Recovery time setting for order picking activities

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Abstract: The order picking is a warehouse activity which implies half of the expenses of a warehouse. In most cases, it is performed manually because the use of operators guarantee the flexibility in reacting to changes in the way the activity is carried on or to unexpected situations. To assure the best performance of this kind of system, considering the preferable use of operators, it could be useful to keep much more attention to the effects that human factors can have on the output of a picking context. For the improvement of the system, it is needed to consider innovative ways of monitoring the physical conditions of operators, not in terms of musculoskeletal disorders but in terms of fatigue accumulation on the cardio-vascular system. As far as physical fatigue is concerned, each operator needs some time to fully recover from the accumulated fatigue and this time can be different from one operator to the other. In fact, the way in which fatigue is accumulated is personal such as the way in which it is alleviated. Consequently, this paper aims to give an easy-to-use model to monitor fatigue accumulation of operators and to estimate the time necessary to each one for the recovery, considering not only personal characteristics but also the kind of the activity performed in terms of intensity and duration.

Keywords: Fatigue, Recovery Time, Rest Allowance, Order Picking, Human Factor, Energy Expenditure

1.Introduction and literature review

The order picking, is defined as the process of retrieving items from their storage location to fulfil customers' orders (Tompkins et al., 2010). This activity can be done automatically or manually. Normally the manual picking is preferred because it can assure flexibility. In fact, if the picking activity is performed by an operator it can be easier to react to unexpected changes in the activity. As far as order picking is concerned, it needs to be improved in terms of efficiency because it implies 50% of the costs of a warehouse (Tompkins et al., 2010). This makes the managers conscious of the necessity of increasing both the productivity and efficiency of the warehouse. As explained in Grosse et al. (2016), to reach this objective, the existing literature has mainly focused on minimizing travel distances, total costs, throughput time and use of space. However, considering the preferable use of humans rather than machines it has become necessary to put more attention on the influence of human factors on the efficiency of the overall system (Grosse et al., 2015). In fact, the use of humans can determine a lower performance of the system because of injuries or musculoskeletal disorders which affect the condition of operators and consequently their ability in carrying on the activity as requested (Grosse et al., 2015). Human factors not only have a relevant influence on manual material handling activities in warehouses but in all the daily activities where the presence of humans is fundamental. For this reason, different disciplines such as industrial design, anthropometry, engineering, physiology, biomechanics and psychology have focused their studies on the human factors (Wogalter et al., 1998; Karwowski, 2005). Basing on the definition of the "International Ergonomics Association" (IEA, 2003) the term "human factor" is related to the use of theories and methods for the designing of the system to reach both the improving of the performance and better conditions of humans, taking into account how and with which element of the system the human has to interact (Lodree et al., 2009; Grosse et al., 2016). This objective is reached reconsidering the workplace and by improving the devices with whom the humans have to interact, for meeting their necessities and the personal abilities of each of them (Christmansson et al., 2000; Kadefors et al., 2000; Neumann et al., 2002; David, 2005; Battini et al., 2014; Dode et al., 2016). The recognised causes of the decreasing in operators' capacities or injuries are musculoskeletal disorders as affirmed in David (2005). In fact, different methods such as self-reports, observational methods or direct measurements have been put in practice in an industrial context as exposure assessment techniques (David et al., 2005). Related to this, recently even more attention has been paid to innovative full-body system for real-time ergonomic evaluations of manual material handling activities (Battini et al., 2014). Besides this, the consequences of musculoskeletal disorders can be greater if the age of operators increases (Fonseca et al.,2013; Čiutienė et al., 2014) and is strictly linked to characteristics that distinguish one person from the other. For this reason, there has been developed job rotation schemes to prevent this kind of problems (Fonseca et al., 2013). Despite this, normally the industries are not keen on investing their time on finding solutions for improving consistently operators' well-being because of the need of caring of the optimisation of the efficiency and the short time results in terms of profitability (Grosse et al., 2015). Even though for the musculoskeletal disorders some methods have been developed for the analysis of awkward postures, little attention has been paid to the kind of fatigue the operator feels during the performance. This kind of fatigue can be physical or mental. The first one is due to the necessity of using a certain force for a predetermined time and the second one is experienced in activities where it is necessary the continuous retrieval of information stored in memory. Consequently, focusing on the reducing of physical fatigue accumulation, which can be evaluated objectively, it is important to evaluate which activity has to be attributed to which kind of operator. In fact, as affirmed by Konz (1998) the consequences of this kind of fatigue can be the reduction of force or the worsening of the reaction time of the operator. For reducing this kind of fatigue and avoiding overfatigued operators some of the literature has analysed the time necessary to the operator to recover completely. Normally this time necessary for the recovery is obtained by using formulations related to the muscular fatigue an operator feels (Rohmert,1973; Imbeau et al., 2009; Milner, 1986; Rose,1992) and it is called rest allowance (RA). But, as affirmed by Konz (Konz, 2000) the physical fatigue can be related to the condition of the muscle (muscular fatigue) such as to the cardio-vascular system (general body fatigue). Moreover, not only the recovery time depends on the fatigue accumulated but also on the kind of recovery the operator performs (Konz, 2000). In fact, the operator can rest by having a sitting or standing rest but also can partially recover by performing a different kind of activity. Related to muscular fatigue the most used terms in existing models are the maximum holding time (MHT), defined as the maximum time a muscle can sustain a load without interruptions and the maximum voluntary contraction (MVC), used for the measurement of the intensity of the exertion (Imbeau et al., 2009). Both the terms are used in the formulation of Rohmert (Rohmert, 1973), considering that if the percentage of MVC is below 15% there is no fatigue. Instead, in the models of Milner (Milner, 1986) and Rose (Rose, 1992) it is not considered the combined effect of MHT and MVC but only the influence of the MHT expressed in Milner as a fraction of MHT. On the other side, some models do not consider the MHT but only the intensity of exertion expressed as %MVC (Bystrom and Fransson Hall, 1994). As far as picking activities is concerned, this kind of models for the monitoring of fatigue level have a limited value because this is an activity which implies the use of the whole body and if it is carried on with a certain intensity it affects the cardio-vascular system.

