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A multi-criteria ergonomic and performance methodology for evaluating alternatives in “manuable” material handling

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ABSTRACT

The objectives of this study were: 1) to develop an efficient multi-criteria approach for choosing the optimal alternative for “manuable” material handling, and 2) to apply the multi-criteria approach to a case study. In this paper, the authors use the single-word term “manuable” to refer to the definition “can be performed manually”. The case study results indicated that the use of the manipulator tested in this work may be preferable to manual material handling in situations in which the lifted weight is large (61% vs. 39%) as well as those situations in which the weight of the load could not apparently justify the investment necessary for a manipulator (53% vs. 47%). The case study also validated the selected approach. Furthermore, the applicability of the methodology was confirmed by the CEO of an Italian logistics and supply chain management company (Blu Pegaso S.r.l.).

Relevance to industry: This paper provides to the decision manager a structured approach regardless of industry and country for selection of the best alternative for manuable material handling that is able to satisfy the company objectives related to ergonomic criteria and production performance measures. The methodology also supports manufacturers of material handling devices in the optimisation of their products.

1. Introduction

Manual material handling (MMH) tasks may expose workers to several risk factors, mainly of the physical type. If performed repeatedly or over long periods of time, these tasks can lead to overwork and injury. The main risk factors or conditions associated with the development of injuries in MMH tasks include:

- Awkward postures (e.g. bending, twisting);
- Repetitive motions (e.g. frequent reaching, lifting, carrying);
- Forceful exertions (e.g. carrying or lifting heavy loads);
- Pressure points (e.g. grasping [or contact from] loads, leaning against parts or surfaces that are hard or have sharp edges);
- Static postures (e.g. maintaining fixed positions for long periods of time).

Repeated or continual exposure to one or more of these factors may initially lead to fatigue and discomfort (Van der Beek et al., 1999). Over time, injury to the back, shoulders, hands, wrists, or other parts of the body may occur. Injuries can include damage to muscles, tendons, ligaments, nerves, and blood vessels (NIOSH, 2007). Repetitive high-exertion lifting is a major contributor to injuries of the low back (Resnick and Chaffin, 1997), and MMH activities are a significant source of worker absence and high costs due to compensation claims. Numerous investigations have demonstrated the association between unassisted manual material handling and increased risk of musculoskeletal injury occurring particularly in the low back and upper extremities (Nussbaum et al., 2000). The relevance of this issue is also evidenced by the European Council Directive 90/269/EEC of 28 May 1990 (Council of European Communities, 1990), which highlights this problem as a risk factor and calls for the assessment and definition of manual load handling as “transporting or supporting of a load, by one or more workers, including lifting, putting down, pushing, pulling, carrying or moving of a load, which, by reason of its characteristics or of unfavourable ergonomic conditions, involves a risk particularly of back injury to workers”. Specifically, the general provision of the Directive obliges the employer to take appropriate organisational measures or to use the appropriate means (e.g. mechanical equipment) to avoid the need for manual load handling by workers or, at the very least, to reduce the risks involved in manual load handling.

Consequently, manufacturing engineers specify the use of material handling devices (MHDs) to eliminate or reduce the lifting requirements in MMH in many industrial facilities. These devices

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are used to assist in such diverse tasks as assembly, racking, palletising and other jobs that may include both vertical and horizontal translation (Resnick and Chaffin, 1997). Among the major MHDs mentioned are chain blocks, cranes, hoists, industrial manipulators, jib cranes and overhead cranes. The authors have focused their attention on industrial manipulators because these devices are better suited to the tasks considered in this study: the handling of moderate loads (manuable material handling). The definition of a manipulator given by the European Committee for Standardization is a "powered machine, where the operator has to be in contact with the load or holding device, in order to guide and/or control the motion of the load to bring it to a position in space" (EN 14238, 2009). The basic function is simple: to eliminate the magnitude of the static (gravitational) load that the worker must handle, with an expected reduction in musculoskeletal stresses.

Even if manipulators exist for this purpose, their use can be ineffective because it requires significant dynamic forces due to large system inertias and forced pace production. Woldstad and Chaffin (1994) state that many MHDs do not always decrease the workload or the workload as perceived by the operator. In addition, a number of informal interviews with workers who use these devices have revealed that, in many cases, the workers find using the devices equally as fatiguing as actually lifting and carrying the load. Indeed, in a situation where the load is only marginally heavy (i.e. 30–50 lbs, approximately 13.6–22.7 kg), it is not unusual to see the assist devices discarded in favour of manual methods. For moderate loads, manipulators are often discarded after installation, and the operators do not always report decreases in perceived workload when using them (Nussbaum et al., 2000). Nussbaum et al. (2000) also claims that a significant time penalty is incurred when using manipulators, especially in jobs with relatively short cycle times. Rossi et al. (2012) defined a methodology to select the best solution to perform a task from an ergonomic point of view. However, the analysed papers rarely propose a comparison of the performance of the different handling solutions as well as a cost-benefit analysis.

