Inventory Lot-Sizing under Dynamic Stochastic Demand with Carbon Emission Constraints

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ABSTRACT: In this paper we investigate the effects of emission- and system-related parameters on inventory lot-sizing problem and supply chain performance under dynamic stochastic demand, considering carbon cap-and-trade regulatory mechanism. We develop an integer linear programming model to conduct extensive computational experiments to produce results for different business settings. Furthermore, we show that the cycle service level and the demand coefficient of variation have significant effects on costs, inventory and emission generated in a supply chain.

I. INTRODUCTION

Recently, United Nations report on climate change suggests that carbon emissions are causing irreversible and widespread damage to the planet and governments can keep it in check by cutting greenhouse gas emissions to zero by 2100. Reducing emission through operational decisions has been newly explored area of the forward supply chain. Benjaafar et al. (2013) incorporate carbon emission constraints on single and multi-stage lot-sizing models with a cost minimization objective. Inventory lot-sizing problem has been widely studied and integrated with supplier selection or carrier selection to minimize total logistics costs (Choudhary and Shankar 2011, 2013, 2014). Absi et al. (2013) present new carbon emission constraints in multisourcing lot sizing problems. They also analyze computational complexities of the mathematical programming models incorporating these constraints. Jaber et al. (2013) account for green house gas emissions generated due to vendor’s production process under cap-and-trade system using EOQ model. They jointly optimize inventory related cost and emission related cost. The work of Plambeck (2012) shares the experiences of how it is possible to profitably reduce gas emissions in supply chains. In this paper we attempt to explore the effects of ordering costs, cycle service levels, demand coefficient of variations and emission parameters on inventory lot-sizing problem and supply chain performance under dynamic stochastic demand. We consider carbon cap-and-trade regulatory mechanism, a successfully implemented regulatory mechanism in various parts of the world including the European Union. Using an integer linear programming model, we conduct extensive computational experiments to produce results for different business settings. We analyze and document the results of the computational tests, to illustrate the effects of parameters considered in the study.

II. EXPERIMENTATION

We conduct full factorial experiments considering different levels of the parameters considered in the study. While ordering cost and ordering emission both are assumed to have values to be 200, 400, and 900 units, carbon cap CAPHorizon £ [10000, 25000] and carbon price p £ [1, 5]. Likewise, we investigate effects of cycle service level CSL £ [0.9, 0.95, 0.99] and demand coefficient of variation CV £ [0.1, 0.4, 0.7]. The planning horizon consists of 18 periods of equal duration without any initial inventory.
impact on supply chain performance and emission generated in the supply chain. With the increase in CSL from 0.90 to 0.95, there is significant increase in total cost, total inventory and total emission but the increase in the values are even steeper when CSL increases from 0.95 to 0.99. Figure 1 demonstrates the variation in costs, inventory and emission with CSL.

Likewise, the demand coefficient of variation also has significant influence on supply chain performance and emission produced and has variations similar to that of CSL. When the value of coefficient of variation is low, the total cost may even become negative i.e. the organization start earning revenue. The required inventory for such cases is low, so the emissions produced due to inventory holding are also low and unused emission credits may be sold to earn revenue. In carbon cap-and-trade regulatory mechanism, the effect of carbon cap on emissions is insignificant, as depicted in Figure 2. But it affects total cost extensively, whereas inventory remains constant. There is increase in total inventory, total cost and total emission with increase in ordering related emissions as shown in Figure 3. At higher values of ordering emission, the rate of increase in corresponding values of inventory, costs and emission are higher. We get similar results by varying ordering costs.
The lowest as dispersed size of carbon black in suspension achieved with use of PVP as a dispersing agent and measured by laser diffraction was 199 nm. This must be seen in light of the fact that the primary size of carbon black particles is less than 10 nm as determined by Nitrogen adsorption method and TEM observation, thus suggesting that even in the best dispersion achieved in the present study the carbon black particles were agglomerated.

The viscosity of alumina-clay-carbon black slurries increased with carbon black addition. But since the carbon black was still agglomerated the increment was not as dramatic and all slurries were still pourable with highest viscosity being lesser than 14 Pa s (for 8 wt% carbon black samples) at a shear rate of 10 s⁻¹. As discussed in the experimental section since the carbon black and alumina-clay slurries were separately prepared and then mixed, the carbon black in the slip cast sintered samples appeared to be almost uniformly distributed (Fig. 1). The carbon black as seen in the sintered samples existed in the form of agglomerates (Fig. 1) which seemed to be of the similar scale as observed independently in dispersion (~200 nm). As compared to samples processed from slurries, CCC samples prepared from compaction of powder blends resulted in samples which were fragile and could not even be handled.

The alumina-clay-carbon black composites sintered at 1400 °C were highly porous as was visible in Fig. 1. The open porosity of the composite samples as measured by water absorption increased with increase in carbon black amount, from being 14% for samples with 2 wt% carbon black to 27% for samples with 8 wt% carbon black. The increasing open porosity and lower overall density of the composites were responsible for the observed decrease in the thermal conductivity of the samples with increase in carbon black amount (Fig. 3). At and above 4wt%, percolation became significant as reflected in terms of electrical characteristics, with a sharp increase in viscosity. The percolation network formed resulted in significant inhibition of inter-particle sintering leading to rapid reduction in strength but the density followed close to that as expected as per the rule of mixtures.

With increase in carbon content beyond 5 wt% the slurries became thicker. Under such circumstances when the slurries are highly viscous prior to slip casting, the particles do not pack as well and thus the density was reduced rapidly. Further increase in viscosity resulted in a linear decrease in density contributed both from increased porosity due to inhibited sintering and poorer packing.

The increase in porosity with increase in carbon black amount was caused by inhibition of densification of the composites by presence of carbon black. Carbon black particles are not expected to sinter to each other and rather they resulted in poorer packing and contact between alumina-clay particles restricting densification. Clay played the dual role of inorganic binder binding alumina particles as well as forming in situ mullite crystals (Fig. 2) which is expected to contribute to strengthening of the body. Samples prepared without clay (alumina-carbon black only) were too fragile and could not even be handled.

Though the porosity had a detrimental influence on the compressive strength it must have resulted in improvement in thermal shock resistance of the composite samples [11-13]. The thermal conductivity of the samples, as per expectation, decreased with decrease in density for increasing carbon black content (Fig. 3). Thermal conductivity of all samples increased with temperature as it is characteristic of carbon black (Fig. 3). The increase in thermal conductivity with temperature is beneficial for the application of ceramic carbon resistors in power applications where sample temperature rises with passage of large currents during voltage surge.

Assuming that high compressive strength and thermal conductivity are desired for the application of ceramic carbon composites which serve as resistors in power applications the sample with 2 wt% carbon black appeared to be the most suitable.

IV. CONCLUSION

We study the inventory lot-sizing problem under non-stationary stochastic demand with emission and cycle service
level constraints and analyze the impacts of product-related features, system- and environment-related parameters on inventory costs and emissions. We use an integer linear programming model under carbon-cap-and-trade regulatory mechanism and conduct comprehensive computational tests. The model explicitly accounts for emissions due to ordering and storage activities along with emission per unit purchased. In addition, the model also considers the total cost incurred, including the purchasing cost, the ordering cost, the inventory holding cost and the cost (revenue) due to emissions produced beyond (under) the carbon cap with a constraint on emissions generated. The results find that how cycle service level, demand coefficient of variation and emission parameters affect the total cost, total inventory and emissions generated.

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