Waste Management 31 (2011) 1121–1132

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Improving the layout of recycling centres by use of lean production principles

Erik Sundin [a,*], Mats Björkman [a], Mats Eklund [b], Jörgen Eklund [c], Inga-Lill Engkvist [c]

[a] Division of Assembly Technology, Department of Management and Engineering, Linköping University, SE-58381 Linköping, Sweden
[b] Division of Environmental Technology and Management, Department of Management and Engineering, Linköping University, SE-58381 Linköping, Sweden
[c] Division of Ergonomics, School of Technology and Health, Royal Institute of Technology, Alfred Nobels Allé 10, SE-141 52 Huddinge, Sweden

ARTICLE INFO

Article history:
Received 5 July 2010
Accepted 24 December 2010
Available online 3 February 2011

ABSTRACT

There has been increased focus on recycling in Sweden during recent years. This focus can be attributed to external environmental factors such as tougher legislation, but also to the potential gains for raw materials suppliers. Recycling centres are important components in the Swedish total recycling system. Recycling centres are manned facilities for waste collection where visitors can bring, sort and discard worn products as well as large-sized, hazardous, and electrical waste. The aim of this paper was to identify and describe the main flows and layout types at Swedish recycling centres. The aim was also to adapt and apply production theory for designing and managing recycling centre operations. More specifically, this means using lean production principles to help develop guidelines for recycling centre design and efficient control.

Empirical data for this research was primarily collected through interviews and questionnaires among both visitors and employees at 16 Swedish recycling centres. Furthermore, adapted observation protocols have been used in order to explore visitor activities. There was also close collaboration with a local recycling centre company, which shared their layout experiences with the researchers in this project.

The recycling centres studied had a variety of problems such as queues of visitors, overloading of material and improper sorting. The study shows that in order to decrease the problems, the recycling centres should be designed and managed according to lean production principles, i.e. through choosing more suitable layout choices with visible and linear flows, providing better visitor information, and providing suitable technical equipment. Improvements can be achieved through proper planning of the layout and control of the flow of vehicles, with the result of increased efficiency and capacity, shorter visits, and cleaner waste fractions. The benefits of a lean production mindset include increased visitor capacity, waste flexibility, improved sorting quality, shorter time for visits and improved working conditions.

1. Introduction

1.1. Increased importance of recycling

Recycling centres are manned facilities for waste collection where visitors can bring, sort and discard worn products as well as large-sized, hazardous, and electrical waste. The recycling centres are primarily intended for use by private citizens and employees from smaller companies. Different waste/material fractions in the form of different products and materials (e.g. furniture, home appliances, wood, and garden waste) are placed in different large steel containers, depending on the type of product or material. An example of a schematic view of a recycling centre is shown in Fig. 1. Some types of waste are put into smaller cages or boxes at designated areas for particular waste fractions. These are often waste fractions like hazardous waste such as solvents, oils, and paint but also electrical apparatus. Almost everything but kitchen waste is accepted at the centres, since that is dealt with by a separate kerbside collection scheme. The items that the visitors bring to the recycling centres will hereafter be denoted as 'waste', whether these disposed items are worn products, materials, or other waste. According to Swedish Waste Management (SWM), there are more than 700 recycling centres in Sweden (SWM, 2008).

Environmental legislation and directives have a strong affect on the recycling centres. For example, the European Union has directives concerning how to handle waste; two such directives are the *Packaging and Packaging Waste (PPW)* and *Waste of Electric and Electronics (WEEE)* and (see EU, 1994 and EU, 2003). Industry and consumers are affected by an even tougher Swedish environmental legislation. Sweden currently has one of the world's highest amounts of collecting and recycling electrical and electronic equipment: 15.4 kg per inhabitant and year (SWM, 2010), a figure which illustrates the high impact of the Swedish recycling centres.

* Corresponding author. Tel.: +46 13 286601; fax: +46 13 282798.
E-mail addresses: erik.sundin@liu.se (E. Sundin), mats.bjorkman@liu.se (M. Björkman), mats.eklund@liu.se (M. Eklund), jorgen.eklund@sth.kth.se (J. Eklund), inga-lill.engkvist@sth.kth.se (I.-L. Engkvist).

0956-053X/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.wasman.2010.12.021

