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Linking human availability and ergonomics parameters in order-picking systems

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Abstract: Most of the warehouse picking systems are based on manual activities, performed by human operators. Therefore, their performances and costs deeply depend on human availability and productivity, affected by the fatigue of operators and the probability of injuries and their gravity. In this paper, a real case studies analysis concerning the ergonomics of different picking warehouses is proposed, from which two functions that link the human availability and the rest allowance to the ergonomics level have been obtained. Furthermore, two different cost models, estimating the total expected cost considering both human availability and rest allowance, have been developed.

Keywords: Warehouse picking, Human Availability, Injuries, Ergonomics, Cost Models.

1. INTRODUCTION

Nowadays, there are still many production and logistics systems based on human operations, such as order picking warehouses, manual assembly lines, intra-logistics systems and other material handling activities in general. Many researches have studied human factors and ergonomics (HF&E) in order to improve the well-being of workers in several sectors, considering very different aspects. Based on the definition given by the International Ergonomics Association, *"ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance"*. A particular field of HF&E is the Human Reliability (HR) that concerns the reliability of human in industrial context, such as manufacturing, transportation, logistics and others, for example medicine and armed forces. The main theory standing at the base of this branch of research focuses on considering HR as probability to commit errors in the performed process, together with their impact on system performance. Therefore, the existing methods for HR analysis are based on probability risk assessment and cognitive theory of control (Kirwan, 1994; Kirwan and Les, 2003).

In this paper, we have studied the performance of industrial systems, such as production and logistics ones, under a different point of view. Starting from some real practical case studies, concerning different order-picking warehouses, we have linked the performance and, consequently, the cost of the systems to operators availability and productivity, which are affected by the working conditions ergonomics. On one hand, the availability of workers depends on the number and the gravity of injuries, in the same way of machine availability. On the other one, the reduction of productivity is strictly connected to the fatigue of operators, resulting from the increase of required rest allowance. Both these effects are affected by ergonomics conditions.

In the rest of the paper, Section 2 introduces some different case studies and the two functions that have been derived in order to link human availability and productivity to the ergonomics level. Then, in Section 3, we have discussed the cost models useful to estimate the total cost based on these two functions, also proposing a parametrical analysis and their application on the case studies, giving some guidelines to improve the systems from an ergonomics point of view and consequently reducing the total cost. Finally, the conclusions describe the advantages of this study and discuss some possible further researches.

2. ERGONOMICS AND HUMAN AVAILABILITY IN PICKING SYSTEMS

Ergonomics evaluations have become very important in the last years, both for industrial and academic sectors. It has been demonstrated that the future long-term muscular pain, such as musculoskeletal disorders (MSDs), depends on the discomfort felt by the workers (Hamberg-van Reenen, et al., 2008). Generally, MSDs caused by manual tasks represent a large part of all work-related MSDs (Burgess-Limerick, 2007; Euzenat, 2010) and are a central issue for public health (Larco Martinelli, 2010). Moreover, as well demonstrated in Battini et al. (2011), including the ergonomics evaluations in the human operations analysis is a win-win approach due to the strict interaction between productivity and motion efficiency as well as operational safety.

Since warehouse picking mostly deals with human operators and manual activities, a new frontier of research on this field propose the consideration of human factors on order-picking throughput and performance (Neumann and Dul, 2010). In fact, order-picking is typically characterized by repetitive tasks, often involving high load weights and unfavorable body postures, that could lead to musculoskeletal disorders for workers (Grosse et al., 2014; Weisner and Deuse, 2014), which are, moreover, one of the most reported causes of absence from work (52% of all work-related illnesses)

