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Addition by subtraction: Integrating product deletion with lean and sustainable supply chain management

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ABSTRACT

Product management activities have typically focused on the innovation, acquisition, expansion and management of product lines and products. However, product deletion or discontinuation is also critical. Despite its strategic importance, product deletion has received relatively less attention in both academia and practice. Researchers have conceptually investigated product deletion, its influence on firm's resources, the factors influencing product deletion decisions, and the product deletion process. However, very few papers have related product deletion decisions to supply chain management, especially when leanness and sustainability are major objectives. This paper aims to integrate lean and sustainable supply chain dimensions with product deletion by proposing a multilevel decision model that can facilitate a product deletion decision with an objective of developing a leaner and more sustainable supply chain. The model has three major decision dimensions with 8 factors with 29 influencing determinants. The model uses an integrated analytical hierarchy/network process (AHP/ANP) and a benefits, opportunities, cost and risks (BOCR) analysis. An illustrative company scenario is provided for the model application. The paper contributes by filling an important gap by integrating lean and sustainable supply chain management and product deletion literature to formulate a product deletion decision making model which aids in enhancing the leanness and sustainability of supply chains. The model also allows for cross-functional participation involving marketing, operations, finance, and environmental sustainability fields.

1. Introduction

Organizations' long-term survival depends upon their product portfolio management, for example adding new products to the portfolio, replacing existing products with new ones, or modifying existing products (Saunders and Jobber, 1994). In addition to this, deleting a product is also a critical decision in product portfolio management. Product deletion or elimination is defined as discontinuing or removing a certain product from an organization's product portfolio (Avlonitis and Argouslidis, 2012; Shah et al., 2017). Product deletion may benefit firms across various aspects including organizational, financial, operational, and marketing dimensions. For example, Procter & Gamble (P&G) has been dedicated to refining its product portfolio on a regular basis with a mission of keeping its strongest products that contribute to 90% of its sales and 95% of its profits (Ng, 2014). Resources freed up from the deleted products are redeployed into stronger products that can deliver greater returns (Carlotti et al., 2004). Although product deletion offers several advantages to a firm, it is a complex strategic choice to make as multiple factors influence and are influenced by this decision, such as financial performance metrics and drivers, internal and external stakeholders, organization's strategies and goals, and efficient resource utilization (Avlonitis and Argouslidis, 2012; Shah, 2015).

However, despite the fact that supply chains are designed around products, to our knowledge, there have been few investigations of the influence of operations and supply chain management factors on a product deletion decision (e.g., Ashayeri et al., 2015; Grussenmeyer et al., 2014). Product deletion decisions can be influenced by sourcing, operations and manufacturing, distribution and logistics, as well as product usage and service factors in supply chain management. Additionally, maintaining or improving a lean and sustainable supply chain could also be an important objective while evaluating candidates for product deletion. The deletion of products can make supply chains more lean and efficient and can also contribute to the environmental sustainability of supply chains as an 'eco-efficient' strategy (Subramanian and Gunasekaran, 2015). A thoughtful product deletion policy can add value to the organization through elimination of products an "addition by subtraction" decision.

For example, Novartis Pharmaceuticals has gone through a product

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rationalization approach in order to reduce waste, costs, and inventory levels with deletion of items such fil-coated tables and pre-filled syringes (Leiter, 2011). The goal of this company was to become the "Toyota" of the pharmaceutical industry. The implication of this goal was to become leaner in their quest for operational excellence. However, becoming too lean and reducing product portfolio complexity may also hinder organizational performance, which leads to an inverted U shape relationship between product portfolio complexity and organizational performance (Fernhaber and Patel, 2012).

With multiple variables playing an important role in this decision, the strategic choice of product deletion becomes a complex and daunting task for managers. In this case, a comprehensive decision model integrating the product deletion and lean and sustainable supply chain factors can be of practical import to managers in arriving at a sound product deletion decision that avoids the omission of any strategic product deletion or lean and sustainable supply chain factors. This paper presents such a decision model using a joint analytical hierarchy/network process (AHP/ANP) approach and incorporating analysis of benefits, opportunities, costs, and risks (BOCR). The model is applied to an illustrative example.

The contributions of this paper include (1) contextually conceptualizing the product deletion decision, an important strategic concern for organizations, by incorporating lean and sustainable supply chain management factors with product deletion factors; (2) filling an important gap by integrating lean and sustainable supply chain management, and product deletion literature to formulate a product deletion decision making model which aids in enhancing the leanness and sustainability of supply chains; (3) the development of a comprehensive decision model that helps organizations to make a sound product deletion decision yielding lean and sustainable supply chain implications; and (4) the development and application of a flexible and replicable model providing significant opportunity for future research, model expansion, and practical validation.

