



Contents lists available at ScienceDirect

European Journal of Operational Research

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

Promoting sustainability of automotive products through strategic assortment planning

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ARTICLE INFO

Article history:

Received 31 August 2016

Accepted 17 August 2017

Available online xxx

Keywords:

OR in environment and climate change

Assortment planning

Automotive products

Network design

Sustainability and environmental regulations

ABSTRACT

Assortment planning seeks to find an optimal set of products that the company should offer to its customers. Traditionally, it is a trade-off between offering larger assortments to maximize customer choice vs. smaller assortments to minimize costs associated with design, manufacturing, and distribution. Existing assortment planning models are quite lacking when it comes to configurable products such as automobiles and detail level of supply chain considerations. Further complications stem from increasingly strict environmental regulations and broader expectations for sustainable products and supply chains. We present a mixed-integer linear programming formulation for integrated assortment and supply chain network design models for automotive products to provide effective decision support and directional guidance to strategic product planners. Our models account for product use and supply chain emissions as well as fuel efficiency requirements. We also present an illustrative case study motivated by a global automaker to demonstrate the utility of the models and study the effects of sustainability requirements on the assortment and supply chain design.

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1. Introduction

Sustainability is becoming an utmost priority for many organizations, governments, and citizenry around the world. While there are several reasons for this trend, the negative effects of global warming in the form of extreme weather events, related illnesses, and economic losses can be readily witnessed all around (Denchak, 2016; Nature.org, 2016). The United Nations (U.N.) concluded that climate change is a global issue, affecting every country, and is expected to affect even more in the future (United Nations, 2016).

The global surface temperature has increased by 1.5 degree Fahrenheit since 1880, with more than half of that rise is observed since 1980 (UCSUSA, 2016). Data show that carbon dioxide (CO₂) levels have steadily increased every year, with levels 25% higher today than in 1957, and has contributed the most to climate change between 1750 and 2005 (Jones et al., 2007). One of the primary contributors to CO₂ emissions is the transportation sector. Globally, transportation is contributing 14% of the greenhouse gas (GHG) emissions (U.S. EPA, 2014). The GHGs, including CO₂, methane, ozone, and the fluorocarbons, absorb solar and thermal radiation as well as heat fluxes from Earth's surface, and in turn

the atmosphere warms the Earth's surface which is called as the "greenhouse effect". In 2013, transportation contributed more than half of the carbon monoxide and nitrogen oxides (UCSUSA, 2016) and over a quarter of the total U.S. GHG emissions, only second to the electricity sector (U.S. Department of State, 2014). Of these emissions in the transportation sector, more than half come from gasoline consumption of automobiles and other highway vehicles (U.S. EPA, 2014), and is the focus of this study.

Early on, the "Brundtland Report" commissioned by the U.N. led to the recognition that while the environmental focus of sustainability efforts is important, a balanced concern for also the economic and social pillars of sustainability is also critical (Brundtland et al., 1987). It defined sustainable development as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs". While disagreements exist today regarding the "three legged-stool" model of sustainable development (Dawe & Ryan, 2003), it is understandable that the private sector has to be concerned about profitability of their products/services besides environmental sustainability. This is certainly the case for the automotive industry with its global and complex supply chains that is expected to produce nearly 90 million vehicles globally in 2016 (Lehle, 2016). The product assortment planning models proposed in this study aim to help strategic product planning groups within the automotive companies to better understand and manage these trade-offs, in particular, the trade-offs between the resulting GHS emissions

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during production and use, and the sales/profitability of the vehicle programs.

We define *assortment* as the set of products a manufacturer builds and offers to its customers. The goal of the *assortment planning* is to identify an assortment that maximizes sales, profit, or gross margin while satisfying numerous constraints including budget, shelf space, and capacity (Kök, Fisher, & Vaidyanathan, 2008). A *configuration* is a combination of required (e.g., powertrain, seats, wheels) and optional (e.g., moonroof, adaptive cruise control) components, and each model is offered in various configurations for *configurable products* (Rodríguez & Aydin, 2011). Taghavi and Chinnam (2014) introduced *product definition* as the set of configurations and the corresponding logic for a configurable product. Assortment planning requires balanced trade-offs between expected sales, revenue, and product offering costs (MacDuffie, Sethuraman, & Fisher, 1996), not to mention environmental impact, which is the focus of this study.

The product offerings and configurations have steadily grown globally in the automotive industry until recent years. For instance, the number of automobile models offered in the U.S. increased from 30 in 1955 to 142 in 1989 (Womack, Jones, & Roos, 1990), and to 394 in 2013 (Baumann, 2013). However, Pil and Holweg (2004) have not found significant correlation between the number of configurations and total sales for European automotive market. In addition, large product configuration assortments come with increased cost due to manufacturing complexity and productivity problems. Recently, the volume-driven original equipment manufacturers (OEMs) have begun to control their assortments to attain a balance between operational costs, sales, and market shares (Taghavi & Chinnam, 2014). This is particularly the case for the North American (NA) market given that vast majority of customers buy or lease vehicles from the dealer's limited on-hand or local inventory (unlike European markets where a majority of the vehicles might be built-to-order). For instance, Ford Motor Company reduced the number orderable configurations by more than 90% for 2009 F-150 and cut the number of core entity combinations by 95% for 2010 Ford Focus, in comparison to prior models (Wilson, 2008). OEMs lack objective and holistic decision support tools for their strategic assortment planning problems for managing product variety, sales, market share, and costs (Kremer et al., 2016; Taghavi & Chinnam, 2014; Umpfenbach, 2013).

