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Reducing fatigue level through tasks and breaks assignment in order picking system

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Background

At the present scenario in production and logistics systems, some activities are still carried out manually by the operators such as lifting, lowering pushing/ holding, or carrying of objects (Napolitano, 2012). Thus, it is necessary to highlight the conditions of the operator such as fatigue, stress, safety, and errors while designing such systems particularly, in cases where the whole body is used intensively, such as order picking (OP) process (Battini, Delorme, Dolgui, Persona, & Sgarbossa, 2016). The order picking process is the retrieval of items from the warehouse to fulfill customer and production requirements, which is the most time consuming and labor-intensive activity in warehousing. Moreover, order picking could demand a great deal of physical effort because of frequent handling of items, gradually resulting in increased physical fatigue level due to the demand of high energy expenditure by the pickers. Thus, energy expenditure depends on some attributes of OP such as item characteristics, order profiles, and storage assignments (Battini, Glock, Grosse, Persona, & Sgarbossa, 2016).

Consequently, there has been a need for reducing the fatigue level of the order pickers to improve their performance in picking by providing recovery to the operators during their work. To reduce the accumulated fatigue, adequate recovery time has been found out through Rest Allowance (RA), which is based on energy expenditure rate of the working period and the resting period (Price, 1990), as well as on the maximum acceptable work level or maximum energy expenditure rate. This is even more important when considering the ageing workforce because the maximum energy expenditures tend to decrease with an increase in age i.e. lower acceptable work level for an ageing workforce. Hence the age of order picker plays an important factor in determining the fatigue and recovery trend (Achten & Jeukendrup, 2003).

Aim

Among the order picking systems, the picker to part OP system involves excessive and repetitive manual material handling of items, which renders the order picker to a high risk of musculoskeletal disorders (MSDs), lower back pain, sprain and strains (Punnett & Wegman, 2004). These are due to the characteristics of orders, pickers, and as well as breaks. The orders are characterized by execution time (t_o) and energy expenditure of orders (E'_w). The pickers are characterized by weight (*W*), age, and gender (*S*). Breaks are defined as the orders with energy expenditure at rest (E'_r) in a defined time such as 5 or 10 min. Thus, it is important to allocate the orders and breaks to the order picker based on these factors.

The aim of this paper is first to develop a model to calculate RA considering the ageing factor of the operators. It is based on the main assumption that general physical fatigue level can be linked to total energy expenditure and task execution time and resting period. Subsequently, to define an optimal assignment of tasks and breaks in order to minimize the total fatigue level, i.e. to reduce the total fatigue level accumulated on order pickers after completing all activities, and also in order to minimize the total makespan, i.e. to reduce the total time for all activities with the inclusion of breaks.

Method

Model for RA considering the ageing factor of the operator

The model is generated based on RA equation (Calzavara, Persona, Sgarbossa, & Visentin, 2018). The RA equation introduced in this paper is estimated based on the varying characteristics of the order pickers. Also, RA is considered to be 0 if the value of (1) is negative.

$$RA = \frac{E'_w(\lambda, \mu) - AWL(weight, age, gender)}{AWL(weight, age, gender) - E'_r(weight, height, age, gender)} \tag{1}$$

$E'w(\lambda, \mu)$ stands for the energy expenditure rate of the task and depends on the characteristics of both task (energy expenditure rate and time) and operator (fatigue rate λ and recovery rate μ). Which is shown below.

$$E'_w = \frac{\int_0^{t_o} F(t_o) + \int_{t_o}^{t_o+t_r} R(t_r)}{t_o + t_r} \tag{2}$$