The remainder of the paper begins with a theoretical and practical foundation of various principles relating to product deletion, operational and supply chain sustainability, and lean dimensions. This background sets the foundation for model construction and application. The model is then presented with an analytical illustrative example. The illustrative example provides insights into the effectiveness, sensitivity, and effort required to complete this analysis. A group decision making perspective using four key organizational functions marketing, supply chain, finance and sales is also introduced. Managerial and research implications related to the execution and outcome of the model and process are then discussed. Future research directions are presented in the summary and conclusion section.

2. Background

Product portfolio management involves cross-functional teams from marketing, operations/supply chain, finance, and sales departments. These activities include optimizing product portfolio complexity. Product portfolio complexity is defined by a product set and its mix of variants, features and component choices (Closs et al., 2008). It is commonly assumed that increased product portfolio complexity can benefit firms in many ways from both brand image and financial perspectives. Therefore, firms have been devoting effort and resources to product innovation, acquisition, as well as expanding its brand house and product lines. The deletion of products can reduce product portfolio complexity, which may make the deletion decision less appealing to managers. Few conceptual investigations and empirical studies have considered the potential implications of product deletion decisions on supply chains, especially those that incorporate lean and sustainability principles. We aim to present a model that brings together product deletion, sustainable supply chain management, and lean supply chain management literature. This section provides a summary of this literature and their inter-relationships.

2.1. Product deletion

Product deletion (elimination or pruning) is defined as discontinuing or removing a certain product from an organization's product portfolio (Avlonitis and Argouslidis, 2012). Product deletion decisions can occur when firms start to suffer from weak and poorly fitting products that underperform. Underperforming products consume firms' material resources and increase the complexity of internal processes across functional areas, such as external sourcing resources, logistics, and human capital (Putsis and Bayus, 2001; Thonemann and Brandeau, 2000). Deleting these products can help reduce operational costs and increase organizational profits (Bayus and Putsis, 1999). Organizational resources resuscitated from deleted products could be redeployed to other products within the portfolio or even outside the portfolio and their supply chains.

Deleting certain products may bring various organizational, financial, operational, marketing, and strategic benefits to firms (Shah, 2017b). However, if not planned and implemented well, product deletion can also bring disadvantages to firms. For example, firms could lose a certain market segment and revenues associated with the deleted product (Harness and Mackay, 1997). There could be customer dissatisfaction, loss of market share, poorer operational activities, and loss of competitiveness (Harness and Mackay, 1997; Shah, 2017a). Thus, careful strategic and operational considerations need to be integrated into the product deletion process.

The product deletion process comprises four stages: (1) identification of candidates for elimination, (2) analysis and revitalization/modification, (3) evaluation and decision making, and (4) implementation (Avlonitis and Argouslidis, 2012). The proposed model aids the evaluation and decision making phase and includes three important product deletion evaluation factors tested by Avlonitis (1984, 1985), including impact on resources, strategy, and financial performance. These factors are explained in detail in section 3.2.1.

2.2. Supply chain management and sustainability

Supply chain management has been defined as the integration of key business processes from end user through suppliers that provide products, services, and information that add value to end-users and other stakeholders (Arndt, 2004; Handfield and Nichols, 1999; Mentzer et al., 2001).

Sustainability has been defined in a number of ways. The triple-bottom-line of economic, environmental, and social sustainability has been broadly utilized to define organizational and supply chain sustainability (Bai and Sarkis, 2010; Carter and Rogers, 2008; Sarkis and Dhavale, 2015). The concepts of supply chain management and sustainability have become increasingly aligned and connected, although sustainable supply chain management still represents a novel and evolving area of research (Ahi and Searcy, 2013; Seuring and Müller, 2008). Supply chain management decisions should include firms' responsibilities to their stakeholders including customers, society, and the natural environment. The sustainability dimension of the proposed decision model is based on an overview of current supply chain management literature with a major focus on the environmental dimensions of sustainability (e.g. Hashemi et al., 2015).

This paper is one of the early endeavors to integrate supply chain sustainability into product deletion decision-making process. First, supply chain sustainability goals can influence and determine a product's candidacy of deletion (Bai et al., 2018). For example, product portfolio expansion will require greater resources and potentially produce more waste. If the supply chain is to be sustainable and eco-friendly, those products which have the lowest resource efficiency while delivering the least value can be prime targets for deletion. Second, product deletion can in turn contribute to the firm's supply chain sustainability. With redundant products being deleted, the optimized product portfolio can result in less wasted products, less warehouse space requiring energy resources, and fewer unnecessary transportation activities; which contribute to organizational and supply chain eco-efficiency (Dubey et al., 2017; Sarkis, 2001; Zhu and Shah, 2018).

