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Ergo-Lot-Sizing: Considering Ergonomics in Lot-Sizing Decisions

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Abstract: One aspect that has mostly been overlooked in traditional economic lot-sizing is the implication of decisions on manual tasks and workload. Although lot-sizing decisions can have a significant impact on required manual material handling and on human performance, works that consider ergonomic aspects in lot-sizing are rare. This paper presents a model that integrates ergonomic aspect in terms of human energy expenditure and rest allowance in a traditional lot-sizing model. The behavior of the model is analyzed in a numerical study, showing its ability to reflect manual workload, and that ergonomic aspects should be considered in lot-sizing decisions.

Keywords: EOQ; Lot-sizing; Ergonomics; Human factors; Social sustainability

1. INTRODUCTION

Global competition and the need for fast delivery times force companies to reduce costs and increase service levels. One of the most important decisions that affect raw material availability and lead times in industrial companies is the determination of so-called production lot-sizes, i.e. quantities of a product that are manufactured on a facility without interruption. Lot-sizes influence inventory levels in the company and may also affect product quality, productivity, or product deterioration, to name just a few examples (see, forcomprehensive reviews of the lot-sizing problem, Glock et al., 2014, Andriolo et al., 2014). The common objective of lot-sizing decisions is the minimization of total costs by determining economic production quantities that balance inventory holding, setup and other affected costs (cf. Beck et al. 2015).

The lot-sizing problem has received a lot of attention in recent years (Glock et al. 2014, Andriolo et al. 2014). Just recently, a new research stream that focuses on sustainability issues in lot-sizing emerged ('sustainable EOQ'), with some notable works being those of Battini et al. (2014), Absi et al. (2013), Bouchery et al. (2012), Glock et al. (2012) and Andriolo et al. (2013). The concept of 'sustainability' referred to in these works, however, only considered the environmental and economic dimensions of sustainability, and neglected the social component (such as worker welfare) that is regularly cited as the third pillar of the 'triple bottom line'-approach (cf., Elkington 1997). This is surprising as lot-sizing decisions can have a significant impact on workload and manual material handling, which makes ergonomic aspects relevant. For example, if large lots are produced that have to be transported manually into the warehouse of the company (e.g., by using a trolley or a cart), excessive pushing or pulling of a vehicle or carrying of the product may lead to worker fatigue or worker injuries (Jung et al. 2005; Knapik and Marras 2009; Grosse et al. 2015). Preventing high load and worker fatigue may make it necessary to reduce lot-sizes, which, in turn, results in an increase in setup costs. Interdependencies as the ones just described have thus far not been considered in the literature on lot-sizing.

The determination of production lot-sizes affects the amount of manual material handling and thus the risk for workers developing musculoskeletal disorders (MSDs). Risk factors include repetitive work with forceful exertions, awkward body postures, heavy lifting, insufficient recovery time and rapid work pace (Punnet and Wegman 2004). MSDs are the single largest category of work-related illness, with manufacturing and handling tasks, such as those that occur in assembly work and warehousing, representing high-risk environments (Punnet and Wegman 2004). Work-related disorder is defined as '*one that results from a number of factors, and where the work environment and the performance of the work contribute significantly, but in varying magnitude, to the causation of the disease*' (WHO 2003). In the European Union (EU), MSDs account for over 38% of occupational diseases, with lifting of loads being a high-risk factor for workers developing MSDs (EHSAW 2010). The economic cost of work-related MSDs accounts for up to 2% of the Gross National Product in the EU. It is estimated that direct costs of MSDs (which include cost for detection, treatment and rehabilitation) and indirect costs (which include lost work output, lost productivity and lost earnings) are in excess of 240 billion € (Bevan 2012).

To reduce the risk of MSDs, various ergonomic assessment methods have been developed that help to derive a risk value for the execution of specific manual tasks (Chiasson et al. 2012). In general, ergonomics (HF: Human Factors) aims to optimize human well-being and overall system performance (Karwowski 2005). Among these ergonomic assessment methods are the NIOSH lifting equation (Dempsey 2002), the OWAS method (De Bruijn et al. 1998) and the European assembly worksheet (Schaub et al. 2013).

In this paper, we integrate the rest allowances and energy expenditure of operators during the task execution as

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ergonomic variables (Rohmert, 1973; Garg et al. 1978) in a lot-sizing model. As will be shown below, considering HF in lot-sizing models influences the lot-sizing decision and helps to generate results that improve worker well-being in a practical application.

