Int. J. Production Economics 127 (2010) 85–94

Contents lists available at ScienceDirect

Int. J. Production Economics

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

Evaluation of joint replenishment lot-sizing procedures in rolling horizon planning systems

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ARTICLE INFO

Article history:
Received 10 June 2009
Accepted 27 April 2010
Available online 7 May 2010

Keywords:
Joint replenishment
Lot sizing
Rolling horizon

ABSTRACT

Joint replenishment problems are commonly encountered in purchasing, manufacturing, and transportation planning. Literature evaluates various algorithmic approaches for solving the joint replenishment problem in a static environment, but their relative performance in a dynamic rolling horizon system is unknown. This research experimentally evaluates nine joint replenishment lot-sizing heuristics and policy design variables when implemented in a dynamic rolling schedule environment. The findings indicate that a single algorithm does excel on both dimensions of schedule cost and stability. Hence, management must trade off these two performance metrics when choosing the best approach for their specific problem. Generally, metaheuristics provide the best cost replenishment schedule, but forward pass based heuristics yield the most stable schedules. The results also indicate that the choice of lot-sizing heuristic is the major cost performance driver in rolling planning systems, with policy design variables (frozen interval and planning horizon length) having little impact. While the simulated annealing heuristic of Robinson et al. (2007a) is the most effective solution procedure for the static joint replenishment problem, the perturbation metaheuristic of Boctor et al. (2004) produces lower schedule costs and greater stability in rolling schedule environments.

1. Introduction

Joint replenishment problems (JRPs) determine the time-phased replenishment schedule that minimizes sum of ordering and inventory costs for a product family. A joint ordering cost is incurred each time one or more items in the product family are replenished and an item order cost is charged for each line item replenished. Silver (1979), Stowers and Palekar (1997), and Robinson and Lawrence (2004) provide examples of joint replenishment problems in production, procurement, and transportation operations. An illustrative problem is procurement operations of a grocery chain where a family of items is sourced from a single vendor. Each replenishment order is accessed a fixed delivery charge regardless of quantity shipped, while each line item incurs a fixed cost for inventory maintenance, receipt, inspection, and put-away. The objective is to minimize sum of delivery charge, line item costs, and inventory costs for the product line recognizing that item replenishment costs are jointly linked through the shared delivery cost.

This research investigates the JRP in a rolling horizon planning system with stochastic demand that is forecast. Moving closer in time, the forecast is replaced with booked customer orders as each time period enters the replenishment planning horizon. The resulting problem is a short-term, or "static", JRP with deterministic, dynamic demand. After solving this static problem, replenishment decisions within the frozen order interval are implemented rolling through time. After a pre-specified re-planning periodicity, a new short-term plan is constructed using the updated demand received since the last planning cycle. When constructing the new replenishment plan, orders from the prior planning cycle that lay outside the frozen order interval may be rescheduled if doing so results in an improved solution for the new planning cycle. In this manner, solutions to a series of linked static planning problems are implemented rolling through time (Blackburn and Millen, 1982). Fig. 1 depicts two planning cycles and illustrates the basic definitions and concepts used in rolling horizon planning systems.

Prior research indicates that effectiveness of rolling horizon planning systems may be determined by planning horizon interval, frozen order interval, re-planning periodicity, choice of lot-sizing procedure for solving the short-term planning problem, and cost and demand factors defining the planning environment.

While several researchers study performance of heuristic and optimization-based approaches for solving the static JRP, their

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doi:10.1016/j.ijpe.2010.04.038

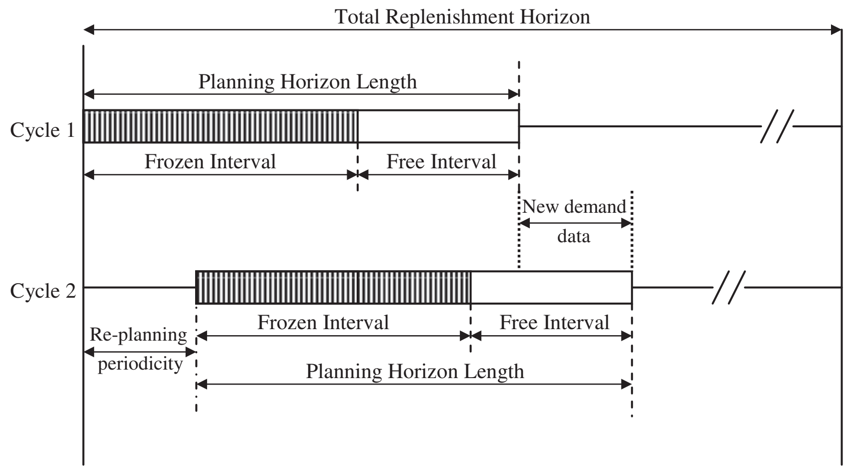

Fig. 1. Illustration of rolling horizon planning environment.