2.3. Lean practices and supply chain management

Lean is a business principle or managerial philosophy that pertains to many aspects of organizational operations and policy. Lean thinking can aid organizations examine supply chain processes with considerations of minimizing unnecessary costs, reducing waste and improving inefficient operational activities; all of which are interrelated. The waste elimination focus is not limited to environmental issues such as solid waste but includes waste in time and process resources (e.g. capital and labor). All of these goals are meant to be addressed while ensuring specified product and service level requirements (Mason-Jones et al., 2000).

Supply chains are designed and managed to match supply and demand with a goal of minimizing costs while simultaneously improving value to end-users (Bortolotti et al., 2016). For this reason, lean principles play an important role in supply chain management (Prajogo et al., 2016). Lean principles in the supply chain can help facilitate a more predictable upstream demand. In some studies, leaning and greening are two interrelated practices (Arthur, 2010; Azevedo et al., 2012; Fahimnia et al., 2015; Martínez-Jurado and Moyano-Fuentes, 2014). In this study, lean principles and greening can be balanced. That is, green operational practices help achieve lean results within supply chains.

The lean philosophy helps identify and evaluate a product's deletion candidacy; and in turn, sound product deletion can result in a leaner supply chain. Using lean value thinking, products which deliver limited value after consumption of materials, labor, time, facilities, etc., would be prime candidates for deletion. If poor performing products are deleted, product portfolio complexity decreases, which likely results in less material and time waste and more efficient processes (Chavez and Mokudai, 2016); with an expectation of better business returns.

3. Decision model development

Building on the extant literature in product deletion, sustainability, and lean supply chain management, a decision model is presented. The decision model development will set the stage for how multiple criteria dimensions, factors and influencing determinants are identified. A candidate for product deletion is evaluated based on the impact of its deletion on developing a leaner and more sustainable supply chain, maintaining stakeholder interests and enhancing strategic and financial benefits.

3.1. The AHP/ANP/BOCR methodology

Product deletion decisions are not a short-term trivial exercise. Multiple dimensions and criteria need to be considered while making a strategically and operationally robust product deletion decision. It is also important for some firms to consider how this decision influences sustainable and lean supply chain management. Since multiple factors influence and are influenced by the product deletion decision, decision makers would benefit from a tool that enables them to weigh the importance of each factor and rank a set of decision alternatives to facilitate this complex yet crucial decision making. Depending on the complexity and the strategic importance of the decision, it a wide range of tools could be used. These tools include modeling from a straightforward linear weighted sum approach to sophisticated stochastic modeling (Sarkis and Sundarraj, 2000). Table 1 provides a summary comparative analysis of a number of existing multiple criteria decision-making methodologies and their characteristics.

Although there exist a plethora of alternative methods for solving multi-criteria decision making problem, the methodology selected in this study is AHP, a compensatory, discrete-alternative, multi-criteria decision model based on a hierarchical inter-related set of attributes. It is one of the most widely used approaches due to its ease of understanding and flexibility in integrating variations of factors (Subramanian and Ramanathan, 2012). One of the limitations of AHP is the static and unidirectional interactions of the criteria set with insufficient feedback across decision alternatives, criteria dimensions, and component factors (Triantaphyllou, 2000). Therefore, an expanded integration of AHP to the Analytic Network Process (ANP) and an analysis that considers benefits, opportunities, costs, and risks (BOCR) provides a more rigorous analysis. Although, there is additional complexity and effort by incorporating these two additional aspects, the advantage of a more realistic and thoughtful managerial decision environment provides additional robustness to the overall decision model. The AHP/ANP decision-making process includes criteria and decision alternative sets that can be assigned with different weights (importance) based on strategic and operational organizational goals. Scales are needed when making comparisons amongst decision alternatives. In this study the ratios assigned to factors are based on the fundamental scale (Saaty, 2004) shown in Table 2. This scale is required to quantify intangible factors such as competitive strategic dimensions. The quantification and integration of tangible and intangible criteria and factors is a major advantage of AHP/ANP (Sarkis, 2003b).

ANP is a more general form of the AHP approach, allowing for a systemic strategic analysis of multiple dimensions of decision factors. ANP applies relative measurement to derive attribute priority with the influence of factors that interact with each other rather than independent ratio scales. ANP incorporates interdependence of factors within a set of factors (inner dependence) as well as between different sets of factors (outer dependence). Thus, ANP captures the outcome of dependence and interaction amongst clusters of factors (Saaty, 2004). Adding ANP to the decision model allows comparing not only dimensions and factors but also inter-related consequences of deleting one product on other products across product families.