In these cases, the reference term for the monitoring of the general fatigue an operator feels is the energy expenditure rate (Price, 1990). Consequently, in an industrial context, it is necessary to consider a device for the monitoring of fatigue level of operators performing cardio-vascular activities. The most validated measurement is the oxygen consumption (Christensen et al., 1983) but it is not easy to obtain this measure in this kind of context. Consequently, considering its high coefficient of correlation with the heart rate, the heart rate monitor can be the easier device to be used to evaluate fatigue accumulation continuously (Li et al., 1993; Maxfield,1971). The value of energy expenditure has been used by Price (Price,1990) for the estimation of the value of RA. Although this formulation can be very useful to be applied in activities where the overall body is involved, in Price (1990) it does not evaluate the real trend of fatigue and recovery explained by Konz (1998). This exponential trend of fatigue and recovery is put in evidence also by some other literature focused on the post-exercise oxygen consumption (EPOC) for the evaluation of fatigue level (Rusko et al., 2003; Rusko et al., 2004; Seppanen, 2005). In fact, in Price (1990) the operator performing the activity is considered at the same mean energy expenditure for all the duration of the task and when the activity is finished the operator is immediately at the resting energy expenditure rate.

Accordingly, there is the need to fill the gap of the existing literature on this topic and to evaluate the kind of model, that can be applied for order picking activities, that can able to take into account the effective trend of fatigue and recovery and to put in evidence the difference in the way fatigue is accumulated for different operators. This can be a further step for analysing in depth the influence of human factors in these kinds of activities understanding the impact of humans on the overall performance of the system.

