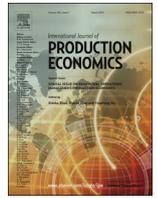




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The lot sizing problem: A tertiary study

Christoph H. Glock*, Eric H. Grosse, Jörg M. Ries

Carlo and Karin Giersch Endowed Chair "Business Management: Industrial Management", Department of Law and Economics, Technische Universität Darmstadt, Hochschulstr. 1, 64289 Darmstadt, Germany

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ABSTRACT

This paper provides a survey of literature reviews in the area of lot sizing. Its intention is to show which streams of research emerged from Harris' seminal lot size model, and which major achievements have been accomplished in the respective areas. We first develop the methodology of this review and then descriptively analyze the sample. Subsequently, a content-related classification scheme for lot sizing models is developed, and the reviews contained in our sample are discussed in light of this classification scheme. Our analysis shows that various extensions of Harris' lot size model were developed over the years, such as lot sizing models that include multi-stage inventory systems, incentives, or productivity issues. The aims of our tertiary study are the following: firstly, it helps primary researchers to position their own work in the literature, to reproduce the development of different types of lot sizing problems, and to find starting points if they intend to work in a new research direction. Secondly, the study identifies several topics that offer opportunities for future secondary research.

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1. Introduction

Since the publishing of Ford Whitman Harris' (1913) seminal paper, the lot sizing problem, which aims at determining economic (production or order) lot sizes by balancing inventory and setup or order costs, has received wide attention both in the academic literature and in practice. According to Google Scholar, the reprint of the original article that appeared in *Operations Research* in 1990 has been cited 660 times, while Scopus lists 214 citations of the original article. The search term "lot size" ("EOQ", "EPQ") results in more than 40,300 (34,100, 32,000) hits in Google Scholar and more than 2400 (1450, 1070) document results in Scopus.¹ These numbers illustrate impressively how the results of Harris' work have disseminated over the last 100 years.² Curiously enough, Harris' paper was cited with an incorrect year of publication for many years, and further it was only very infrequently considered in the literature for almost 70 years after its appearance (cf. Erlenkotter, 1989, 1990). For a comparison between

Harris' lot size formula and Kelvin's Law that was published already in 1881, the reader is referred to Roach (2005).

The attention the lot sizing problem has received is not surprising given the importance of inventories in the global economy. The management of inventories is among the most important operational activities of industrial and trading companies. Inventory levels and structures may directly influence customer service in terms of product availability and delivery speed, which are both indispensable elements for competitiveness in developed economies (see Vastag and Montabon, 2001). In addition, managing inventories efficiently may lead to significant cost reductions. According to the US Census Bureau (2013), the present value of inventory in the United States exceeds \$1.6 trillion, which illustrates the enormous potential a reduction in inventories may have on individual companies and an economy as a whole.

The Economic Order Quantity (EOQ) model proposed by Harris is a simple and efficient tool to avoid excessive inventory build-up in companies, and its robustness has frequently been confirmed in the literature (e.g., Lowe and Schwarz, 1983; Dobson, 1988; Stadler, 2007). An almost uncountable number of extensions of the basic model exists, which include multi-stage production systems (e.g., Bogaschewsky et al., 2001; Glock, 2011), worker learning (see Jaber and Bonney, 1999; Glock and Jaber, 2013), or the determination of safety stocks (e.g., Hadley and Whitin, 1963; Glock and Ries, 2013), among others. A comprehensive review on the lot sizing problem has not been conducted so far. The lack of such an overview is, according to Williams and Tokar (2008), "a handicap to the advancement of theory and practice in inventory management".

* Corresponding author. Tel.: +49 6151 16 75718; fax: +49 6151 16 2626.

E-mail addresses: glock@bwl.tu-darmstadt.de (C.H. Glock),grosse@bwl.tu-darmstadt.de (E.H. Grosse), ries@bwl.tu-darmstadt.de (J.M. Ries).¹ Effective September 2013. Note that some of the hits that were obtained in the search for "EPQ" in Google Scholar and Scopus correspond to the "Eysenck Personality Questionnaire" and the "Revised Eysenck Personality Questionnaire".² For a comparison, a similar citation search for other important operations management problems revealed the following numbers of hits in Google Scholar (Scopus): "Facility Location" 40,200 (3287); "Vehicle Routing" 49,200 (4665); "Order picking" 7110 (555).

Although reviewing all extensions of Harris' model would be a project too ambitious to accomplish, the existing literature permits the identification of popular research streams, whose analysis and synthesis may help researchers in identifying relevant works in the area of lot sizing. In this line of thought, this paper presents the results of a tertiary study on the lot sizing problem. In this study, review papers on lot sizing-related topics are identified in a systematic search of the literature and evaluated with the help of a structured framework. The intention of this paper is to show which streams of research emerged from Harris' seminal lot size model, and which major achievements have been accomplished in the respective areas. Thus, this tertiary study presents an overview that may support primary researchers in positioning their own work in the literature, in reproducing the development of different types of lot sizing problems, and in finding starting points if they intend to work in a new research direction. In addition, this study also derives suggestions for reviewing the literature in the area of lot sizing, which may be of help for future secondary research.