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(Schneider and Irastorza, 2010). However, the integration of ergonomics effects on order picking systems has not received for now enough attention in literature (Grosse et al., 2014). In this sense, one of the first analyses that could be useful to perform is the understanding of the elements that mostly affect the ergonomics level of the order-picking activities. For example, Grosse et al. (2014) highlight how the definition of a maximum acceptable pick height and depth of the storage racks in the storage assignment and the limitation of the weight transportable by each picker in the routing policies could lead to ergonomics improvements and, hence, to long-term benefits, such as costs reduction of the whole system. Also according to Weisner and Deuse (2014), the body posture is influenced by size, weight and type of the packaging and by the configuration of the shelving. They propose the storing of parts according to their picking frequency: items with a low picking frequency and/or a high weight should be positioned in low shelf floors, while items picked more often should stay in a height of 0.85 m up to shoulder height. It derives that human availability is strictly correlated to the ergonomics aspects; hence, it could be interesting the modelling of this parameter in function of the ergonomics assessment. Moreover, several studies can be found regarding the link between ergonomics and human performance, usually expressed through the introduction of the rest allowance concept (Rohmert, 1973; Battini et al., 2013).

2.1 Analyzed warehouse order-picking systems

The reported research starts from the analysis of different case studies, dealing with manual picking picker-to-parts warehouses. In such systems order picking activities are performed by human operators, called pickers. Each picker travels inside the picking area on board of a picking cart. For each row of the order, he/she picks up the required number of item stocked in the shelf and he/she puts them in a pallet. When the pallet is full, the pallet is wrapped manually with a transparent film. All these tasks are hard and the ergonomics level is moderate, also considering the productivity of each picker (in terms of number of handled boxes per hour) and the average weight of the boxes. Furthermore, the considered warehouse contexts refer to different working conditions, in terms of kind of performed activities but also in terms of kind of products stored and handled.

The data about the injuries of such different warehouses have been collected, estimating also the corresponding ergonomics levels using an innovative tool based on motion capture technology, developed by the authors and called Ergo-Log (Fig. 1; Battini et al., 2014). Among the others aspects, a main difference between the studied warehouses concerns the way the operators are employed, which can be of two types. The first kind of warehouse is a normal managed one, in which the operators are directly employed by the company. The other one, instead, considers the presence of stand-by units; since the operators are not direct employees of the company but of a third part, a constant number of resources is assured over time, with a higher efficiency also in case of absences or injuries.

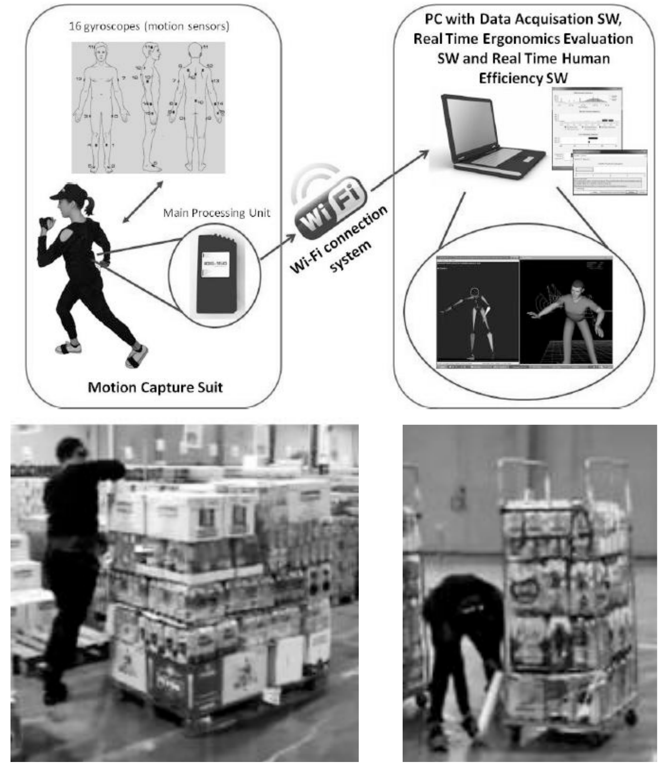

Fig. 1. Example of analysis in picking activity using the Ergo-Log motion caption technology