Subsequently, first of all, this paper wants to demonstrate, by using the heart rate monitor for operators carrying on activities of different intensities, that the trend of fatigue and recovery is effectively as explained by Konz (1998). After that, by using the data given by this device, the final objective is the development of a model for evaluating the value of RA. This model has to consider the characteristics of the activity related to its intensity and duration and the specificities of the operators. Thus, it is possible, through the application of the model, to effectively evaluate the time needed to the operator to return to the initial physical conditions and, by knowing this, it can be better obtained the improvement of the whole picking system.

The structure of this paper is as follows. In the next section it will be put in evidence the formulation of Price (Price, 1990) explaining its meaning and it will be compared with the data obtained through the use of an heart rate monitor.

After that, in the third section, basing on the data obtained from the application of the heart rate monitor in a laboratory test, it is developed a new mathematical model for RA estimation that can consider not only the kind of activity performed but also the personal characteristics of operators. Finally, some conclusions and future steps for the improvement of the model will be explained.

2. RA evaluation using energy expenditure

As said in the section before, the model of Price (1990) estimates the value of rest allowance by using as input data the value of energy expenditure of the activity. In fact, the characteristics of the activity influence the general body fatigue that an operator perceives. However, the effect on the perceived fatigue is not only due to the intensity of the activity (which influences the value of the energy expenditure) but also to the duration of the activity. Because of this, it is useful to know how much an activity impacts on operators in the phase of scheduling because this allows to estimate how the activities have to be distributed among operators to reach the minimization of the total recovery time, which is considered time with no value added. Looking at the formulation of Price (1990) for obtaining the value of RA the mean working rate of the considered activity (MWR), which is obtained by dividing the total energy expenditure of the activity by the total duration, is equated to the acceptable work level (AWL).

The acceptable work level is obtained by Price (1990) by basing on the research of Astrand (Astrand et al., 1954), where it is indicated for a variety of activities the maximum oxygen intake. Basing on the fact that for manual material handling activities the average maximum oxygen intake is 2.7 l/min and that one litre of oxygen per minute corresponds to 350 W, Price (1990) obtained that the value of AWL for a work level of 8 hours per day is around 300 W. The original formulation of Price for the estimation of RA is the following:

$$RA = \frac{MWR-300}{300-RR} \quad (1)$$

Where RR is considered the relaxation rate of standing or sitting, which is indicated respectively as 130 and 105 W.

This formulation has been transformed by Battini et al. (2017) by considering the energy expenditure not expressed in Watt but in Kcal/min:

$$RA = \frac{\dot{E}_W-4.3}{4.3-\dot{E}_R} \quad (2)$$

In this formulation, it is transformed respectively the mean working rate and the standing relaxation rate expressed in Watt to the working energy expenditure rate $\dot{E}_W$ and to the relaxation energy expenditure rate, both expressed in Kcal/min. Formulation (1) and (2) are both useful because they can take into account the effects of different combined tasks.

The next sections aim to develop what lacks in Price's formulation (Price, 1990): how personal characteristics of an operator can influence the value of rest allowance. In fact, Price's formulation (Price,1990) is set on a general individual and it does not consider that the recovery time of an individual can be different from an operator to another one because of their physical characteristics in terms of training status. Moreover, the following sections will give not only a model for the evaluation of the recovery time necessary but also it will be indicated the kind of instrument to be used, to obtain the energy expenditure rate in an industrial context.

2.1 Real trend of fatigue and recovery

Regarding physical fatigue, some recent literature has focused on the analysis of how the trend of fatigue and recovery is exponential (Konz,1998; Jaber et al., 2013).

In particular, in Konz (1998) it is explained how most jobs have not a constant load during the performance but, despite this, the fatigue accumulated exponentially with time. Moreover, he put in evidence how the fatigue perceived can be different for different parts of the body and that the rest can be static or dynamic. In fact, if the operator performs the same activity done before but at a lower intensity or if he performs an activity that stimulated a different part of the body he is able to partially recover from the past effort. As far as recovery is concerned, in all the cases the rest declines exponentially with time and it is necessary to have the rest before the operator becomes overfatigued (Konz, 1998).

