Incorporating ergonomic risks into assembly line balancing

Alena Otto, Armin Scholl*

Friedrich-Schiller-University of Jena, Chair of Management Science, Carl-Zeiß-Straße, D-07743 Jena, Germany

A R T I C L E  I N F O
Article history:
Received 23 October 2010
Accepted 29 January 2011
Available online 4 February 2011

Keywords:
Scheduling
Combinatorial optimization
Ergonomic risk assessment
Assembly line balancing
Simulated annealing

A B S T R A C T
In manufacturing, control of ergonomic risks at manual workplaces is a necessity commanded by legislation, care for health of workers and economic considerations. Methods for estimating ergonomic risks of workplaces are integrated into production routines at most firms that use the assembly-type of production. Assembly line re-balancing, i.e., re-assignment of tasks to workers, is an effective and, in case that no additional workplaces are required, inexpensive method to reduce ergonomic risks. In our article, we show that even though most ergonomic risk estimation methods involve nonlinear functions, they can be integrated into assembly line balancing techniques at low additional computational cost. Our computational experiments indicate that re-balancing often leads to a substantial mitigation of ergonomic risks.

1. Introduction
The problem of unfavorable working conditions, or poor workplace ergonomics, is an acute topic today. Ergonomic risks at the workplace cause a lot of damage on health and quality of life of workers, deteriorate economic results of employers and of the economy as a whole. In 2008, along 315,000 cases of work-related musculoskeletal disorders (MSDs, often referred to as ergonomic injuries), requiring a median of 10 days away from work, were reported in the US (Bureau of Labor Statistics, 2009). Annual compensation cost for MSDs paid by employers in the US amount to 15 to 20 billion US dollars. Moreover, occupational diseases of workers indirectly cause further cost on firms: via loss of production capacity due to absenteeism of workers, lower worker productivity and higher defect rates in work. This can be illustrated by the example of Peugeot, whose ergonomics program reduced the cycle time for the final vehicle assembly line together with a simultaneous decrease by 30% in new cases of musculoskeletal disorders (Moreau, 2003).

Workplace ergonomics is becoming even more important following recent developments in legislation (EU Machinery directive, 2006/42/EC, 89/391/EEC, Occupational Safety and Health act of 1970 among others) and an on-going ageing of the workforce in most of the developed countries.

Already today in assembly line production, especially in final assembly, where the share of manual labor is high, a special attention is paid to ergonomics. Most renowned companies incorporate methods for ergonomic risk estimation of working places in their production routine (Toyota Verification of Assembly Line at Toyota, GM-UAW at General Motors, AP-Ergo at Volkswagen to name a few). If ergonomic risks are detected, re-balancing of the assembly line is recommended as an effective method in the short-run (Hilla, 2006).

Ergonomic aspects have been barely considered in assembly line balancing literature, though they are becoming increasingly important in practice. Few articles on this topic are those of Miralles et al. (2008) and Costa and Miralles (2009), who introduce and analyze a problem of assigning workloads to stations and to workers with different (dis-) abilities. Another article, written by Carnahan et al. (2001), examines an assignment of a certain class of tasks – gripping tasks – and their influence on fatigue and recovery dynamics of workers. However, to our best knowledge, no attempt has been made yet to incorporate ergonomic risk estimation methods into state-of-the-art line balancing models, though they are considered important by manufacturers.

To close this gap, we address this important question in the present study. We provide an overview of some methods for ergonomic risks estimation, which are recommended and utilized in practice. Most of those methods are based on nonlinear functions such that incorporating them into state-of-the-art line balancing models and (exact) solution procedures is not straightforward.

We propose different ways to model ergonomic aspects and a two-stage heuristic approach, based on the well-known exact balancing procedure SALOME and the heuristic meta-strategy simulated annealing. By means of this heuristic approach, we can achieve a significant reduction in ergonomic risks of workplaces at low computational cost even without increasing manufacturing capacity, i.e., number of workstations (and workers). The proposed
two-stage heuristic approach, furthermore, allows for a controlla-
ble increase in manufacturing capacity considering the trade-off
between increased costs from adding stations on the one hand
and reduced ergonomic risks on the other hand.

We precede with an overview of ergonomics tools in Section 2.
A line balancing problem incorporating ergonomic risk factors,
ErgoSALBP, is described and modeled in Section 3. In Section 4,
we propose a two-stage heuristic, which is tested in comprehe-
sive computational experiments in Section 5. A discussion in Sec-
ction 6 concludes the paper.