The remainder of the paper is structured as follows: the next section describes the methodology of the tertiary study and descriptively evaluates the sample. Section 2 also presents Harris' seminal EOQ model and develops a classification scheme for lot sizing models. Section 3 assigns the identified reviews to the categories of the framework developed in Section 2 and discusses major findings of the reviews. Section 4 concludes this paper and provides suggestions for future research.

2. The tertiary study

2.1. Literature search and selection strategy

Research, in general, can be differentiated into primary works (i.e., independent research, such as conceptual or empirical studies), secondary works (i.e., literature reviews), and tertiary works (i.e., reviews of literature reviews). Tertiary works are used to evaluate the methodology of secondary studies in a certain area or to investigate core themes that were studied in a particular research area (see, among others, Hochrein and Glock, 2012; Verner et al., 2014). To ensure that readers are able to reproduce sample generation and evaluation, secondary and tertiary studies need to be well structured and documented (see Tranfield et al., 2003; Rhoades, 2011). In the following, we describe the search strategy that was used in this study to identify reviews of works on the lot sizing problem. The methodology applied in our study is based on the works of Tranfield et al. (2003), Cooper (2010), Rhoades (2011), Glock and Hochrein (2012), and Hochrein and Glock (2012).

In a first step, keywords were defined that were later used to identify relevant works in the literature. First, two groups of keywords were defined, where group A contained keywords related to the lot sizing problem ("economic order quantity", "EOQ", "economic production quantity", "EPQ", "lot streaming", "economic lot scheduling problem", "ELSP", "lot size", "lot sizing", "inventory management", "inventory model", "lot", "inventory") and group B keywords related to literature reviews ("review", "overview", "survey", "literature"). The final keyword list was generated by combining each keyword from group A with each keyword from group B. Subsequently, two databases, namely Scopus and Ebsco Host, were searched for works that contain a keyword from the final keyword list either in their title, abstract or list of keywords. The database search was complemented by a forward and backward snowball search, where the references of papers contained in the sample were checked, and where works that cited papers contained in the sample were evaluated for possible relevance. After an initial sample had been generated based on the database and snowball searches, all preselected works were independently checked for relevance by all authors of this paper.

Besides, to be included in the final sample, works had to show the following characteristics:

- The focus of the paper had to be on reviewing the literature. Thus, papers that contain an overview of the literature, but whose focus is on the development of a model or on an empirical analysis, for example, were not included in the sample.
- The literature reviewed in the respective papers had to be predominantly on models that contain the original lot sizing problem, i.e. on models that include the problem of balancing inventory and order/setup costs. Thus, supply chain design problems that can also cover the assignment of order quantities to locations, for example, were not included in the sample.

2.2. Descriptive analysis and general results

The results of our literature search have been documented in a so-called review protocol that can be found in Appendix A. As can be seen, the database search provided 330 initial hits (after duplicate articles had been eliminated), which were complemented by 45 additional hits from the snowball search. Subsequently, a manual analysis of the abstracts of all papers led to a working sample of 94 papers. Papers contained in the working sample were completely read to examine their content, which led to an exclusion of 42 papers and a final sample that consisted of 52 works.

Fig. 1 shows the number of review papers on the lot sizing problem by year of publication. As can be seen, reviewing the literature in this domain has become increasingly popular over the last years, where up to five reviews on lot sizing problems were published per year. In addition, approximately half of the articles contained in our sample were published during the last 10 years, which underlines the on-going relevance of this topic and methodology.

Fig. 2 provides an overview of academic journals that published the highest number of review papers on lot sizing problems. As can be seen, the European Journal of Operational Research, the International Journal of Production Economics, Operations Research and Omega have been the four most popular outlets for review papers in this area.

Fig. 3 highlights the 10 most frequently cited reviews in our sample, where the number of citations was taken from Scopus. The year of publication, which is often an indicator of the number of citations a scientific article receives, is obviously not the only attribute that influences citation frequency, as both very recent as well as early published reviews are contained in this overview. An analysis of the review papers listed in Fig. 3 revealed that (if the number of citations is used as an indicator) some topics have been especially popular in reviewing the literature, namely lot sizing decisions for deteriorating items (cf. Goyal and Giri, 2001; Yano and Lee, 1995; Nahmias, 1982 or Rifaat, 1991) and the combination of lot sizing and scheduling issues (cf. Drexel and Kimms, 1997; Elmaghraby, 1978 or Graves, 1981). In addition, two frequently cited reviews dealt with coordinated lot sizing in supply chains (cf. Goyal and Gupta, 1989; Sarmah et al., 2006), which could be an indicator for the on-going relevance of this topic.

2.3. Problem description and conceptual framework

2.3.1. The basic lot sizing approach of Harris

Determining the most economical inventory levels by balancing its positive and negative consequences in terms of cost has become one of the most influential research areas in the operations management literature (see Grubbström, 1995). In its basic

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