A further step in the evaluation of the trend of fatigue and recovery has been made in Jaber et al. (2013) where it is modelled how fatigue accumulated during the performance of the activity and how it is alleviated if a rest is given to the operator. Related to this, it is shown how the reducing of fatigue is higher during the initial phase of recovery.

This exponential trend of fatigue accumulation and recovery alleviation is not considered in the model of Price (Price, 1990).

However, in Konz (1998) and in the model of Jaber et al. (2013) the term of reference is the maximum endurance time (MET) which indicates the maximum time a muscle can bear a predetermined load or posture. As affirmed in the introduction this measure is related to the muscular fatigue not to the general fatigue, which instead can be monitored with the energy expenditure rate (Price, 1990).

In order picking activities the monitoring of the condition of the muscle is not sufficient because this is an activity which involve the whole body: the arms and hands for picking the item and the legs for moving from one location to the next one. Consequently, as affirmed by Price (1990), the measurement of the energy expenditure rate is the best option to be used for the evaluation of fatigue accumulation. Moreover, the picking activity has to be performed with a certain intensity for having an impact on the cardio-vascular system. Referring to some of the physiological literature (Spurr et al., 1988; Li et al., 1993) it is possible to consider the heart rate monitor a valuable device for obtaining the monitoring of the energy expenditure in the field. In fact, by using the formulation stated by Spurr (1988) it can be obtained the energy expenditure if it is monitored the heart rate continuously and if it is set the coefficient of correlation between heart rate and oxygen consumption for the specific individual.

Consequently, there have been made different lab tests simulating a picking context with a certain intensity with an operator wearing both the oxygen mask and the heart rate monitor. Moreover, the oxygen consumption (VO2) and heart rate (HR) were monitored also during the rest. The picking activity was simulated by picking a predetermined item of 5 kilos from a shelve and putting it on a pallet on the ground and vice versa. In Figure 1 and in Figure 2 it can be seen, respectively, the heart rate trend for a picking intensity of 12 and 4 product units per minute where the maximum heart rate reached is respectively 160 and 120 beats per minute. The trends of the two figures can put in evidence the trend of fatigue and recovery for the specific operator: the two trends are exponential both in reaching the maximum heart rate and in the decreasing for reaching the heart rate at rest. It needs to be considered that heart rate is strictly related to the energy expenditure as said before (Spurr et al., 1988; Li et al., 1993).

It can be seen, in terms of heart rate, not only how the trend of fatigue and recovery is exponential but also how the changing in the intensity of the activity determines a changing in the maximum heart rate reached during the performance. In fact, for a specific operator performing a predetermined activity it is necessary a certain amount of time for reaching the maximum heart rate but after this time he remains at that value of energy expenditure rate for the entire duration of the task if the intensity of the task is constant during the performance. This can put in evidence how valuable is a heart rate monitor for revealing the impacts of an activity on operators.

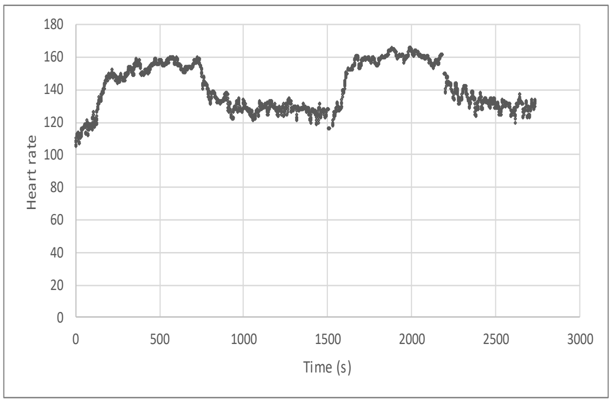

Figure 1. Fatigue and recovery trend for a picking intensity of 12 product units/minute