2.2 Human Availability in function of ergonomics level

Considering a production or logistics system where operators work, the productivity of the system and the corresponding cost depend also on the availability of human resources, especially in case of labour-intensive system. In this case, human availability can be estimated using the number of injuries and the average recovery time, happened in a certain time period. Taking the data regarding the injuries happened in the last years as an input, we can define the real human availability A_h as follows:

$$A_h = 1 - \frac{N_{inj} \cdot \overline{t}_{inj}}{T} \tag{1}$$

where N_{inj} is the number of injuries happened and caused by the work load conditions, $\overline{t}_{inj}$ is the average recovery time and T is the referred period of time, typically 1 or 2 years. These two parameters are strictly correlated to the ergonomics level of the job performed by the operators under analysis; in this study, we firstly introduce a simple mathematical model to link the human availability A_h to the ergonomics level EL. Analyzing these two parameters in similar industrial systems with different workload and environmental condition, and performing a regression analysis, we propose a general function defined in (2) and characterized by the behavior depicted in Fig. 2. The human availability A_h has a decreasing trend with the increasing of the ergonomics level EL, corresponding to a worsening of the working ergonomics conditions.

$$A_h = f(EL) = 1 - a \cdot EL^b \quad (2)$$

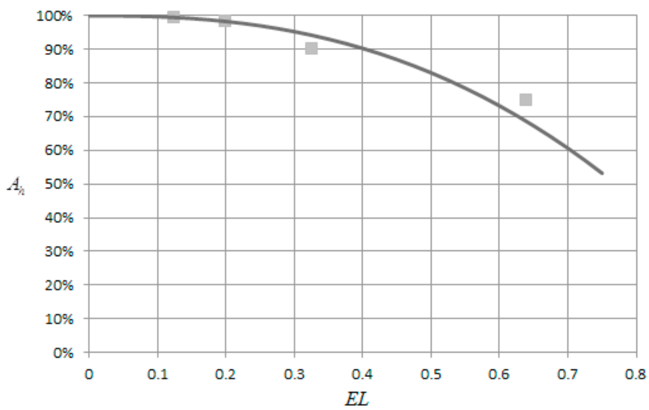

Fig. 2. Human Availability in function of Ergonomics Level

2.3 Human Performance in function of ergonomics level

The human performance can be correlated to the ergonomics level through the introduction of the concept of Rest Allowance, already well used in literature and industry. In fact, it is clear that high ergonomics levels typical of worst working conditions affect the fatigue of the operator and consequently also his/her productivity.

Some previous studies (Rohmert, 1973; Battini et al., 2013) have introduced the Rest Allowance (RA) parameters to include the recovery time to let the operator relax him/her-self after a hard work. Nevertheless, the RA is generally linked to the energy expenditure or to the muscle activity, with several difficulties to be applied in an industrial environment. In order to make the concept of RA easier to apply, we have extended the previous idea also to this step of the research, linking the RA to the Ergonomics Level, with the introduction of a simple equation, according to some previous studies, such as Rohmert's one (1973):

$$RA = f(EL) = c \cdot EL^d \quad (3)$$

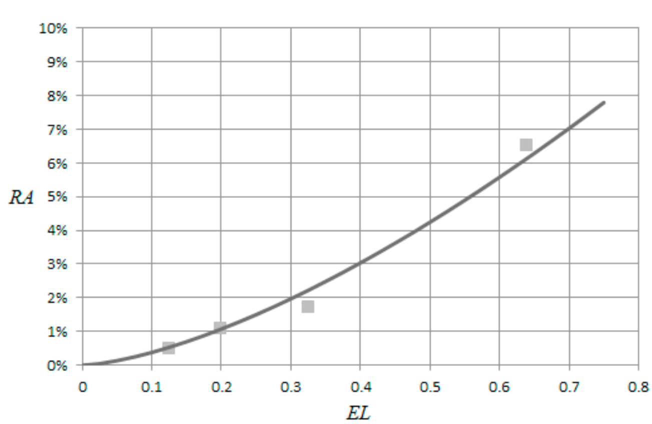

Fig. 3. RA in function of Ergonomics Level

The trend of the function is reported in Fig. 3; the two parameters could be estimated starting from several collected data from different work environments, using curve fitting or regression analysis.