In the automotive industry, there are increasingly strict governmental regulations effecting product offerings (Geffen & Rothenberg, 2000; Koplin, Seuring, & Mesterharm, 2007). In the U.S., the Corporate Average Fuel Economy (CAFE) standards are the main federal regulations, which are set by the National Highway Traffic Safety Administration (NHTSA). The achieved CAFE level, expressed in miles per gallon (3.785 liters), is the production-weighted harmonic mean of fuel economy of an OEM's fleet for a given model year. The required CAFE levels are calculated based on the CAFE standards and characteristics of the OEM's fleet. From 1978 to 1984, the CAFE standards significantly increased from 18 miles per gallon to 27 miles per gallon and stayed relatively stable until 2010 for passenger cars. Since 2011, CAFE standards are expressed as a function of vehicle wheelbase and average track wide. The CAFE targets are rapidly increasing over the next several years: For passenger cars and light-duty trucks, the fuel economy target of 35.5 miles per gallon in 2016 will increase to 54.5 miles per gallon in 2025. If an OEM does not achieve the required CAFE levels, the OEM either applies for CAFE credits or pays a penalty, which is currently \$5.5 per 0.1 miles per gallon for every vehicle produced for the U.S. market. Additionally, the Gas Guzzler Tax applies to passenger cars with fuel economy less than 22.5 miles per gallon and can reach up to \$7700 per vehicle in 2016. Alternatively, some countries, including European states, followed high fuel taxation policy (Ekins, 1999; Sterner, 2007).

This policy has been seen one of the most effective instruments for controlling energy consumption and air pollution as well as promoting cleaner fuels and alternative energy sources in transportation sector (Steenberghen & Lopez, 2008).

Overall, product assortment planning models are lacking when it comes to facilitating effective trade-offs between market share, profitability, and broader sustainability considerations (Taghavi & Chinnam, 2014). This is particularly the case for configurable products as is the case within the automotive industry and others (Kremer et al., 2016; Taghavi & Chinnam, 2014; Umpfenbach, 2013). This study aims to address these shortcomings and provides a tractable modeling framework that is particularly aimed at supporting upfront strategic product planning efforts in automotive companies, that often take place several years ahead of actual production. The goal is to provide effective decision support and directional guidance to product assortment planners while accounting for the entire product life-cycle.

Due to differences in fuel-efficiency regulations, customer expectations, and even differences in the fuel and road infrastructure, OEMs often tailor their vehicles to specific market needs. For example, European vehicles tend to be much smaller due to narrow streets in many cities/countries, and lighter due to stricter regulations and higher fuel-efficiency expectations with respect to North American products (Spector, 2007). Hence, European products generally employ more lighter materials (e.g., by replacing steel body panels with aluminum panels) and adopt efficient powertrains (e.g., use smaller engines with turbochargers instead of naturally aspirated engines to provide better fuel efficiency) albeit at the expense of higher product pricing. For this reason, our models are aimed at providing assortment planning guidance and support for product planning groups working on individual products for specific markets (e.g., the mid-size (C-segment) Ford Focus car for North America). To the best of our knowledge, this is the first study aimed at strategic product assortment planning for configurable products with integrated consideration for supply network design, manufacturing, logistics, supply chain carbon footprint, and product use emissions considerations. While the study is mainly aimed at the automotive industry, the proposed models can be adapted to other industries and sectors that deal with configurable products (e.g., copiers, computers, housing appliances).

The main contributions of this paper are as follows. First, we introduce sustainability aspect to the integrated assortment planning and supply chain optimization problem. Second, we utilize three variants of sustainability targets for an automaker: average fuel efficiency of a fleet, average product use CO₂ emissions, and average supply chain CO₂ emissions. Third, a case study based on a North American automotive manufacturer is introduced with extensive parameter estimation via consultation with subject matter experts. Fourth, we discuss the effects of each sustainability target on profit, sales, average fuel efficiency, as well as product use and supply chain CO₂ emissions.

The remainder of this paper is organized as follows. Section 2 discusses the related literature. The strategic assortment planning problem and constraints pertaining to sustainability targets are introduced in Section 3. Section 4 discusses data considerations for sustainability modeling. Section 5 analyzes the effects of sustainability constraints on the assortment and supply chain design via a case study. Finally, Section 6 concludes the paper with a summary and recommendations for future research.

2. Literature review

Our contribution relates to the literature on assortment planning, effect of environmental emissions and standards on automotive manufacturing, life-cycle analysis of automotive products

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