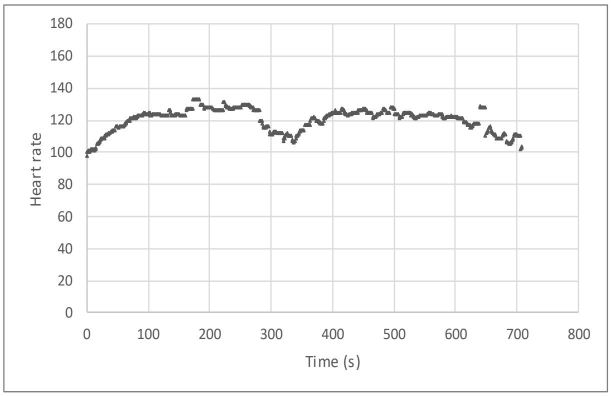

Figure 1. Fatigue and recovery trend for a picking intensity of 4 product units/minute

3. A model for the setting of the recovery time

Basing on the trends of fatigue and recovery put in evidence in the section before from the heart rate and referring to the formulation of Jaber et al. (2013), this section aims to model the trend of fatigue and recovery and to modify the formulation of Price (1990) to obtain a new formulation for rest allowance estimation. If it is considered to monitor the heart rate of an operator during a picking activity carried on for a certain duration t_w, there is reached a value of maximum heart rate (and consequently of the maximum energy expenditure rate $\dot{E}_W$) strictly linked to the intensity of the activity. Price (1990), in his formulation, considered that the whole activity is carried on at the maximum heart rate, not that this value is reached only after a while from the beginning of the activity and that the operator after the end of the activity is immediately at $\dot{E}_R$, the energy expenditure rate at rest In Figure 3 it can be seen the trend of fatigue and recovery put in evidence by Price (1990).

In fact, in Price (1990), the value of time the operator has to rest, defined as rest allowance is set by knowing the value of the energy expenditure rate of the activity measured in Kcal/min (formulation (2)).

As explained in the section 2, this value of rest allowance is expressed as a percentage of the duration of the activity t_w. This formulation can easily be applied in an industrial context because a heart rate monitor can be used to evaluate the maximum energy expenditure rate and the energy expenditure rate at rest. In this way, it is possible to have a feedback on how the specific operator perceives fatigue because the value of maximum heart rate is not only a consequence of the intensity of the activity but it depends also on personal characteristics of the operator. In fact, if it is considered two different operators performing the same activity they reach a value of $\dot{E}_W$ different one from the other.

However, as can be seen in Figure 3, in Price (1990) it is not taken into account that the trend of fatigue and recovery is exponential in reaching $\dot{E}_W$ and $\dot{E}_R$ and that personal characteristics can influence the time necessary for reaching $\dot{E}_W$ and $\dot{E}_R$. Consequently, by referring to the formulation of Jaber et al. (2013) and knowing the values of the maximum energy expenditure rate and of the energy expenditure rate at rest, it has been modelled fatigue trend as follows:

$$F(t_w) = \dot{E}_W + \left(\dot{E}_R - \dot{E}_W\right) * e^{-\lambda t_w} \quad (3)$$

As can be seen in formulation (3) the fatigue trend is influenced by $\dot{E}_W$, $\dot{E}_R$ and t_w. Moreover, the parameter λ describe how fatigue accumulated for the specific operator.

As far as recovery trend $R(\tau)$ is concerned it is modelled as follows:

$$R(\tau) = F(t_w) * e^{-\mu\tau} \quad (4)$$

In formulation (4), where τ indicates the passing time till the reaching of the energy expenditure rate at rest, it is considered that not only the beginning of this trend is the $\dot{E}_W$ reached at the end of the activity, but also that there is an influence of the factor of recovery alleviation μ of the operator. In Figure 3 can be seen the exponential trend of fatigue and recovery in reaching $\dot{E}_W$ and $\dot{E}_R$.