AHP and ANP together utilize the idea of both a control hierarchy and a control network, and each of these decision hierarchies can be evaluated from a benefits, opportunities, costs, and risks with regard to the ultimate organizational goal. BOCR can be represented as a ratio of benefit and opportunity to cost and risk valuations. Any organizational decision, including product deletion, requires investigation of the positives (benefits and opportunities) and negatives (costs and risks) in an attempt to express the ratio in quantitative terms. BOCR can be expressed in quantitative terms as the ratio scores of each alternative, which can then be used to rank those alternatives such that they provide the best approach to achieve benefits and capitalize on opportunities while reducing costs and tackling risks.

The overall AHP-initiated and ANP-based BOCR model is a computational modeling approach for assessing synthesized results. In this case, the complexity of the model provides a more realistic set of factors and interrelationships, enabling a systematic evaluation of the strategic decision of product deletion.

There are six steps for completing the synthesized AHP/ANP decision making process that incorporates BOCR. Details of these six steps within the context of product deletion decisions incorporating sustainability and lean concerns are presented in section 4.2 with a detailed illustrative example.

3.2. Dimensions, factors and relationships

To develop the decision network hierarchy, a series of important factors related to the strategic decision at hand need to be identified. Based on strategic management literature, Nooraie (2012) identified dimensions that influence strategic decision making. These dimensions included (1) decision-specific characteristics, (2) internal organizational characteristics, and (3) external environmental characteristics.

Table 1
Characteristics of multiple criteria evaluation techniques.

Evaluation Techniques	Cost of Implementation	Data Requirements	Ease of Sensitivity	Economic Rigor	Decision Maker Involvement	Management Understanding	Mathematical Complexity	Parameter Mixing -Flexibility
Scoring Models	L	L	L	L	H	H	L	H
AHP	M	M	L	L	H	M	L	H
Outranking	M	M	L	M	H	L	M	M
MAUT	H	H	M	M	H	M	M	H
DEA	M	M	L	M	L	L	H	M
Goal Program	M	M	M	H	M	L	H	L
Simulation	H	H	H	H	L	H	H	M
Expert Systems	H	H	L	H	M	M	H	H

Note: H = High, M = Medium, L = Low; Adapted from (Sarkis and Sundarraj, 2000).

The model proposed in this paper adapts these dimensions in the context of product deletion and lean and sustainable supply chain management. The three main dimensions used in the proposed model are (1) product deletion decision specific characteristics, (2) internal organizational operational characteristics, and (3) external environmental characteristics. Within each of these three dimensions, multiple factors with consideration of influencing determinants are considered to have an impact on the overall decision-making process. These factors and their determinants are explained in detail in sections 3.2.1, 3.2.2, and 3.2.3.

3.2.1. *Product deletion decision-specific characteristics*

In the product deletion literature, a traditional evaluation and decision reaching process involves multiple decision factors. The selected product deletion decision factors within our proposed model are from this product deletion literature (Avlonitis, 1984, 1985). These factors are impact on resources, strategy, and financial performance.

Impact on Resources. Management's ultimate concern is the identification and evaluation of the human, physical, and financial resources committed to a given product or product family. Therefore, in the context of product deletion, it is important to determine what, how, and when released resources from the deleted product could be shifted to the production and marketing of the other products in the portfolio. This involves two determinants (1) reallocating capital resources and facilities to other opportunities and (2) productive use of the released management and employee time spent on the deleted product (Avlonitis, 1984, 1985).

Impact on Strategy. Managers also contemplate various strategic considerations before deciding on whether to discard a product. Thus, to make a sound decision, several strategic alternatives are considered, and detailed information is processed. A product deletion decision can have a considerable impact on other strategic areas of the firm (Avlonitis, 1984) such as (1) full-line strategy, (2) corporate image, (3) and competitive moves.

Companies with full-line strategies attempt to enhance product line depth by carrying a high number of variations of similar products in order to satisfy a wide range of different customer desires. However, high variation in product lines causes consumer confusion, which reduces their motivation to purchase (Matsubayashi et al., 2009). Redundant products that cause consumer confusion are eventually deleted and this helps the firm streamline its product portfolio (Shah, 2017a) and thereby influences its full line strategy.

Organizations are sensitive to maintaining and protecting their intended image, construed image, and reputation (Brown et al., 2006). If a product has positive social contributions or is environmentally beneficial, its deletion might hurt corporate image and reputation.

In terms of competitive moves, some firms have a greater tendency to employ mimetic behavior, i.e., when they observe that their main competitors are engaging in particular behaviors, they also tend to engage in similar behaviors (Varadarajan et al., 2006). Thus, if the major rival of a mimetic firm is engaging in pruning its bulky product line, the mimetic firm might also engage in a similar behavior and decide to delete weak products. On the other hand, a firm that is not mimetic might even choose to retain its products or launch new ones if it notices that its competitor who has undergone the elimination process has left out more of the market open to the firm (Alexander, 1964). Thus, a product deletion decision can have a strong influence on competitive moves.