2. PROBLEM DEFINITION

We investigate a typical logistics process, namely the manual handling of a certain amount of products at different stocking points inside the production/logistics system. Examples of this process are the transportation of products from the final stage of a production system to a storage facility, or the refilling process performed in an order picking warehouse from the reserve area to the forward area. In particular, we consider a stocking point, called "A", where items are stored until they are shipped to the next stocking point, named "B". Human workers are responsible for transporting the items from point "A" to point "B". They pick a certain quantity of products from point "A" and then put them on a trolley, which is used for transporting the items manually to point "B". At this point, items are stored in a rack or other storage facilities.

The quantity that each operator handles for each trip is the decision variable and its value depends on:

- the standard time spent for each activity (picking, travelling and storing);
- the travel speed, which is a function of the item weight and trolley load. Thus, the larger the batch size, the lower the travel speed;
- the rest allowances necessary to guarantee an acceptable ergonomics level, which is a function of the energy expenditure (Rohmert, 1973; Garg et al. 1978) of the operator during the task execution. One break after each cycle of tasks is assumed.
- the availability of the worker affected by the accumulated manual load, which impacts to the number of injuries and their magnitude.

We model this problem in the next section using an analytical formulation of the total time spent in the whole process, and by introducing several functions in order to consider ergonomic aspects in lot-sizing decisions. By minimizing the total time function, the optimal ergonomic lot-size can be derived.

3. ERGONOMIC LOT-SIZING MODEL

3.1 Model definition

Based on the problem description, we introduce the following equation in order to estimate the total time spent for handling the total amount of items Q, with an item weight of w:

$$ET(q) = \frac{(T_p + T_t + T_s)\cdot(1 + RA)}{A}\cdot N_t \quad (1)$$

where $T_p = q \cdot t_p$ is the total time required to pick the lot q from the stock point "A" and to put it in the trolley, t_p is the unitary picking time; $T_t = d / s_t + d / s_{max}$ is the total travel time required to bring the lot q from "A" to "B", covering the distance d at a travel speed s_t, and for returning to point "A" at maximum speed s_{max}. $T_s = q \cdot t_s$ is the total storage time that is needed to store the lot q at the stock point "B", where t_s is the unitary storing time. RA is defined as the rest allowance necessary to maintain a low level of fatigue and to avoid ergonomic risks, while A is the availability of the operator. Finally, $N_t = Q / q$ is the total number of trips necessary to ship the total amount of items Q from "A" to "B".

3.2 Travel speed, rest allowance and availability functions

In order to consider the ergonomic aspect in the lot-sizing decision, we model the travel speed, rest allowance and human availability using the following equations. We use these functions based on our experiences and by simplifying several equations developed in the literature (Rohmert et al, 1973). The travel speed s_t is a function of s_{max} (we assume it is equal to 1.2 m/s), and it is modelled by the following equation, where two speed parameters s_1 and s_2 have been used to define the behaviour of the curve function:

$$s_t = s_{max} \cdot \left[1 - s_1 \cdot (w \cdot q)^{s_2}\right] \quad (2)$$

Figure 1 shows the travel speed as a function of q and for different item weights *w*. We assume s_1 and s_2 are equal to 0.08 and 0.4. Their values depend on the used equipment for product transportation and are estimated by measuring the speed performance of the operator for different levels of trolley load.

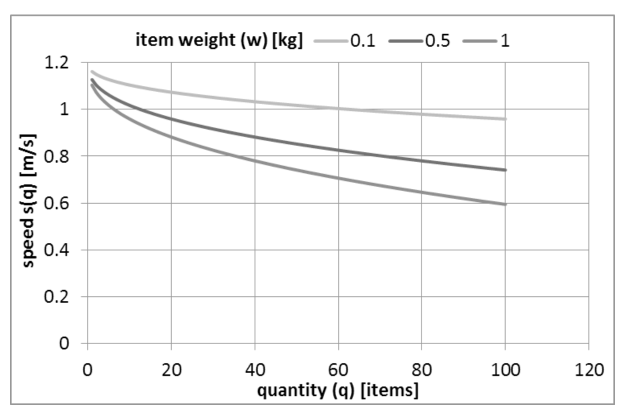

Fig. 1. Speed functions for different item weights.

The rest allowance is estimated using a model similar to the one introduced by Rohmert (1973), where the rest time after a task execution is exponential to the time spent and the energy expenditure. In our model, the time spent is a function of q, while we assume that the energy expenditure increases proportionally with the handled load during the task