In formulations (3) and (4), τ is the recovery time necessary to the operator to alleviate the accumulated fatigue, whose value is 0 at the end of the activity and is equal to τ_r when it is reached the value 1.86 Kcal/min defined as the energy expenditure rate at rest.

Moreover, it is also considered the personal characteristics by putting the value of λ and μ, respectively the factor of fatigue accumulation and recovery alleviation of the operator. These parameters are included in the model in order to permit to include human factors in picking activities and they need to be set every time a new operator is considered. In fact, the value of these two parameters is strictly related to physical condition of the operator: if an operator is well trained he has a low value of λ and a high value of μ. This means a slow fatigue accumulation and fast recovery alleviation.

By setting $R(\tau)$ to the value of 1.86 Kcal/min, the energy expenditure at rest, it is obtained τ_r,the time necessary to the operator for reaching 1.86 Kcal/min:

$$\tau_r = \frac{-\ln 1.86 + \ln F(t_w)}{\mu} \tag{5}$$

As put in evidence in Figure 3, in this model the operator accumulated fatigue till the achievement of the 1.86 Kcal/min. Consequently, the RA is calculated as a percentage of t_w as it is done in Price (1990).

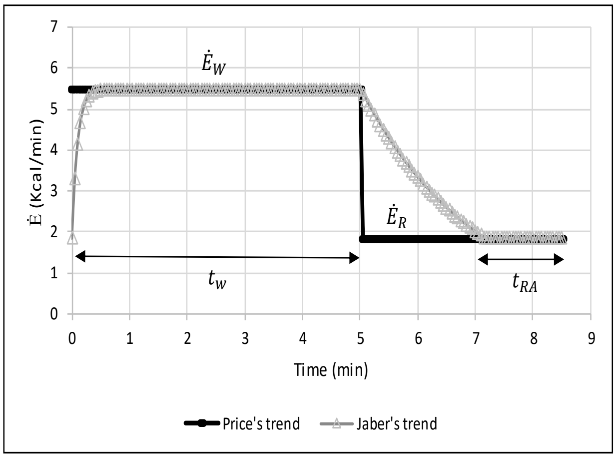

Figure 3. Real trend of fatigue and recovery

Consequently, to calculate a new value of RA, considering the exponential trend of fatigue and recovery, it is necessary to use Price’s formulation, not on the maximum energy expenditure rate but on a new value $\dot{E}_W{}'$. This new value is obtained considering the fatigue accumulation during the performance of the activity till the achievement of $\dot{E}_R$ as follows:

$$\dot{E}_W{}' = \frac{\int_0^{t_w} F(t_w) + \int_{t_w}^{t_w+\tau_r} R(\tau)}{t_w + \tau_r} \tag{6}$$

Where the fatigue accumulation during the performance is obtained by integrating the fatigue function from the beginning till the end of the picking activity:

$$\int_0^{t_w} F(t_w) = \dot{E}_W * t_w + \left(\dot{E}_R - \dot{E}_W\right) * \frac{e^{-\lambda t_w}}{-\lambda} + \frac{(\dot{E}_R - \dot{E}_W)}{\lambda} \tag{7}$$

And the fatigue accumulation after the end of the activity is calculated by integrating the recovery function from the end of the activity till the reaching of 1.86 Kcal/min:

$$\int_{t_w}^{t_w+\tau_r} R(\tau) = \frac{F(t_w)}{-\mu} * \left(e^{(-\ln F(t_w) + \ln(\dot{E}_R))} - 1\right) \tag{8}$$

The calculation of $\dot{E}_W{}'$ is a step in the development of the model of Price (1990). In fact, this value can be used in formulation (2) for obtaining the value of RA referred not only to t_w but also to τ_r:

$$RA = \begin{cases} \frac{\dot{E}_W{}' - 4.3}{4.3 - \dot{E}_R} & if\ \dot{E}_W{}' > 4.3 \\ 0 & otherwise \end{cases} \tag{9}$$

As explained in section 2, there is not recovery if the value of $\dot{E}_W{}'$ is below the acceptable work level of 4.3 Kcal/min and the RA indicates how much time the operator has to stay at 1.86 Kcal/min to return to the initial physical condition.

