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A multi-objective model for cleaner production-transportation planning in manufacturing plants via fuzzy goal programming

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ABSTRACT

In traditional supply chain management, manufacturers aim solely to reach a cost-effective way to meet customers' demands. Nowadays, increased social awareness together with new governmental regulations are forcing manufacturers to reconsider their production and transportation plans with respect to environmental issues. This paper proposes a multi-objective optimization model for a cleaner production-transportation planning (CPTP) problem in manufacturing plants. When a manufacturer is planning for production-transportation of mid-term future, the aim is to determine optimal production level, inventory level, back order level, workforce level, transportation mode, overtime, and subcontracted products, while attempting to minimize production and transportation costs as well as environmental effects (e.g. generated wastes, gas emissions, noise disturbance, workers injuries, and energy consumption). To handle the original optimization problem, fuzzy goal programming is adopted and heuristic algorithms are designed. Moreover, extensive computational experiments as well as real case studies are considered to evaluate the quality of algorithms and applicability of the proposed model.

1. Introduction and related literature

The cleaner planning of supply chain (CPSC) is a recent efficient way to improve the environmental performance of firms and companies. CPSC is an important approach to reduce adverse environmental effects and ensure economic benefit [1]. It is related to the adoption of cleaner issues into supply chain drivers. By increasing awareness on observing environmental considerations, the CPSC is now becoming important during recent years. The increasing pressures and challenges to enhance environmental performance have forced manufacturers to consider and start implementing CPSC [2,3]. The cleaner planning of supply chain aims to make a balance between performance and environmental issues [4]. It is a planning approach which not only reduces environmental impacts of operations, but also enhances economic achievements of all supply chain units. Over the last decade, the literature on the CPSC has increased considerably and different supply chain-related problems are now subject to cleaning issue. The aim has been to incorporate clean concepts into logistics network design, operation management, manufacturing, supplier selection, material selection, sales, and recovery [5]. One of the important problems in the CPSC is cleaner production-transportation planning (CPTP) in manufacturing processes, which has been widely ignored in the related literature. It employs management principles to re-plan production operations to rekers' damaduce greenhouse gas emissions, industrial wastes, noise pollutions, worge, and energy consumption while satisfying acceptable production economy.

During recent decade, the optimization of the CPSC to incorporate environmental issues into supply chain management has attracted an increasing deal of research attention [6]. Generally, these studies has followed three main directions [7,8]: (*I*) identifying one or multiple supply chain drivers, e.g., inventory control problems [9,10,11], supply chain network design problems [12,13], supplier selection and evaluation problems [14,15], packaging problems [16,17], shipping problems [18,19,20]; and reverse logistic network design problem [21,22], (*II*) defining the objective criterion, e.g., reducing quantity of wastes [23,24], reducing greenhouse gas emissions [25,26], reducing noise disturbance [27,28], improving workers' health [29,30], and managing energy consumption [31,32], and (*III*) applying cost-benefit modeling techniques to design the best configuration of the selected driver(s), e.g., life cycle assessment technique (see the review article: [33], multiple attribute decision-making modeling [34,35], multi-objective optimization [36,37,38], and fuzzy optimization [39,40,41]. The CPTP problem is a special type of the CPSC, where the driver is a combination of the drivers of production and transportation plan-

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ning. Since we concentrate, in the current paper, on production and transportation drivers, a brief review on the related literature is presented in the sequel. We first discuss the production part of the CPTP problem. Being the most useful model in mid-term production planning of manufacturers, aggregate production planning (APP) can be incorporated into the CPTP. The APP aims to determine production quantity, inventory level and workforce level in a cost-effective way to satisfy customers' demands. It is often carried out at an aggregated level without the need to have detailed information of individual products. A lot of efforts have been attracted to the APP for several years [42]. The first research on the APP was presented by Holt et al. [43]. Moreover, proposed a goal programming scheme based on the APP model. Afterward, described a chance-constrained goal programming APP model. Additionally, discussed a decision rule to solve the APP problem. In another work presented by Ashayeri and Selen [44], a pharmaceutical case in Netherlands was evaluated by the APP. In addition, Wang and Liang [45] investigated a multi-product aggregate production planning problem in a fuzzy environment. Wang and Liang [46] presented a multi-objective APP, and Jain and Palekar [47] analyzed the APP considering dissimilar machines and lines. Jamalnia and Soukhakian [48] considered a fuzzy AP Su and Lin [49] and Subulan et al. [50] studied the application of fuzzy multi-objective optimization to supply chain problems with reverse flow of materials. Zhang et al. [51] introduced a heuristic approach to the APP with capacity considerations.

Discussed an integrated pricing and APP problem under fuzzy parameters. Karmarkar and Rajaram [52] devised an extension to the APP for process industries. Raa et al. [53] suggested an aggregate production–distribution planning for a plastic producer across Europe. As an important part of the CPSC, the cleaner production planning aims to reduce wastes, noise disturbance, workers' damage, and energy consumption by making appropriate decisions on the production plan [54,55]. Some researchers focused on optimizing decisions on manufacturing parameters to reduce wastes and energy consumption [56]. However, to the best of our knowledge, there has been only few studies on incorporating the clean issues into the APP problem. As another part of our CPTP, transportation is one of the most important drivers of the supply chain and plays an essential role in economic growth. The performance of transportation planning greatly affects the performance of logistics and supply chain operations. However, as ECOFYS [57,58] reported, transportation serves as the source of 15% of 2010 greenhouse gas emissions, i.e. it has significant impacts on the environment, so that it is important to plan for reducing the emissions in transportation. Supply chain researchers have formulated the environmental impact of transportation in terms of greenhouse gas emissions. In another research, a simulation model was developed by Harris et al. [59] to evaluate total costs of logistics and CO_2 emission in an automotive supply chain considering vehicle characteristics. Bloemhof et al. [60] investigated the environmental effects of inland navigation compared to rail and road transportation. Nieuwenhuis et al. [61] proposed a model to assess CO_2 emissions considering transportation costs along a vehicle supply chain from plant to distribution zones, taking Hyundai Motor Company and Kia Motors as case studies. Sadjady and Davoudpour [62] designed an optimization model for a supply chain network design with two echelons, taking into account mode selection and inventory costs. Dekker et al. [63] discussed four transportation choices addressed by optimization models; the choices included transportation mode, intermodal transport, equipment, and fuel. Le and Lee [64] suggested an optimization model to design transportation modes, minimizing total costs as well as environmental effects of CO_2 emissions. Zhang et al. [65] took into account environmental issues for the classical vehicle routing problem, so as to control adverse effects of the vehicles on the environment. Chena and Wang [66] evaluated the impact of carbon emission reduction on transportation mode selection considering a stochastic demand scheme.

The rest of this paper is organized as follows. Section 2 describes the problem structure and formulates it as an optimization problem. In Section 3, a solution approach is proposed and discussed. Section 4 designs the experiments and analyzes the results. Finally, Section 5 concludes the paper.

2. Problem description and formulation

In this section, the proposed cleaner production-transportation planning (CPTP) problem in this paper is described and formulated. Nowadays, increased social awareness together with new governmental regulations have made manufacturers seek some way(s) to provide their customers with economic products while attempting to minimize adverse environmental effects of the production and transportation processes. This problem is relevant to production and transportation planning of multiple products produced in a manufacturing plant and then transported to customers' zones. The production part of the CPTP is a version of the classical aggregate production planning problem. The aim is to seek optimally cost-effective values of production, inventory, back order, overtime, and subcontract productions. It also aims to find the best numbers of hired and laid-off workers for the manufacturer. Once the production process comes to completion, finished products are proceeded to the transportation phase which can be done via different transportation modes in a direct shipment scheme. From an environmental point of view, the aim is to select the appropriate production and transportation modes seeking to minimize per product generated wastes, gas emissions, noise disturbance, workers' damage, and energy consumption.

2.1. Notations

The parameters and variables used in this paper are introduced as follows.

Parameters$i$Index of products$t$Index of time periods$c$Index of customerspmIndex of production modes at regular timeomIndex of production modes at overtimesmIndex of subcontractorstmIndex of transportation mode$I$Number of products$i = 1, \ldots, I$$T$Number of time periods in planning horizon$t = 1, \ldots, T$$C$Number of customers$n = 1, \ldots, C$$PM$Number of available production modes at regular time $pm = 1, \ldots, PM$$OM$Number of available production modes at overtime $om = 1, \ldots, OM$$SM$Number of available subcontractors $sm = 1, \ldots, SM$$TM$Number of available transportation modes $tm = 1, \ldots, TM$$D^{c}_{i,t}$Demand of customer c for product i at period $t$$p^{pm}_{i,t}$The cost of regular time production of one unit product i at period t by production mode $pm$$o^{om}_{i,t}$The cost of overtime production of one unit product i at period t by production mode $om$$s^{sm}_{i,t}$The cost of outsourced production of one unit product i at period t by subcontractor mode $sm$$h_{i,t}$The cost of inventory of product i at period $t$$b_{i,t}$The cost of back ordering of product i at period $t$$ws_t$The cost of salary of one worker at period $t$$wh_t$The cost of hiring of one worker at period $t$$wl_t$The cost of laying off of one worker at period $t$$tr_t$The cost of training of one new worker at period $t$$\gamma_t$The ratio of regular time workers available for use in overtime at period $t$$v_{tm}$The cost of transportation mode $tm$$r^{pm}_i$The cost of one unit waste product i produced by production mode at regular time $pm$$r^{om}_i$The cost of one unit waste product i produced by production mode at overtime $om$$r^{sm}_i$The cost of one unit waste product i produced by subcontractor $sm$$f^{pm}$A fraction of waste products produced by production mode at regular time $pm$$f^{om}$A fraction of waste products produced by production mode at overtime $om$$f^{sm}$A fraction of waste products produced by subcontractor $sm$$\eta$The unit tax cost of CO_2 emissionψ^{pm}_iThe noise severity