3. COST MODELS FOR HUMAN AVAILABILITY IN ORDER-PICKING SYSTEMS

In this section, two different models are introduced in order to estimate the impact in terms of cost of human availability in production and logistics systems, particularly referring to labor-intensive systems, such as warehouse contexts, where picking activities are performed by human operators, or in some production systems, for example assembly workstations where handling activities require the presence of humans. In these cases, ergonomics affects in a relevant way the productivity of the systems, and especially the availability of the resources. Considering the faced case studies, we decide to model two different situations: the first one concerns a simple basic system, while the second one permits the use of a stand-by operator in a basic system. Each cost model is the sum of several additional terms related to the unavailability of the system and the level of performance of the operators, each of them linked to the ergonomics of the working conditions.

3.1 Cost model for a basic system

In this situation, depicted in Figure 4, the system works only when the operator is available: considering the case of a picking warehouse, the order picking lists are processed only if the operators work.

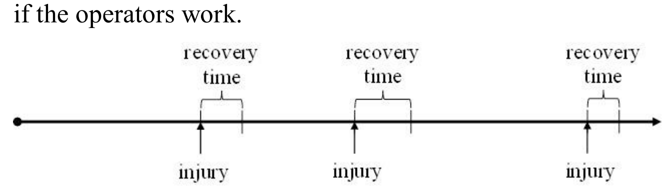

Fig. 4. Operating scheme for a basic system

Moreover, due to the working conditions already described in Section 2, in the time intervals in which the pickers are available, the productivity is anyway affected by the rest allowance, according to the function introduced in the previous section. Therefore, the proposed Total Expected Cost for a basic system TEC_{bs} turns out to be:

$$TEC_{bs} = c_h \cdot h_T \cdot (1 - A_h) + c_h \cdot h_T \cdot RA \cdot A_h \quad (4)$$

where c_h is the hourly production cost in €/h and h_T is the time period expressed in hours. Hence, the first term refers to the unavailability cost of the system and the second one is linked to the ergonomic condition and the consequent productivity reduction due to the necessity of rest allowance.

Expressing all in function of the Ergonomics Level, the equation 4 can be written as follows:

$$TEC_{bs} = c_h \cdot h_T \cdot [1 - (1 - a \cdot EL^b)] + c_h \cdot h_T \cdot (c \cdot EL^d) \cdot (1 - a \cdot EL^b) \quad (5)$$

It can be noticed that for a value of the ergonomics level *EL* = 0 the final result is equal to 0, while increasing the *EL*, the total expected cost increases more than proportional.

3.2 Cost model for a system with stand-by unit

The other studied system considers the presence of a stand-by operator, which is always introduced in the warehouse when an injury happens after a certain time in order to minimize the cost of the unproductivity period. Figure 5 explain the timing of this situation.

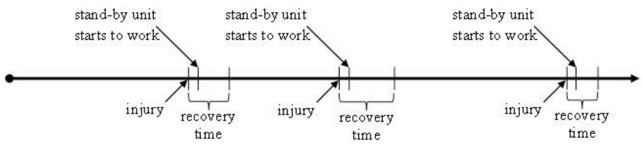

Fig. 5. Operating scheme for a system with stand-by unit

In this case, some terms have been added in order to consider the productivity of the operator introduced as stand-by unit. Then, considering Q the lower productivity of the stand-by operator with respect to the standard operator (expressed in percentage) the Total Expected Cost for a system with stand by unit TEC_{sb} is:

$$TEC_{sb} = c_h \cdot h_T \cdot (1 - A_h') + c_h \cdot h_T \cdot RA \cdot A_h + c_h \cdot h_T \cdot RA \cdot (A_h' - A_h) + c_h \cdot h_T \cdot (1 - Q) \cdot (A_h' - A_h) \quad (6)$$

