Applied Mathematical Modelling 52 (2017) 527–543

Contents lists available at ScienceDirect

Applied Mathematical Modelling

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

A mathematical programming model for integrating production and procurement transport decisions

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ARTICLE INFO

Article history:
Received 30 December 2016
Revised 26 July 2017
Accepted 3 August 2017
Available online 14 August 2017

Keywords:
Production planning
MRP
Transport planning
Mathematical programming

ABSTRACT

In this paper, we propose a new mathematical programming model for integrating production and procurement transport planning decisions in manufacturing systems in a unique optimization model. This problem was introduced conceptually and dubbed as MRP IV by Díaz-Madroñero et al. (2012) to extend the current MRP (material requirement planning) systems. This proposal simultaneously considers material, production resources capacities and procurement transport planning decisions with different shipping modes (such as full-truckload, less-than-truckload and milk-run) in the supply chain to avoid suboptimal results, which are usually generated due to sequential and independent plans. We considered an industrial automobile company to validate the proposed model using real world data. The results obtained by the MRP IV proposed model, in terms of total planning costs and transport efficiency indicators, are better than those obtained in the current heuristic procedures followed in the company under study.

1. Introduction

Nowadays, supply chains are characterized by their members' considerable offshoring, and most are located in countries with lower labor costs and less strict regulations. In this context, production planning and materials procurement in current industrial firms are highly influenced by transportation planning, and cannot hence be considered independent processes. However, most current production planning systems calculate production, procurement and transport planning decisions separately by generating plans that have to be rescheduled or manually amended given their suboptimality from an economic perspective or their infeasibility due to capacity constraints [1].

The material requirement planning (MRP) system, proposed by Orlicky [2], continues to be the most widely used production planning system. MRP is based on the explosion of a BOM, which translates the production plan into the required amounts and time instants by considering inventory levels and lead times for raw materials and components [3,4]. The MRP system does not consider any capacity constraint, and this led to evolution toward closed-loop MRP and MRP II (manufacturing resource planning) systems [5] and extended the original MRP system with master schedule calculations and capacity requirements planning or CRP. In the 1990s, the MRP II system evolved to MRP III (money resource planning) [6] and ERP (enterprise resource planning) systems [7], whose main goal was to incorporate all business functions (finances, sales, production, etc.) into a single decision-making system. Yet despite the features added in recent decades, such as supply chain management or transport issues and new communications and IT features, the main element of ERP systems still

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http://dx.doi.org/10.1016/j.apm.2017.08.009

lies in the logic of the original MRP systems. In current competitive business environments, firms need to optimize their production planning decisions, hence the demand of MRP models with optimization features. According to Yenisey [8], although the earliest MRP approaches did not provide optimal solutions, the maximization of profit and constraints related to demand or productive resources was gradually included in order to optimize the production and procurement plans that derived from MRP systems. The works by Karni [9] and Billington et al. [10] can be considered original contributions in this area as they propose mathematical programming models for MRP problems under capacity constraints. Other authors like [8,11–16] have addressed MRP optimization by different approaches based on mathematical programming solution methods in deterministic scenarios.

Regarding transport planning, Coyle et al. [17] defined transport as the physical link that connects fixed points in a logistics supply chain. Hence transport processes are fundamental parts in supply chains because they enable raw materials and finished goods to flow among suppliers, manufacturers, warehouses and retailers. Hence transport planning can contribute to increase the degree of supply chain managers' satisfaction by supporting the planning and control of material flows [18] and the delivery of superior value to end consumers [19]. According to Fleischmann et al. [20], two types of transport processes can occur in a supply chain. On the one hand, the supply of materials from external suppliers to a production site [21–26], and, on the other hand, the distribution of products from a factory to customers [27–30]. According to Chandra and Fisher [31], the integration of production and transportation planning decisions is a way to reduce costs and to increase efficiency in operations in industrial firms [32,33]. In line with this, several surveys have been published on simultaneous production and transport planning [34–39]. Most of these reviewed models simplify transport processes by considering only direct shipments or the full truck load shipping mode, and by disregarding the less-than-load or routes distribution mode. The simultaneous consideration of production and transport routes is addressed by a research area, called the production and routing problem, which has developed in the last few years [40,41]. The production routing problem consists of a manufacturing plant, from which products are sent to customers by determining the necessary distribution transport routes and the corresponding inventory levels for both the production plant and customers in order to minimize the corresponding total costs [31,42–47].

Transport planning in these distribution problems is usually the supplier's responsibility, but there are some main exceptions, e.g., in the automobile industry, where the manufacturer controls transport from its suppliers. In this case, transport planning also occurs on the procurement side [20]. In such contexts, integration related to production and transport procurement decisions is usual lacking, so production planning is done separately and sequentially in relation to the transport planning of raw materials and components from suppliers to manufacturing centers [38]. Therefore, optimization models and tools for simultaneous production and procurement transport planning processes that contemplate different forms of transport, e.g., full truck load, less-than-load and milk-run, etc., are needed [48].

In this context, in [1] we conceptually approached the problem of integrating into a unique optimization model the MRP II production system, which is widely used by companies around the world, and procurement transport planning decisions, of increasing relevance because global supplier network developments are expanding. Therefore, we dubbed our conceptual approach as MRP IV as an extension of previous MRP systems, which is the basis of our proposal. Other extensions of MRP systems have also arisen with different denominations, such as DDMRP [49], Green-MRP [50] and MRP/sfx [51], which respectively address aspects of driven demand, sustainability and shop floor orientation.

Here, the present paper proposes a mathematical programming formulation for modeling and solving the MRP IV problem, which integrally addresses material, production, capacity and transport requirement planning to support a manufacturing company's decision making. The main contributions of this paper are summarized as follows: introducing a novel mathematical programming model for integrating production and procurement transport decisions in a unique optimization model by considering several shipping modes, e.g., full truck load (FTL), less-than-load (LTL) and milk-run, and model validation in a real-world company that belongs to the automobile industrial sector. In this context, other alternative approaches that address the integration of production and procurement transport planning problems have been proposed by Kuhn and Liske [52,53], who combine the economic lot sizing and vehicle routing problems, and called it the economic lot and supply scheduling problem (ELSSP); and Hein and Almeder [54] who extend it from a capacitated lot sizing and vehicle routing problem (CLSVRP) perspective.

The rest of the paper is organized as follows: Section 2 presents describes the MRP IV problem. Section 3 presents the mathematical programming model proposed to address the MRP IV problem. Section 4 offers an application of the proposed model in the automobile industry by presenting an evaluation of the obtained results and highlighting the managerial implications of the proposal. Finally, Section 5 provides the conclusions drawn and future research lines.

2. MRP IV description

Díaz-Madroñero et al. [1] and Mula et al. [55] originally introduced the conceptual model for the MRP IV problem, which is the starting point used to develop the mathematical programming model explained in this paper. Other academic studies have suggested analytical models for solving the production-transportation problem [56–61]. For an extensive review on production-transportation analytical models, we refer readers to [37,38] and [41]. It is important to highlight that most of the conducted studies address production and distribution planning to customers rather than production and procurement transport planning, as addressed herein. Regarding this restricted research area, the proposals by Kuhn and Liske [52,53], Hein and Almeder [54], Chen and Sarker [62] and Liotta [63] are highlighted. In line with this, Kuhn and Liske [52] com-