2. Literature review

Although LP models are not the totality of product mix formulations, they are common representations in many applications including the modeling of green product mix. The following literature discussion is intended to provide context for the modeling framework in which IA is illustrated.

2.1 Literature of the product mix problem

Early in its history, the product mix problem was formulated as an LP problem and applied in a wide variety of settings. Some early industry applications included Charnes et al (1952) in petro-chemical processing, Fabian (1958) in integrated iron and steel production, Eisemann and Young (1960) in textile manufacturing, Koenigsberg (1961) in wood products manufacturing, and Swanson and Woodruff (1964) in agriculture. Over time, formulation innovations emerged to address special features of the decision-making environment. They included fuzzy features such as the decision maker's ability/inability to rationalize the tradeoffs in product mix decision-making. Recent contributions to accommodate fuzzy modeling aspects included Bhattacharya and Vasant (2007), Bhattacharya et al. (2008), Kunsch et al (2004), Kunsch and Springael (2008), Tsai and Hung (2009), and Hasuike and Ishii (2009). Susanto and Bhattacharya (2011) accommodated fuzzy features under multiple-objectives. Bhattacharya et al (2006) utilized an analytical hierarchy process (AHP) approach to the determination of optimal product mix. Other contributions included activity-based costing (ABC) aspects and theory of constraints (TOC) approach. Kee (1995) incorporated both. The integration was intended to capture the interaction among costs (direct and indirect) of production and resource capacity (utilization and expansion) under a variety of product mix scenarios. Kee and Schmidt (2000) developed a model in which ABC and TOC were special cases. Malik and Sullivan (1995) also addressed ABC aspects of mix determination. **For the interested reader,** Chaharooghi and Jafari (2007) presented a review of TOC literature related to product mix determination.

2.2 Literature of green product mix determination

Contributions that addressed green aspects of product mix determination included Kunsch et al (2004), Kunsch and Springael (2008), Mirzaesmaeeli et al (2010), Mollerten et al (2003), and Tsai, Lin, Fan et al (2012) for CO_2 reduction; Dvorak et al (2010) for control of dioxins and NO_x emissions; Rong and Lahdelma (2007), Xin et al (2009), and Jaehn and Lemathe (2010) for emission trading; Lu et al (2008) for green house gas emission control and mitigation under a single emission (carbon) constraint; and Sheng and Srinivasan (1995) with a framework for incorporating the environmental impact of the materials and processes used in manufacturing and the emission streams they generate; and Sheng and Srinivasan (1995) for multiple objectives. Other treatments of green product mix modeling are found in Boons (2002) and Klemes et al (2010).

Of particular interest in this paper is the green product mix modeling of Lemathe and Balakrishnan (2005) and Tsai et al (2012). They provided LP formulations of green product mix problems that lend themselves well for illustration of IA. Their models incorporated charges associated with emission generation; cost (revenue) associated with procuring (selling) emission allowance when emission generation exceeded (fell short of) the compliance quantity; and piecewise linear emission costs that accounted for penalties that depended on the quantity of emissions (Tsai et al, 2012, p. 1176). The composite modeling also includes the conversion of emissions to products in the form of recycled and processed by-products such as recycled batteries (Revkin, 2013), conversion of organic waste to renewable biodiesel fuel (Anonymous, 2012), and the procurement and sustainability of food chains (Akkerman, Farahani, and Grunow, 2010, p.871). According to Atasu et al (2008, p.483), some conversions have economic value that depending "on the economics of a particular situation, recovery processes may reuse the entire product, selected modules, components, and/or parts. CLSCs (close-loop supply chains) represent a rapidly growing industrial activity characterized by a lack of formal systems and procedures to guide management decision-making. There has also been a recent surge in academic research interest." Material and energy recovery in solid waste management is discussed in Najam et al (2002). Other contributions related to green product mix include King and Lenox (2001) and Galbraith (2013) on taxing or carbon emissions (2013).

Post-optimality analyses of the product mix solution appeared in Malik and Sullivan (1995, p174), Kee (1995, p.???), and others. The investigations generally consisted of sensitivity analysis of certain model parameters and shadow price studies. However, except for the one-constraint two-product modeling of Lu et al (2008), none attempted individual, pairwise, or other grouped impact assessment of emission controls.

Akkerman, R., Farahani, P., Grunow, M., 2010. Quality, safety and sustainability in food distribution: a review of quantitative operations management approaches and challenges. OR Spectrum 32, 863-904.

Anonymous, 2012. Available at http://phys.org/news/2012-11-facility-ghana-human-renewable-biodiesel.html on November 19, 2012.

Atasu, A., Guide Jr., V D. R., Van Wassenhove, L. N., 2008. Product reuse economics in closed-loop supply chain research. Product and Operations Management 17(5), 483–496.

Galbraith, K. available at http://www.nytimes.com/2013/07/25/business/global/a-carbon-tax-by-any-other-name.html?src=recg&pagewanted=print on July 26 2013.

King, A. and Lenox, M., 2001. Lean and green? An empirical examination of the relationship between lean production and environmental performance. Production and Operations Management 10 (3), 244-256.

Najm, M. A., El-Fadel, M., Ayoub, G., El-Taha, M., and Al-Awar, F., 2002a. An optimization model for regional integrated solid waste management I. model formulation. Waste Management & Research 20 (1), 37–45.

Najm, M. A., El-Fadel, M., Ayoub, G., El-Taha, M., and Al-Awar, F., 2002b. An optimization model for regional integrated solid waste management II. model application and sensitivity

analyses. Waste Management & Research 20 (1), 46–54.

Revkin, A., 2013. Available at http://dotearth.blogs.nytimes.com/2013/07/18/a-u-s-battery-recycler-says-we-should-keep-the-lead-in/?src=recg on July 21, 2013.

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2.3 Literature related to strategic issues of green product mix determination

Much like green supply chain management, green product mix determination is an integral part of the overall environmental strategy of an organization, Daniel et al (1997), Penkuhn et al (1997), Lemathe and Balakrishnan (2005), Radulescu et al (2009), and Tsai et al (2012).