F(t_w) and R(t_r) are respectively the fatigue and the recovery trend of the operator (Calzavara, Persona, Sgarbossa, & Visentin, 2018)

$$F(t_o) = E'_w + \left(E'_r - E'_w\right) \cdot e^{-\lambda t_o} \tag{3}$$

$$R(t_r) = F(t_o) \cdot e^{-\mu t_r} \tag{4}$$

AWL, the acceptable work level, is calculated with equations (5) and (6) respectively for male and female (Price, 1990; Silva, Franklin, Forman, & Araújo, 2016). This parameter is operator-dependent; in particular, it varies according to age, gender, and weight (Finco et al, 2019b).
In men:

$$AWL[kcal/min] = \frac{(60 - 0.55 \cdot age) \cdot 0.005 \cdot W}{3} \tag{5}$$

In women:

$$AWL[kcal/min] = \frac{(48 - 0.37 \cdot age) \cdot 0.005 \cdot W}{3} \tag{6}$$

$E'r$ stands for energy expenditure at rest and is calculated with equation (7). It varies according to age, gender (S), weight (W) and height (H) of operators (Mifflin, Jeor, Scott, Daugherty, & Koh, 1990).

$$E'_r[kcal/min] = \frac{S + 10 \cdot W + 6.25 \cdot H - 5 \cdot age}{24 \cdot 60} \tag{7}$$

Where S is equal to 5 and -161 respectively in male and female.

To define an optimal assignment of tasks and breaks in order to minimize the total fatigue level

If there are *n* tasks to be completed by the order picker, there are different criteria with which the breaks could be assigned. For instance, assigning one long break after k^{th} task or assigning discrete short breaks during the shift. Thus, the overall energy expenditure rate (E'_{w_o}) of all the tasks and breaks during the shift is calculated using the below equation (8) (Visentin, Sgarbossa, Calzavara, & Persona, 2018).

$$E'_{w_o} = \frac{\sum_{i=1}^{n} \int_0^{t_{o_i}} F(t_o)_i + \sum_k \int_{t_{o_k}}^{t_{o_k}+t_{r_k}} R(t_r)_k}{\sum_{i=1}^{n} t_{o_i} + \sum_k t_{r_k}} \quad (8)$$

Where, $\int_{i=0}^{t_{o_n}} F(t_o)_i$ is the fatigue accumulation of i^{th} task and can be calculated with equation (9)

$$\int_{i=0}^{t_{o_n}} F(t_o)_i = \begin{cases} E'_{w_i} \cdot t_{o_i} + \left(F(t_o)_{i-1} - E'_{w_i}\right) \cdot \frac{e^{-\lambda t_{o_i}}}{-\lambda} + \frac{\left(F(t_o)_{i-1} - E'_{w_i}\right)}{\lambda} & if\ E'_{w_i} \geq F(t_o)_{i-1} \\ E'_{w_i} \cdot t_{o_i} + \left(F(t_o)_{i-1} - E'_{w_i}\right) \cdot \frac{e^{-\mu t_{o_i}}}{-\mu} + \frac{\left(F(t_o)_{i-1} - E'_{w_i}\right)}{\mu} & if\ E'_{w_i} < F(t_o)_{i-1} \end{cases} \quad (9)$$

$\int_{t_{o_k}}^{t_{o_k}+t_{r_k}} R(t_r)_k$ defines the recovery alleviation after k^{th} task and can be calculated with the equation (10).

$$\int_{t_{o_k}}^{t_{o_k}+t_{r_k}} R(t_r)_k = \frac{F(t_o)_k}{-\mu} \cdot e^{-\mu t_{o_k}} \cdot (e^{(-\ln F(t_o)_k) + \ln(\dot{E}_R)} - 1) \quad (10)$$

Thereafter, E'_{w_o} for different combinations of tasks and breaks are tabulated from equation (8) and minimum total fatigue level is pointed out.

To define an optimal assignment of tasks and breaks in order to minimize the total makespan

Initially, the scheduling of activities is done on the basis of McNaughton's Algorithm (McNaughton, 1959). The activities are characterized on the basis of energy expenditure rate and the execution time. Thereafter, the rest allowance (RA) of each operator are calculated based on the equation (1). Thus for each scheduling sequence, the makespan is calculated and the optimal makespan could be located.

Results and Limitations

In this paper, a model for rest allowance are developed by considering the ageing factor. The paper also discusses an optimum combination of tasks and breaks that could minimize the overall fatigue level on the order pickers. Finally, the model also provides optimal scheduling of tasks and breaks in order to reduce the total makespan.

The model cannot be used for activities with repetition, the continuous use of the same muscles would cause muscular fatigue and finally, the results are mainly based on the modeling of energy expenditure rate (Finco et al, 2019a)

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