relative performance in rolling horizon systems is not addressed. This is a major shortcoming of the literature since the best performing lot-size procedure in a static environment may not be the best performer in a rolling horizon environment. This is due to the end-of-horizon effect, where not knowing the demand beyond the planning horizon may lead to relatively poor quality short-term schedules. Even with optimal solutions to the static problems, their implementation in a rolling horizon environment provides at best a heuristic solution (Simpson, 1999). Prior research on single-item and multi-level rolling horizon problems finds that the problem's demand pattern, cost structure, choice of lot-sizing procedure, and policy variables governing rolling schedule implementation play a significant role in determining schedule cost and stability. Hence, studying the joint replenishment problem in rolling horizon systems is well justified.

This study conducts extensive computational experiments evaluating impact of rolling horizon policy variables (e.g., planning horizon and frozen interval lengths) and joint replenishment lot-sizing procedures on system cost and schedule stability. The findings indicate a tradeoff between schedule cost and stability when selecting a particular lot-sizing procedure for implementation. A single algorithm does not excel on both performance dimensions. The results provide managerial guidelines for implementing joint replenishment lot-sizing procedures in rolling horizon planning systems.

The following section reviews the relevant literature on the JRP and rolling horizon planning systems. Next, the experimental design and computer simulation model is described. Research findings are discussed in Section 5 and the final section provides research conclusions and implications.

2. Literature review

Numerous researchers study algorithms for solving the JRP in a static setting. Goyal and Satir (1989) and Khouja and Goyal (2008) survey the broad JRP literature. Robinson and Lawrence (2004) and Robinson et al. (2009) study approaches for solving the deterministic, dynamic demand JRP. Heuristics for the JRP are often classified as specialized heuristics, metaheuristics, and mathematical programming-based approaches. Specialized heuristics include dynamic programming based procedures (Fogarty and Barringer, 1987; Silver, 1979), forward pass algorithms (Atkins and Iyogun, 1988; Iyogun, 1991; Robinson et al., 2007a), and construction based heuristics (Robinson et al., 2007a). The metaheuristics approaches include perturbation metaheuristic (Boctor et al., 2004) and simulated annealing metaheuristic (Robinson et al., 2007a). Mathematical programming-based heuristics include branch and bound based partition heuristic (Federgruen and Tzur, 1994) and dual ascent heuristic (Robinson and Gao, 1996). Boctor et al. (2004) and Robinson et al. (2007a) provide extensive evaluation of alternative JRP heuristics for solving static planning problems.

There is also an extensive literature addressing rolling horizon planning systems. Instead of duplicating these reviews, the literature most closely related to this study is summarized. See Yeung et al. (1998) and Robinson et al. (2007b) for surveys of problem parameters and policy design variables that affect performance of rolling horizon planning systems.

Baker (1977) investigates single-item rolling schedules, finding that ideal planning horizon length is an integer multiple of natural time between orders (TBO). Sridharan et al. (1987, 1988) study single-item single-level systems and introduce the basic tradeoff between schedule cost and stability when setting rolling schedule design parameters. Their results indicate that longer freezing horizons promote system stability while shorter freezing horizons yield lower cost schedules; order-based freezing methods are superior to period-based methods; and shorter planning horizons are favored for schedule stability.

Blackburn and Millen (1980) find that due to end of horizon effects simple heuristics may perform better than optimization procedures in rolling schedule environments. Stadtler (2000) adjusts replenishment fixed costs in later time periods to lessen the end of horizon effects and improve performance of optimization-based single-level lot-sizing rules. Heuvel and Wagelmans (2005) show that the ending inventory valuation (EIV, Fisher et al., 2001) heuristic, an extended Wagner Whitin algorithm, and Stadtler's (2000) lot-sizing procedures have similar cost performance in a rolling schedule environment.

Subsequent researchers (Blackburn and Millen, 1982; Zhao and Lee, 1996; Zhao and Lam, 1997; Zhao et al., 2001; Xie et al., 2003; Simpson, 1999, 2001) consider policy design variables and implementation in different settings, such as multi-level and capacitated systems. Findings show longer planning horizons reduce schedule cost but increase schedule instability; shorter frozen intervals yield lower system cost; schedule instability is exceptionally high when frozen interval length is less than 50% of planning horizon length; re-planning at the end of frozen interval reduces