2. Methods for estimating ergonomic risks

In the mandatory Appendix D.1 to §1910.900 of “Final Ergono-
mics Program Standard”, the Occupational Safety and Health
Administration (2000; OSHA for short) provides a list of methods
recommended for the estimation of ergonomic risks of workplaces.
In this section, we provide a brief description of selected methods
recommended by OSHA for application in assembly line production
—the revised NIOSH (the National Institute for Occupational Safety
and Health) equation and the job strain index; the method OCRA
(Occupational Repetitive Action) recommended by European
Norms on repetitive actions (EN 1005-5, 2007) and the EAWS
(European Assembly Worksheet) method, which was created for
and adapted by several European firms that employ an assembly
production system.

Throughout the paper, we will use an example of an assembly
line, the precedence graph for which is given in Fig. 1. The graph
consists of \( n = 11 \) tasks \( i = 1, \ldots, n \) with task times \( t_i \) to be executed
on each workpiece at a workstation during the cycle time of
\( c = 63 \) seconds. Every task involves several actions of upper limits,
while some of them demand application of forces (see Table 1).

2.1. Risk estimation for manual handling: revised NIOSH equation

The NIOSH equation was developed in 1981 by the National
Institute for Occupational Safety and Health for risk estimation of
working conditions, where manual handling activities are the main
source of risk and lifting comprises more than 90% of manual han-
dling activities (Waters et al., 1994).

The NIOSH equation communicates a lifting index \( LI \) that shows the relation of the current load weight to the recommended load
weight limit:

\[
LI = \frac{\text{Load weight}}{\text{Recommended weight limit}}
\]

The higher the lifting index, the higher percentage of the workforce
is likely to be under risk for developing low back pain. The recom-
ended weight limit is calculated depending on lifting conditions
\( TS \), e.g. vertical travel distance of hands or degree of asymmetry
in posture, and the frequency of lifting \( FM \):

Recommended weight limit = \( TS \cdot FM \)

The frequency multiplier \( FM \) is calculated based on the average
number of lifts per minute. It takes into account the duration of
the lifting activity, as well as the vertical height of the lift from the
floor. In Table 2, we present frequency multipliers for 2–8 hours
of continuous lifting and vertical lift height of 30 cm or more. \( TS \)
considers task specific parameters and indicates the maximal recom-
ended weight of the load that can be lifted by healthy workers
under certain lifting conditions. For example, under the ergonomi-
cally most favorable lifting conditions (e.g. when the weight is held
close to the body), \( TS \) is equal to 23 kg.

In our example, let us assume that tasks 6 and 7 are performed
on the same station. The worker lifts – under ergonomically favor-
able lifting conditions – a 17 kg and a 15 kg load in each cycle of
63 seconds (see Table 1). The task specific parameter \( TS \) for both
cases of lifting has the ideal value of 23 kg and the frequency mul-
tiplier \( FM \) for both cases is 0.7557 (60/63 = 0.9524 lifts per minute,
the value of \( FM \) is retrieved from Table 2 by interpolation). So, the
recommended weight limit is 17.38 kg and the resulting lifting
indices are 0.98 for task 6 and 0.86 for task 7.

In case of several lifting tasks, we compute the composite lifting
index \( CLI \) as follows:

\[
CLI = LI_1 + \left( LI_{12}^2 - LI_1^2 \right) + \left( LI_{123}^2 - LI_{12}^2 \right) + \cdots
\]

\( LI_{1-1} \) is calculated for the lifting task \( j \) based on the cumulated
frequency of the tasks 1, 2, …, \( j \). Tasks are numbered in non-increasing
order of their individual lifting indices \( LI_j \). Generally, composite
\( CLI \leq 1 \) is considered to be acceptable.

For a station load consisting of tasks 6 and 7, we get \( LI_1 = 0.98 \)
and \( LI_2 = 0.86 \) as explained above as well as \( LI_{12} = 0.99 \), which
 corresponds to two lifts of 15 kg in 63 seconds, so that the compos-
ite index \( CLI \) amounts to 1.11. Usually, this work load is considered
unacceptable.

Similar Methods. Several other methods are constructed
according to the logics of the revised NIOSH lifting equation,
e.g., the Siemens method (Bokranz and Landau, 2006). Addition-
ally, the Siemens lifting index takes into account \( FI \), a factor that
is dependent on demographic characteristics and fitness of the
worker:

\[
LI = \frac{\text{Load weight}}{\text{Recommended weight limit}} = \frac{\text{Load weight}}{FI \cdot FM \cdot TS}
\]
دریافت فوری
متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات