Journal of Cleaner Production 179 (2018) 478–494

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

A multi-objective Environmental Hedging Point Policy with customer satisfaction criteria

Mohammadbagher Afshar-Bakeshloo [a], Ali Bozorgi-Amiri [a, b], Seyed Mojtaba Sajadi [c, *], Fariborz Jolai [a, b]

[a] School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran
[b] School of Industrial Engineering, Alborz Campus, University of Tehran, Tehran, Iran
[c] Faculty of Entrepreneurship, University of Tehran, Tehran, Iran

ARTICLE INFO

Article history:
Received 4 June 2017
Received in revised form
2 January 2018
Accepted 7 January 2018

Keywords:
Unreliable manufacturing systems
Simulation optimization
Response surface methodology
Customer satisfaction
Emission
Cap-and-trade
OptQuest

ABSTRACT

Recently, a new feedback control policy, named the Environmental Hedging Point Policy, to control the inventory and production was introduced. In this policy, inventory, backlog, and emission costs were taken into account. Employing low-emitting technology, this study aimed at developing this policy in order to integrate three objectives of costs, emissions, and customers' satisfaction. Two prominent environmental control rules, namely command-and-control and cap-and-trade were examined by applying the proposed policy. To solve the problem, a new simulation-based optimization method combining OptQuest, experimental design, variance analysis, and response surface methodology, was conducted. This method improved the procedure of finding the second-order responses. Compromise solutions of a multiple-response problem were calculated thanks to the desirability function approach. Accordingly, the Pareto optimal surface was generated by changes in the weights or shape factors. The effectiveness of introduced policy was examined by sensitivity analysis. Thereupon, the shadow prices for both low-emitting technology and emission penalty were obtained. The results showed that considering shadow prices imposed by the regulatory authorities, the cap-and-trade rule was more effective in comparison with other rules.

1. Introduction and literature review

1.1. Today's manufacturers' dilemmas

In today's competitive environment, aiming to gain more competitive advantage, responsiveness stands as the main driver for differentiation. This is evaluated by giving prompt services (Parasuraman et al., 1985). On the other hand, global warming and emission of Greenhouse Gases (GHGs) are presented as the challenges of the century. Today, the important side effect of the industrial sector is the emission of GHGs, particularly carbon dioxide. In this regard, governments are under growing pressure to sanction legislation to limit the amount of these emissions. As a result, different policy instruments have evolved over time (He et al., 2015; Du et al., 2016a, 2016b; Xu et al., 2016; Wang et al., 2017).

Accordingly, decision makers (DMs), in addition to traditional objectives, should deal with customers' satisfaction and environmental concerns (Afshar-Bakeshloo et al., 2016; Xie et al., 2017). Under these conditions, a firm must incorporate its environmental impact, service quality, and cost information into the decision making process. Reducing carbon dioxide emissions is possible by operational adjustment and without a considerable increase in cost (Chen et al., 2013). Furthermore, customer's satisfaction is affected by product availability and the policy employed by the manufacturer (Assid et al., 2014).

In actuality, manufacturing systems which are highly affected by dynamic and complex context, need an appropriate strategy to reduce the gaps between these three objectives. In this dynamic stochastic context, optimal control theory has been one of the most contributory in the growth of operational manufacturing strategies (Ben-Salem et al., 2015a).

In this study, based on the above discussion, a new strategy to control the production and inventory system was provided. Here, the three objectives of cost, emissions, and customers' satisfaction

* Corresponding author.
E-mail addresses: afshar.mb@ut.ac.ir (M. Afshar-Bakeshloo), alibozorgi@ut.ac.ir (A. Bozorgi-Amiri), msajadi@ut.ac.ir (S.M. Sajadi), fjolai@ut.ac.ir (F. Jolai).

https://doi.org/10.1016/j.jclepro.2018.01.041
0959-6526/

were considered essential.

1.2. Hedging point policy variants

In the context of failure-prone manufacturing systems (FPMS), feedback control policies have always been of interest to researchers and manufacturers. An in-depth review of the literature showed that this field of study has been dealt with by many researchers and evolved during the time after pioneer work of Kimemia and Gershwin (1983). Here, the optimal control policy for the FPMS relies on a specific structure, called hedging point policy (HPP). Inspired by this work, many variants of the problem have been developed by several perspectives over time. Table 1 shows some important variants of this policy. Since this paper was not to explicitly deal with the review of the HPP, a summary table was presented. Here, the initial and final paper in each field of study were indicated.

As it turns out, trade-offs between emissions and economic concerns were dealt with by a few studies. Additionally, there existed few studies which consider customers' satisfaction criteria. To the best of authors' knowledge, incorporating all three objectives of cost, emissions, and customers' satisfaction together with a multiobjective approach were neglected. Indeed, it considerably helps the DMs to select a point (Strategy) that not only accounts for the economic orientation but also considers customers' satisfaction with regards to the environmentally friendly aspects.