Impact on Financial Performance. Building and developing products requires significant financial investment. If a product's performance does not meet its firm's financial goals, the firm might have to delete it in order to minimize its losses (Shah, 2017b). Furthermore, deleting a product can also influence a firm's financial performance by affecting (1) sales of the product, (2) the profitability of the product, and (3) fixed and working capital associated with the product (Avlonitis, 1984, 1985).

3.2.2. *Internal operational characteristics*

For the internal operational characteristics factors we focus on business operations factors that would be influenced by the product deletion decision that the organization manages from a supply chain perspective. These factors include strategic supply chain performance competencies, managing the supply chain processes and activities, and lean management factors.

Strategic Supply Chain Performance Competencies. Flexibility, cost, quality, and time are critical strategic performance competencies that managers should consider when planning, designing, implementing, and managing the supply chain because they help build competitive

Table 2
The fundamental scale of AHP/ANP decision making processes.

Intensity of Importance	Definition	Explanation
1	Equal importance/preference	Two items contribute equally to the objective
3	Moderate importance/preference	One item has moderately more contribution or is more preferred over another
5	Strong importance/preference	One item contributes strongly or is more preferred over another.
7	Very strong importance/preference	One item contributes very strongly or is much more preferred over another.
9	Extreme importance/preference	One item has dominance demonstrated in practice

The intermediate values of 2,4,6, and 8 stand for additional levels of discrimination. For example, “2” means “weak or slight importance/preference” and “4” states “moderate plus importance/preference”.

advantage (Sarkis and Talluri, 2002).

Flexibility is an organization's ability to incur uncertainties with little penalty in time and cost (Upton, 1994). Flexibility stands for a firm's capability to identify, respond, and conform to dynamic changes and associated risks in market environments. Cost competency enables an organization to access a wide variety of markets with optimal costs. Such costs include total landed cost, total cost of ownership, scale-related cost, and variety-related cost (Bowersox et al., 2002). Cost competency and savings can be achieved through technology, process, labor, materials, facilities, and sourcing decisions while providing the organization skills or production techniques that deliver additional values across its supply chains (Lado et al., 1992). Quality is associated with the features and characteristics of a firm's market offerings that satisfy customers' expectations consistently. Quality might make a significant contribution to the perceived customer satisfaction level of the end product or service. Firms have higher motivation to seek quality competency when they distinguish their market offerings to be quality competitive to satisfy customer demand, especially when quality is difficult to imitate by competitors (Garvin, 1987). Time competency stands for a firm's ability to offer high responsiveness to customers through short cycle times in its operational processes, including product design, material purchasing, manufacturing, distribution and delivery (Stalk, 1988). Time competency improves both production efficiencies and customer satisfaction (Heikkilä, 2002).

A product's deletion can affect these supply chain competencies. For example, product deletion may reduce costs if the deleted products utilized some idiosyncratic resources or improve the flexibility of the supply chain if there is extra capacity due to fewer products to produce.

Supply Chain Operations Activities. A product deletion decision influences supply chain activities identified by the supply chain operations reference (SCOR) model. Under SCOR, supply chain management is defined by five integrated processes: plan, source, make, deliver, and return (Bolstorff and Rosenbaum, 2007). Activities within the plan process include assessing suppliers, prioritizing resource allocation, aggregating supply chain capacity for manufacturing, and managing inventory for distribution of all channels. The source process includes activities for obtaining, receiving, inspecting, holding, issuing and authorizing payment for raw materials, and purchased finished goods. The make process represents activities such as requesting and allocating raw materials for manufacturing and testing products, assembling, and packaging. The deliver process consists of executing warehouse network associates' activities, customer-oriented labeling and delivering, managing transportation modes, and efficiency. The return process involves authorizing, scheduling, inspecting, receiving and verifying returned products, and associated disposition and replacements.

The product deletion decision, depending on the products and characteristics, may influence one or more of these supply chain process activities. For example, if a product that has a larger percentage of its material outsourced is deleted, there will be greater influence on the "sourcing" and "make" supply chain processes.

Lean Dimensions. This model also considers lean dimensions because "becoming lean" is a pervasive supply chain philosophy that influences multiple aspects of the supply chain including the processes and competencies (Bortolotti et al., 2016; Naylor et al., 1999). Similarly, various aspects of leanness can also be influenced by the product deletion decision. Three fundamental lean management principles that are utilized to represent lean supply chain criteria performance in this model are (1) waste reduction, (2) a process-centered focus, and (3) high levels of people involvement and participation. These are also the most cited dimensions of lean supply chain characteristics (Martínez-Jurado and Moyano-Fuentes, 2014). Operational factors, such as supplier involvement (e.g., supplier feedback, JIT delivery and developing suppliers), customer involvement, and internal organizational factors (e.g., controlled processes, productive maintenance, and employees' involvement) (Shah and Ward, 2007) are integrated and mapped on to the three lean management principles.