After the calculation of the RA it is possible to evaluate the total time needed to the operator to recover t_R', considering the time necessary to reach the value of 1.86 Kcal/min in terms of energy expenditure rate at rest:

$$t_R' = \tau_r + RA * (t_W + \tau_r) \tag{10}$$

To reach the final aim of setting the percentage of t_W necessary to the operator to recover it is introduced a new term $RA^{\lambda,\mu}$:

$$RA^{\lambda,\mu} = \frac{t_R'}{t_W} \tag{11}$$

The value of $RA^{\lambda,\mu}$ permits to evaluate the new percentage of t_W required, by taking into consideration the characteristics of the activity in terms of intensity and duration and the ones of operators in terms of λ and μ. Consequently, there can be a certain a difference in comparison to the value of RA set by Price (Price,1990).

4. Conclusion and future researches

In this paper, a model for fatigue evaluation and rest allowance estimation has been developed. The contribution of this model is to consider, for activities whose intensity has an influence on the cardio-vascular system, by causing a changing in the value of heart rate and consequently in the value of the energy expenditure rate, how not only the intensity but also the duration of the activity and the characteristics of operators can affect the accumulation of fatigue and the trend of recovery. Accordingly, even if the activity is the same and is carried on for the same duration, the value of the rest allowance can change between one operator and the other.

The steps performed in the paper are the following. First of all, the effective trend of fatigue and recovery is obtained by using a heart rate monitor on operators performing picking activities of different intensities and durations. The fatigue and recovery trend is respectively found to be exponential in reaching the maximum energy expenditure rate and the energy expenditure rate at rest. These trends are validated by existing literature and are compared to the ones stated by Price (1990). Basing on the fact that Price (1990) does not considered the effective trend of fatigue accumulation and recovery alleviation and the characteristics of operators that perform the activity, a new mathematical model has been developed which could consider not only the kind of activity performed but also the kind of operator considered by using λ and μ as parameters.

As affirmed in this model the value of λ and μ can change from one operator to the other because of personal characteristics such as age and level of training. Thus, a future work of this study could consider the better way of estimating these two parameters in an industrial context. Furthermore, it could be useful to carry on a parametrical analysis for evaluating how the value of RA changes with the changing not only of λ and μ, but also of the duration and intensity of the activity considered. In this way, it is possible to analyse when the difference between the value of RA set by this model and the one of Price (1990) increases more.

This kind of analysis can lead to the understanding of how the scheduling of operators' activities can be improved if, in the early stages of allocation of the activities to the operators, it is considered not only the duration and intensity of the activity to be assigned but also the kind of operator that has to performed the activity. In this way, it is possible to understand the best setting of activities to operators for the reducing of the total time necessary to carry on all the activities by a certain number of operators.

Besides this, it could be useful to consider how the trend of fatigue changes if an operator performs an activity of a certain intensity for a predetermined duration and cannot recover all the time necessary but has to start immediately with the following activity. In fact, in an industrial picking context it is not common to give to operators a rest after each activity but usually an operator can recover himself after a certain amount of orders performed. Concerning this, it could be useful to evaluate what happens in terms of fatigue accumulation if an operator is able to take a rest only after he has performed the scheduled number of activities. Related to the improvement of the performance of a picking context considering human factors, some future researches could take into account how a certain amount of physical fatigue can affect the capacity of operators of learning and remembering the activity to be performed. This means how the physical efforts that affect the cardio-vascular system could have an effect on the performance of operators and have an influence on the mental fatigue an operator feels, causing a decreasing in the coefficient of learning of the operator. All these futures researches will be useful for the optimisation of the used resources in terms of operators and the improvement of the performance of the overall manual picking system.

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