In any case, the literature presents several articles that address problems of production performance with the support of multicriteria methodologies (e.g. Byun (2001), Vinodh et al. (2012), and DiDomenico and Nussbaum (2011)) but without treatment of the performance of the industrial manipulators. In light of this evidence, the authors have carried out a study to select the best handling solution for short-distance movements of moderate-load objects considering both ergonomic criteria and production performance. The best handling solution is assumed as the alternative that best satisfies the company objectives.

The study develops a systematic approach using the analytic hierarchy process (AHP), a decision support methodology for multicriteria analysis that enables the combination of tangible and intangible criteria. Various ergonomic methods are available for the assessment of exposure to workplace risk factors for work-related musculoskeletal disorders (David, 2005). So the purpose is to support the integration of the results of those ergonomic methods, although the standardised methods for the ergonomic evaluation of manual handling (ISO 11228-1, 2003; ISO 11228-2, 2007; ISO 11228-3, 2007) are generally applied separately (Cocca et al., 2008). The authors chose this method because it is suitable for resolving complex multi-criteria decision problems by ranking of decision alternatives followed by selection of the best alternative under multiple objectives (Okur et al., 2009; Lee et al., 2009; Saaty, 2008; Hsu and Chen, 2007).

2. Material and methods

The basic problem of decision-making is to choose the best option from a set of competing alternatives that are evaluated under conflicting criteria. The AHP is a multi-criteria decision-making tool developed in the 1970s by Saaty (1980) to solve a specific class of problems that involve prioritisation of potential alternative solutions that considers both qualitative and quantitative criteria (Henderson and Dutta, 1992). This technique consists of a systematic approach based on breaking the decision problem into a hierarchy of interrelated elements. Such a structure clarifies the problem and presents the contribution of each of the elements to the final decision.

Two features of the AHP differentiate it from other decision-making approaches. First, it provides a comprehensive structure that combines the intuitive rational and irrational values during the decision making process. Second, the AHP has the ability to judge the consistency in the decision-making process (Akarte et al., 2001). The advantage of the AHP is its flexibility, ease of use, and the ability to provide a measure of the consistency of the decision maker's judgment (Park and Lim, 1999). In addition, this method allows the incorporation of tangible and intangible factors that would otherwise be difficult to take into account.

The AHP has been used in almost all applications related to decision-making. Vaidya and Kumar (2006) critically analysed a subset of the papers with applications of the AHP published in international journals of high repute and gave a brief summary of many of the referred publications. Subramanian and Ramanathan (2012) reviewed the literature on the applications of the AHP in operations management and suggested possible gaps from the point of view of both researchers and practitioners. They also found that the AHP was predominantly used in the engineering, personal and social sectors. The references were grouped by region and year to track the growth of AHP applications. The AHP has been applied for many purposes (e.g. selection, evaluation, allocation, etc.) and in different areas of applications (e.g. personal, social, manufacturing, political, engineering, education, sports, etc.).

Briefly, and according to Saaty (1980), Saaty (1987, 2008), the step-by-step procedure in using AHP is the following.

1. Structuring of the decision problem into a hierarchical model

This includes decomposition of the decision problem into factors that are important for the decision. These factors are arranged in a hierarchic structure having various levels: from the top (i.e. the Goal, an overall objective) through intermediate levels (i.e. elements: Strategic Criteria, Criteria, Sub-criteria, …) to the lowest level (i.e. the decision alternatives).

2. Making pairwise comparisons and obtaining the matrices of element evaluation

In this step, the elements of each level are compared pairwise, weighting them as a function of their importance for corresponding element of the higher level. The aim is to construct a set of pairwise

Table 1
Scale of relative importance according to Saaty (1980) and Saaty (1987).

Intensity of importance	Definition
1	Equal importance between A_i and A_j
3	Weak/moderate importance of A_i over A_j
5	Essential or strong importance of A_i over A_j
7	Demonstrated/very strong importance of A_i over A_j
9	Absolute/extreme importance of A_i over A_j
2, 4, 6, 8	Intermediate
Rationals	Ratios arising from the scale
Reciprocals	If A_i has one of the above numbers assigned to it when compared with A_j, then A_j has the reciprocal value when compared with A_i