Principle of waste reduction involves a focus on increasing value by reducing or eliminating any supply chain activity that does not add value. In this perspective, supplier feedback, JIT delivery, and developing suppliers are included within this principle. Organizations should engage in supplier relationship management by constantly exchanging feedback concerning the allocation and usage of resources in order to increase manufacturing efficiency while reducing waste. The product deletion decision and its relationship to some of these lean principles could include (1) recommendations from suppliers on which product to delete, (2) the implications of JIT delivery for the products that remain, and (3) the role of developing suppliers who are strategic partners but no longer required for that product.

Process-centered focus includes controlled processes and productive maintenance. Therefore, internal organizational factors such as, controlled processes and productive maintenance are mapped on to this lean management principle. Lean management concentrates on achieving performance throughout all stages of supply chain processes. The lean focus is not limited to solving problems but also preventing problem recurrence. Established mechanisms that enable and ease the continuous material, financial, and information flows, while reducing process downtime between product innovations, is required to ensure each supply chain process will function to its maximum capacity. Total productive maintenance will also help achieve a high level of equipment availability to support subsequent processes and increase overall organizational flexibility. Successful product deletion could help in reducing variability and make processes more efficient. However, an unsound product deletion decision may cause imbalance in supply chain processes and variability across processes.

High levels of people involvement and participation are important for lean supply chain management. The advanced human resource management practices, including both employee and customer involvement and a continuous-improvement culture in the organization, can facilitate and add value in lean management. Customer involvement stands for the organization's focus on customers and their needs. Employee involvement refers to employees' role in their cross-functional team and their problem-solving ability. Product deletion and human resource implications can mean freeing up resources, for example time, in some areas to allow for greater employee involvement in aspects such as continuous improvement programs.

3.2.3. External environmental characteristics

Factors included within the external environmental characteristics are related to environmental sustainability and external stakeholders. These factors are identified as decision-making influencers in terms of product deletion and supply chain management with a lean and sustainable focus. Additional specific environmental sustainability factors that relate to performance outcomes and activities could have been used (e.g., emissions reduction performance; integrating environmental management systems, green supplier development). However, the factors used in this model are general enough to fit across industries and activities that can result in improved environmental performance, if applied appropriately (Sarkis, 2003a).

Environmental Sustainability. The sub-factors in environmental sustainability criterion are represented by the "5Rs" (i.e, reduce, reuse, recycle, reclamation, and remanufacturing) of corporate environmental management (Hashemi et al., 2015; Pan et al., 2015; Xia et al., 2015). *Reduce* refers to resource usage reduction in sourcing or pre-manufacturing processes, energy and material usage reduction in the manufacturing process, and waste reduction in product end-of-life or after-purchase operational service stage. *Reuse* stands for reuse of resources in the manufacturing and remanufacturing process and reuse of a product or its finished components after its first life cycle. *Recycle* involves the process of transforming traditional material or resource waste to new materials or resources to be used within product manufacturing or remanufacturing processes. *Reclamation* involves the process of recovering and reasserting both materials and products or components for reproduction purposes in subsequent product life cycles. *Remanufacturing* represents the collecting, sorting, reassembling, and reprocessing of used products and components and converting them into new product forms for resale purpose without losing original functionality (Scur and Barbosa, 2017). These 5Rs might have an impact on determining which product to delete in terms of how much the product influences the reduce, reuse, recycle, reclamation, and remanufacturing determinants of corporate environmental sustainability management. For example, some products may have used design for the environment (DfE) principles (Jackson et al., 2016). DfE principles focus on designing products with the 5Rs in mind. Deleting one of these products can significantly affect the 5Rs.

Stakeholders. Pressures from stakeholders are triggers for organizations to make certain levels of commitment to lean and sustainable supply chain practices (Hassini et al., 2012). Similarly, several stakeholders such as customers, channel partners, government, and mass media can also influence product deletion and make the decision more difficult and complex (Shah, 2015). *Customers* are the end users of products and therefore customer adoption and final purchase contribute to an organization's revenue stream (Kumar et al., 2008). Deleting products that are ingrained in customers' lives can negatively influence customer satisfaction, firm reputation and evaluation, and customer loyalty (Shah, 2017a) thereby creating a challenge for managers. *Channel partners* include suppliers, retailers, distributors and all other third-party business partners that engage and facilitate inter-organizational supply chain operations. The power of channel partners may enforce or impede a firm's product deletion decisions. *Governmen*tal policies and regulations set and modify industrial standards. These standards influence organizational decisions related to sustainable supply chain management and product deletion. *Mass media* influences individual attitudes toward a firm and its brands and products (Carroll and McCombs, 2003; Fulk et al., 1987; Kiousis et al., 2007). Deleting a popular or eco-friendly product could create negative publicity or media criticism that could in turn generate unfavorable firm reputation and further opposition from other stakeholders (Kiousis et al., 2007; Shah, 2015).