In this situation, the A_h' models the human availability in presence of stand-by operator, based on this formulation:

$$A_h' = 1 - \frac{N_{inj} \cdot t_{sb}}{T} \quad (7)$$

where A_h' is the real availability of the operator, calculated with the collected data about the injuries, considering the presence of another operator as stand-by unit and t_{sb} is the time to replace the injured operator with a new one. Also in this case, this variable can be modelled in a similar way as done for A_h. Then, considering both (1) and (7), it can be obtained a relation between A_h' and A_h:

$$1 - A_h' = (1 - A_h) \cdot \frac{t_{sb}}{\overline{t}_{inj}} \quad (8)$$

A_h' can be seen as the frequency of injuries, such as the reliability of the operator, while A_h is the traditional availability of the resource. Then, by substituting (2) into (8),

$$a' \cdot EL^{b'} = a \cdot EL^{b} \cdot \frac{t_{sb}}{\overline{t}_{inj}} \quad (9)$$

and assuming $b' = b$, it also derives that

$$a' = a \cdot \frac{t_{sb}}{\overline{t}_{inj}} \quad (10)$$

3.3 Some parametrical analysis

In this section a parametrical analysis of the results measured in the faced case studies is proposed. To facilitate the understanding of the analysis, Table 1 reports the legend of all the proposed graphs, in which the x axis reports always the ergonomics level *EL*.

Table 1. Graphs legend

Fig.	y axis	$\overline{t}_{inj}$	*a'*	*b'*	*Q*	Legend
6	A_h	2 5 10	0.005 or 0.01	2.5	-	-◆- -■- -▲-
	A_h'	2, 5, 10				-●-
7	TEC_{bs}	2, 5, 10	0.005 0.01	2.5	-	■ ■
8	TEC_{sb}	2, 5, 10	0.005 0.01	2.5	-	■ ■
9	TEC_{sb}	2 or 10	0.01	2.5	0.6 0.7 0.8 0.9 1.0	-◆- -■- -▲- -×- -✳-

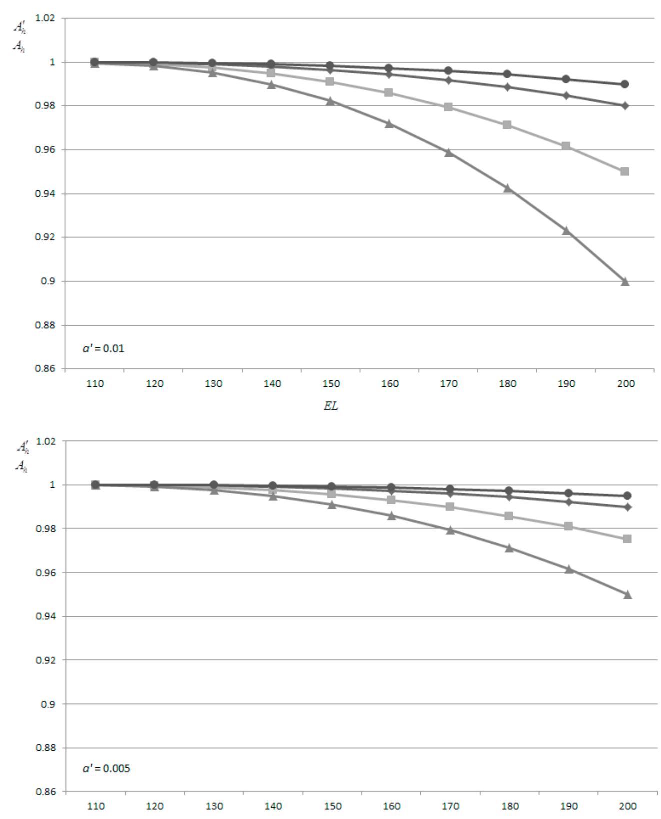

Fig. 6. A_h' and A_h varying *EL* and $\overline{t}_{inj}$ for *a* '= 0.01 and 0.005

Figure 6 reports the plotting of A_h and A'_h varying the values of the ergonomics level *EL* and of the average injury time $\overline{t}_{inj}$ for two different *a'*, 0.005 and 0.01. In this case, having fixed the value of *a'*, the average injury time $\overline{t}_{inj}$ affects only the human availability in case of a basic system.