1.3. Environmental control regulations

Environmental policy instruments can be classified into two main categories: price based (e.g., imposing a tax on carbon emissions) and quantity based (e.g., imposing a cap on emissions, so that emission trading is being permitted) (Benjaafar et al., 2012; Chen et al., 2013). From another point of view, it can be categorized as being either Regulatory or Voluntary pollution control rule. In the former, an environmental standard is imposed on the firms that limit the amount of environmental waste generated by the manufacturing system. This rule corresponds to the so-called command and control policy. In the latter, in order to avoid crossing the standard limit, an internal choice which is self-regulation, is set by the decision support system (DSS). This provides more flexibility for manufacturing systems (Chen and Monahan, 2010). Indeed, among all the rules, two are most prominent. First, command-and-control (CC) rules in which regulatory authorities direct how emissions restrictions can be achieved. Second, market-based rules, which attach the forces of supply and demand to change behavior, and achieve environmental goals. Cap-and-trade (CT) rule has been viewed as one of the most effective methods for restricting carbon emissions in this context. The CT rule means that the company obtains a certain quota (credit) of allowable carbon emissions from governments or different institutions, which can be traded in the market (Shu et al., 2017).

1.4. Environmental Hedging Point Policy (EHPP)

Recently, the idea of integrating environmental dimensions into the optimal control of unreliable manufacturing systems was proposed by Ben-Salem et al. (2015a). Under the class of HPPs, the main objective of this study was to present a control policy that minimizes backlog, inventory, and emission tax costs. Based on the emissions cap rule, it was shown that the model had economic advantages in comparison with the HPP. Here, if the emission level became higher than a voluntary level and inventory level was judged sufficient, then hedging level would drop from Z_1 to Z_2 ($Z_1>Z_2$).

In this regard, two other papers were also dealt with by them (Ben-Salem et al., 2015b, 2016). Here, a machine was considered whose availability decreased over time. Thus, the emission rate rose due to degradation phenomena. Hereupon, a feedback strategy was proposed. It could simultaneously control all the rates and mitigate the effects of the system degradation (Ben-Salem et al., 2015b). In another work, a model was proposed in which a green subcontractor was employed (Ben-Salem et al., 2016).

In the context of sustainable manufacturing systems, a fuzzy system to estimate the hedging level was introduced. Here, all three pillars of economic, environmental and social dimensions were considered (Hennequin and Restrepo, 2015).

1.5. Low-emitting technology

Renewable energies mostly apply to low-emitting technologies (LETs) in which the source is not regular fuels. Here, the LET is as an alternative to the main manufacturing system (MMS). An increase in investment in the LET leads to a decrease in emissions (Palmer et al., 2009). Thus, GHG emissions can considerably be reduced by using a key advanced technology. Moreover, Biofuel, Flex-fuel, Battery, Hybrid, Hydrogen and natural gas are also the main fuel alternatives to oil. Overall, higher maintenance cost and time, lower power, and higher production cost are some of the common disadvantages of the LETs. Producing fewer emissions, on the other hand, offer the most important advantage (Augustine et al., 2011; Walters, 2012).

Recent technological advances show extensive use of natural gas in the industrial sector since its combustion produces fewer GHGs than coal or petroleum.[1] Alternative fuel vehicles (AFV) or engines are examples of such technology. The use of alternative LET or alternative energy such as natural gas can considerably affect the environmental issues. The incentives provided by an environmental control regulation are key in investing in new technologies or adopt alternative LETs. Alternative fuel for an electricity production facility is such an example (Moreno-Bromberg and Taschini, 2011).

1.6. The objectives of this paper

Given two proposed environmental control rules (CC and CT), this paper aimed to extend the EHPP. Utilizing LET at appropriate moments and using the structure of the EHPP, all the objectives were taken into account. In order to attain an approximation of the control policy an experimental approach, as in Kenné and Gharbi (1999), and Gharbi and Kenné (2000), was conducted. It is worth noting that the objective of this paper was not to analytically optimize the model. Instead, it was to experimentally determine the parameters of the modified EHPP. There are several papers in the current literature that approximate a control policy. This is due to the complexity of the problem. See for example (Kenné and Gharbi, 2000, 2004; Berthaut et al., 2011; Hajji et al., 2012; Assid et al., 2014; Bouslah et al., 2014; Ben-Salem et al., 2015a, 2015b; Hlioui et al., 2015a, 2015b; Ben-Salem et al., 2016; Hlioui et al., 2017).

As it turns out, a three-response optimization problem was developed. Here, improvement in one response did not necessarily improve the others. Under these conditions, the desirability function approach was applied. This approach transformed a response to a scale-free scalar. By using a geometric mean between them, the overall desirability function was obtained (Myers et al., 2004). Based on this approach, only one solution may be yielded, whereas

[1] Centre for Climate and Energy Solutions. www.c2es.org/initiatives/natural-gas.