, A. and Scholl, A. (2013), "*Reducing ergonomic risks by job rotation scheduling*" OR Spectrum, Vol. 35 (3), pp. 711–733.

[9] Boenzi, F., Digiesi, S., Facchini, F., Mummolo, G. (2016) "*Ergonomic improvement through job rotations in repetitive manual tasks in case of limited specialization and differentiated ergonomic requirements*" IFAC-PapersOnLine Vol. 49 (12), pp. 1667-1672.

[10] Boenzi, F., Digiesi, S., Mossa, G., Mummolo, G. Romano, V. A. (2013), "*Optimal break and job rotation schedules of high repetitive - Low load manual tasks in assembly lines: An OCRA - Based approach*", IFAC-PapersOnLine Vol. 46 (9), pp. 1896–1901.

[11] Mossa, G., Boenzi, F., Digiesi, S., Mummolo, G., Romano V.A., (2016) "*Productivity and ergonomic risk in human based production systems: a job-rotation scheduling model*", International Journal of Production Economics, Vol.171, pp. 471-477.

[12] Roman-Liu, D., (2014), "*Comparison of concepts in easy-to-use methods for MSD risk assessment*", Applied ergonomics, Vol. 45, pp. 420-427

[13] ISO, (2007), "*System of Standards for Labor Safety. Ergonomics. Manual Handling. Part 3. Handling of Low Loads at High Frequency*", International Organization for Standardization.

[14] McAtamney, L., and Nigel Corlett, E., (1993), "*RULA: a survey method for the investigation of work-related upper limb disorders*", Applied ergonomics, Vol. 24, pp. 91-99.

[15] Manghisi, V.M., Uva, A.E., Fiorentino, M., Bevilacqua, V., Trotta, G. F., Monno, G., (2017) "*Real time RULA assessment using Kinect v2 sensor*", Applied Ergonomics (in press).

[16] Battini, D., Persona, A., Sgarbossa, F. (2014) "Innovative real-time system to integrate ergonomic evaluations into warehouse design and management", Computers and Industrial Engineering, Vol. 77, pp. 1-10