3.3. Decision alternatives

Many companies have extensive product portfolios, with multiple product families and individual products. To decide which product to delete from these product portfolios and at the same time considering its impact on lean and sustainable supply chain management is a complex process. A tool that can aid managers and facilitate this critical yet complex decision can be valuable. However, as per our knowledge, no such tool has been developed in either the product deletion or supply chain management literature. Before the application of a decision model, a tool that identifies and filters products for deletion consideration may be needed. Once a narrowed down set of candidates is determined, the decision model can be applied.

The generalized model is designed to manage a number of identified products within product families. The example scenario used in the model simulation, calculation, validation, and discussion sections, includes three product families. The deletion decision may occur at different levels, for example, a firm can delete a family of products with all its products, or a single product.

In this study, we construct the model (Fig. 1) with decision alternatives at the product family level. The overall objective is deciding which product family and which product to delete to make the supply chain leaner and more sustainable as well as ensuring that the impact on strategy, resource management, financial performance, and stakeholder interests is considered. This generalized model is grounded in marketing, operations and supply chain management, and environmental sustainability literature, and can help a firm with multiple product families make a sound product deletion decision.

Fig. 1 illustrates the items and their relationships in section 3 and will serve as the foundation for the decision network hierarchy for the AHP/ANP/BOCR model. At the top of Fig. 1 are the strategic decision model goal and BOCR elements. Each one of the BOCR elements will have its own analytical hierarchy model. Within each hierarchy are the major criteria dimensions and factors. AHP will be applied at this level. The bottom level represents the product family and product alternatives for deletion consideration. A looped arc is added to this lowest level to signify the interdependencies amongst the decision alternatives; that is, when an alternative is deleted, it will influence other alternatives. This stage uses the ANP model.

4. Model application and illustrative example

After identifying the major decision factors and alternatives in section 3.2, a general conceptual scenario to set the stage for the application of the AHP/ANP/BOCR model is provided in this section. Thereafter, the major steps involved in model calculation are presented.

4.1. An illustrative example scenario

An illustrative hypothetical example with a simulated company scenario is presented in this section. This scenario is based on some company and product related assumptions. It is assumed that the company in the scenario is a global producer of soft drinks. Customers with varied personal preferences and demographic characteristics purchase these drinks from a wide range of retailers, including hypermarkets, convenience stores, vending machines, and online retailers. The company has three product families A, B, and C and each product family has shortlisted three product deletion candidates.

Product family A is the first product introduced by the company in the market. Product family A is sold under the classic signature brand enjoying the largest market share for this company. Customers are loyal to this brand. It is difficult to make changes to this product. Adding a new product (new flavor or packaging) to this product family is not well accepted by the current market base. Revenue has stabilized over the past five years. The overall profit margin is shrinking with a tendency for further decline.

Product family B is sold under the firm's second representative brand. It was launched after product family A. It is a healthier version of product family A and can be viewed as a substitute of product family A. After B's introduction, some market cannibalization occurred between product family A and B. Even though product family A still occupies a larger market share, B has witnessed stable and continuous but relatively slow growth rate over the last decade.

Product family C is an innovative product that has been recently introduced. Limited market information for this product is available and there is less direct competition from other companies. Operations for C are separate from the other two products, with different suppliers and materials. Customer attitudes toward C is still not known. This product was launched to help the company gain greater market penetration and market share.

The company in the scenario has the following characteristics:

1) A thorough mature supply chain system with in-house technology.
2) A reputation for high quality products.
3) A plan to expand into a comprehensive house of brands that ranges widely throughout the beverage industry and all retailer platforms.
4) Nine product candidates are shortlisted as deletion candidates from three product families.

Fig. 2 summarizes the product family and product combinations for the scenario.