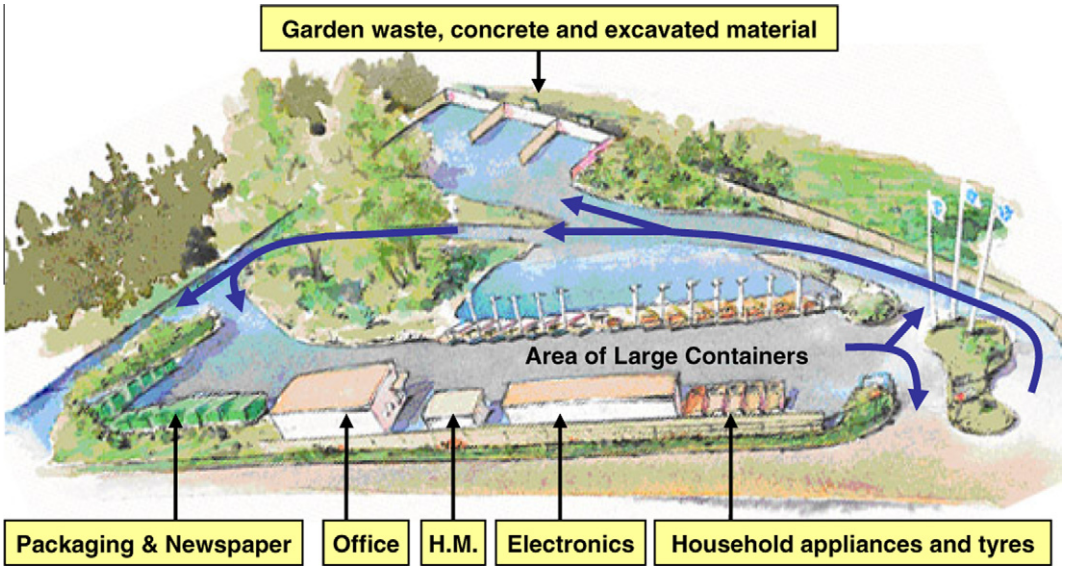

Fig. 1. A schematic 3D-view of a recycling centre illustrating the driving directions for visitors and the different waste fraction's location on the recycling centre. At the upper part of the area of large containers the visitor's can dispose of their wood waste, burnable waste, landfill waste, plastics, metal into the containers standing on a lower level. H.M. stands for hazardous waste (modified from Tekniska Verken (2010)).

1.2. Production challenges within recycling centres

As the trend towards recycling grows, so does the need for increasing the efficiency of recycling centres. One way of doing this is to adapt ideas, theories, strategies, philosophies, and principles from the area of production engineering. However, there are challenges in translating and implementing established production theories and philosophies such as e.g. lean production (Liker, 2004) to enhance the performance and efficiency of recycling centres. Lean production is widely adopted, and is claimed to increase productivity, decrease lead-time and costs and enhance quality (Sanchez and Perez, 2001). The lean production ideas developed by Toyota are in their most basic form the systematic elimination of waste, and thus the increase of efficiency. The word 'waste' in lean production context is not the same as 'waste' in the environmental and recycling context. Instead, waste in the lean production context refers to issues like overproduction, waiting, transportation, inventory, motion, over-processing, defective units. Furthermore, lean production is strongly associated with the implementation of the concepts of continuous flow and customer pull (Womack and Jones, 1996). Lean production focuses on reducing waste in production, and is based on the Toyota Production System (TPS), which relies on 14 principles to reduce waste (Liker, 2004).

For many years, industrial production systems have been analysed from a system performance perspective. This includes analysis of the production system layout, lead time calculations, reduction of bottlenecks, flexibility handling, reduction of queues etc., as discussed in e.g. Shingo (1988). These analyses are often made in order to plan and control the flow of production. Looking at recycling centres from an industrial production system perspective, there is clearly a challenge when it comes to interpreting and implementing this industrial mindset into recycling centre terms.

In production, much focus is put on shortening the lead time for the products leaving the factory, e.g. allowing for fast assembly, testing and packing for delivery (time-to-customer). Also, to minimize material and half-finished products, so-called work-in-progress (WIP) is important since inventories occupy space and create capital costs. Furthermore, production flexibility is something that manufacturers need to effectively manage in order to meet variation in product demand (Slack et al., 1998). Large inventories normally reduce a manufacturer's flexibility.

There are some principal differences between recycling centres and an ordinary industrial production system. For example, it is the function of the recycling centres to receive and take care of visitors' waste, i.e. *'a push system'*, while industrial production systems normally order the incoming material from their suppliers, i.e. *'a pull system'* (Slack et al., 1998). Furthermore, the centres do not get paid for the majority of their output, while normal production systems gain profit on almost all of their output. Thus, a recycling centre can be regarded as a combination of a service and a production operation.

There are different types of lead time concerning recycling centres. The lead time can be defined as the time from when the visitor enters the recycling centre until leaving it. In this research, this recycling centre lead time has been in focus because designing and managing recycling centre operations is in focus in the research. Another important type of lead time is defined as the total time from a visitor's decision to leave their house to discard waste/products until that person leaves the recycling centre or has returned to their home again. This lead time may be a function of the recycling centre lead time, the location of the recycling centre, the means of communications for the visitors to go to the recycling centre, etc. How this function should be optimised has not been a part of this research, but is a very important and interesting area for future research.

The recycling centres must be designed to minimise the recycling centre lead times and/or to maximise the flow rate of the visitors' vehicles. There is obviously a trade-off situation between lead time/capacity and cost in the form of investment cost as well as operation cost. The challenge is to achieve a high level of efficiency in the form of short lead time/high capacity at a low cost.

However, the notion that a visitor's time is also valuable is one that is all too often neglected. Society cannot expect its citizens to spend excessive time waiting in queues at recycling centres. Furthermore, minimisation of the lead time is also important from an environmental point-of-view, as there is a substantial risk that people will try to dispose of their waste in non-environmentally friendly ways if it is too cumbersome to use the recycling centres. Another important design parameter is sorting quality; it must be