From the observation of equations (5) and (6), it can be seen that TEC_{sb} is always lower than TEC_{bs}, having the same value when A'_h is equal to A_h. The graphs reported on Figures 7 and 8 show the trend of the two cost functions for different values of *EL* and $\overline{t}_{inj}$ and for the A'_h functions presented in Figure 6. In particular, it can be noticed as in the basic model the Total Expected Cost is mostly affected by the change in the value of the average recovery time $\overline{t}_{inj}$. On the other side, in the second kind of system, the total cost function is less influenced by such parameter, exactly for the introduction of the stand-by units. Figure 9 reports the plotting of TEC_{sb} varying the ergonomics level *EL* for $\overline{t}_{inj}$ = 2 and 10, for different values of stand-by unit productivity reduction percentage Q: such parameter has a higher impact on the cost for $\overline{t}_{inj}$ = 10 than for $\overline{t}_{inj}$ = 2.

It is important to underline that all these considerations are relevant if they are included in an overall improvement process of the system, focused on the estimation and the possible reduction of the ergonomics level. In particular, in this case, the cost models can foster the effectiveness of a cost-benefits analysis, helping the decision-makers, through the highlighting of where to operate and of which activities need to be revised in order to reduce the global ergonomics level *EL* and, consequently, the total expected cost.

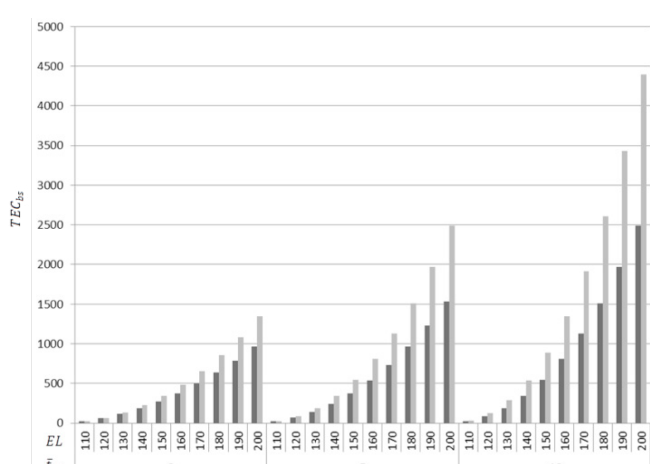

Fig. 7. TEC_{bs} varying EL (expressed in OWAS scale) and $\overline{t}_{inj}$ for two different A'_h functions

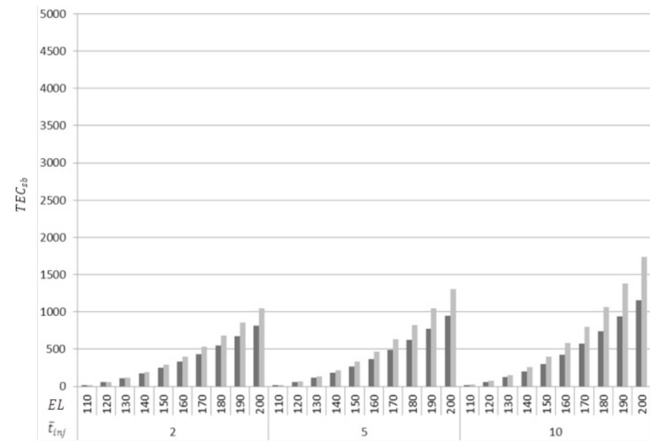

Fig. 8. TEC_{sb} varying EL (expressed in OWAS scale) and $\overline{t}_{inj}$ for two different A'_h functions

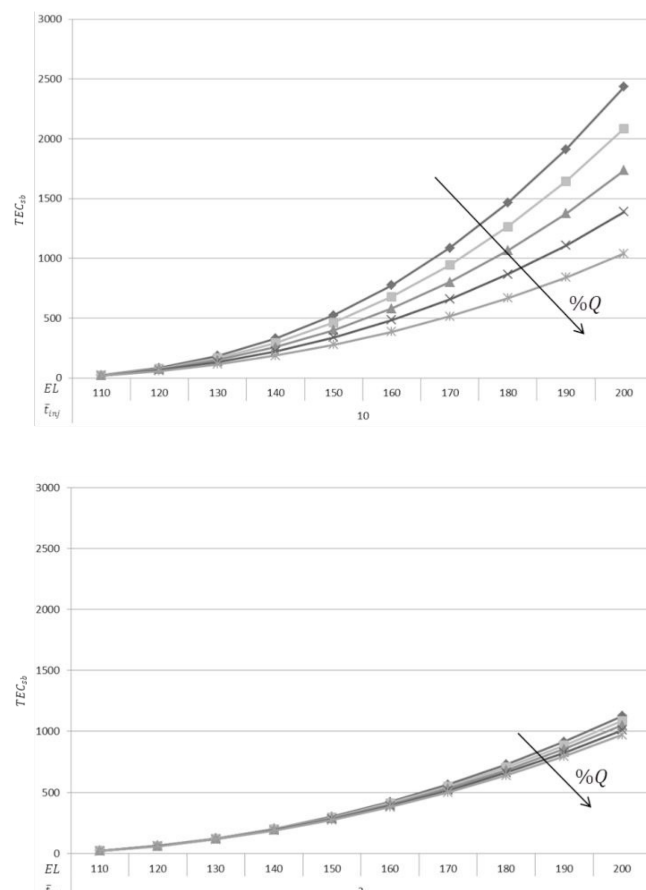

Fig. 9. TEC_{sb} varying *EL* (expressed in OWAS scale) and $\overline{t}_{inj}$ for different *Q* values.

3.4 Cost models application in two real systems

The first considered warehouse is managed in a basic way, with 40 operators directly employed by the company and working 1,760 hours per year without stand by operators. In this case, the ergonomics level measured with the Ergo-Log system is equal to 150, based on OWAS scale. A_h and RA are equal to 99.47% and 0.5%, respectively. Considering a hourly cost c_h = 25 €/h, the Total Expected Cost TEC_{bs} turns out to be 18,618.12 €/year. The definition of such kind of measure allows to easily estimate the potential benefit of introducing some changes in the existing warehouse management. In particular, moving to a system with stand-by units, with a A'_h equal to 99.95%, can lead to the reduction of the total cost to 12,429.17 €/year. Furthermore, the adoption of specific machines for plastic film pallet rolling, which can bring a reduction of the ergonomics level *EL* (from 150 to 140), permits a further saving of about 4,000.00 €/year.

The second analyzed warehouse is characterized by the presence of stand-by units, as already described in the previous sections. The handled items are heavy and medium-heavy food and non-food products, with a resulting ergonomics level *EL* of 180. A_h is equal to 98.28%, A'_h is 99.83% and *RA* is equal to 1.1%. Since the stand-by operators productivity is lower than the normal ones, Q can be set to 0.75; it derives that the Total Expected Cost TEC_{sb} is about 29,118.76 €/year. In this second context the adoption of specific machines for plastic film pallet rolling leads to reduction of the ergonomics level *EL* from 180 to 170, with a saving of about 6,400.00 €/year. On the contrary, the savings obtained by increasing the productivity of the stand-by operators *Q* are not very relevant; hence, no action is reasonable in this sense.

4. CONCLUSIONS AND FURTHER RESEARCH

The present paper has reported an analysis concerning the possible impact of ergonomics working conditions on the availability and productivity of labor-intensive industrial system. Starting from different case studies related to warehouse picking activities, two functions for modelling the relation of the human availability and the rest allowance to the ergonomics level have been proposed. Furthermore, two total cost models have been presented (one referring to a basic system and one to a system with the employment of stand-by units), to evaluate how ergonomics impacts on the total cost of the systems. In particular, it has been demonstrated that a system with stand-by units is generally preferable and less affected by the human availability. Furthermore, the global improvement of ergonomics conditions has a relevant positive impact on the total cost of the system. However, the practitioners should make cost-benefits analysis in order to understand the economic convenience of the interventions of ergonomics improvement. It is well-known that is very difficult to reduce the ergonomics level under certain values, without the substitution of humans with machines.

In the future researches, we would extend the model in other industrial contexts and improve the human availability and rest allowance functions using the innovative motion-capture system integrated with electromyography sensors.

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