A scenario discussion for each of the many dimensions within this model is not provided since the AHP/ANP model can incorporate managerial perceptions and aggregations without having direct data on all factors. Having an overall decision framework can guide and

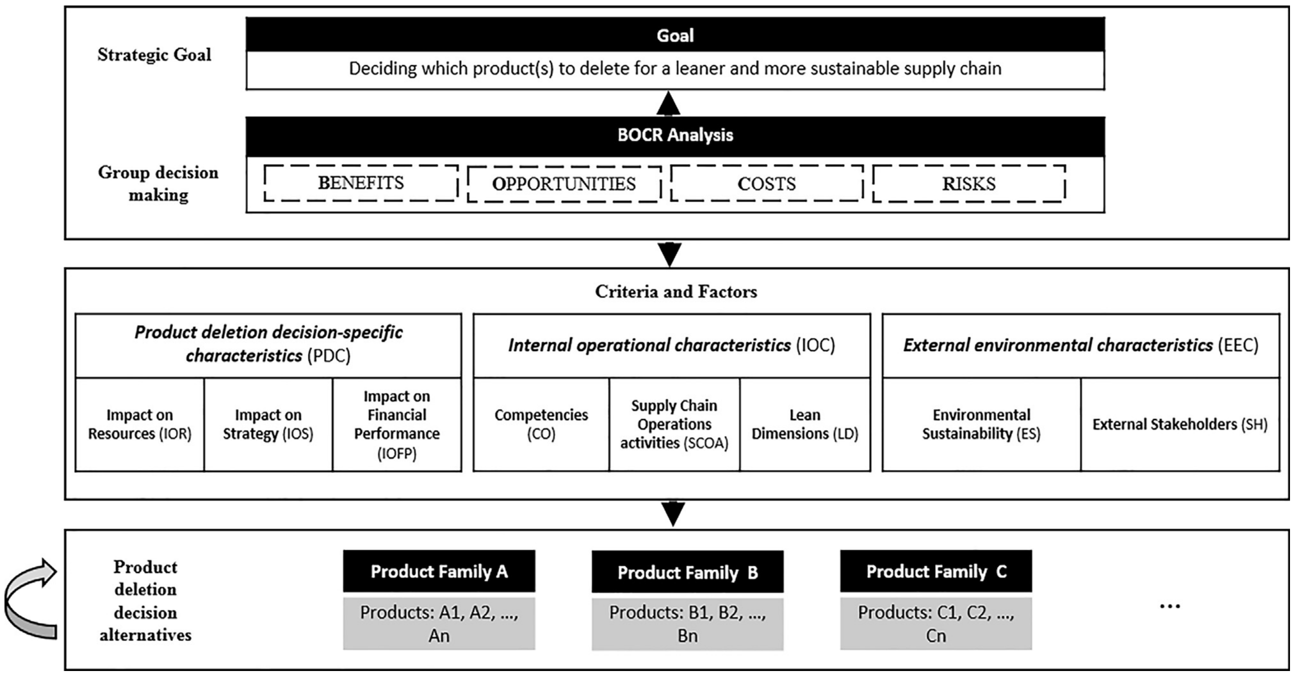

Fig. 1. Strategic product deletion decision making model.

	Plastic Container	Glass Container	Metal Container
Product Family A	A1	A2	A3
Product Family B	B1	B2	B3
Product Family C	C1	C2	C3

Fig. 2. Product family and product combinations in the scenario.

structure managerial discussion. Scenarios of the specific internal, external and product deletion dimensions are not included, but can be gleaned from the resulting importance levels from the methodology results shown below.

4.2. Model calculation

Applying the framework to the illustrative example scenario, the product deletion decision amongst products family A, B and C, as well as their product candidates, will be evaluated and detailed below in six major steps.

4.2.1. Step 1: setting up the decision environment

The first step includes clarifying the overall organizational objective of the decision and modifying the decision network hierarchy based on the proposed general model (Fig. 1). Considering the current business situation of this company, the firm and its management is looking for a product deletion occurrence to make the supply chain leaner and more sustainable, considering stakeholder interests, and seeking strategic opportunities to improve financial performance and competitiveness. For this illustrative example and decision environment, the model proposed in Fig. 1 is considered appropriate. For a different decision environment, an adjusted decision network hierarchy may be needed. The overall illustrative example decision will be to delete one product candidate from one product family. The final decision will depend upon an integrated ratio of benefit and opportunity to cost and risk associated with this decision according to four key organizational functions.

4.2.2. Step 2: constructing AHP pairwise comparison matrices and determining AHP relative importance weights

This step focuses on constructing pairwise comparisons and initial eigenvector (relative) importance weights for each group of factors. The pairwise comparison throughout the hierarchy is done from the top to bottom, i.e., the local weights for each level of the hierarchy, then for the dimension/criteria, followed by factors, and finally for alternative sets. The weights allocation are all based on the fundamental pairwise comparison scale presented in Table 2. The focus of this initial set of calculations are for the benefit analysis portion of the BOCR analysis. Similar calculations are needed for the O, C, and R elements of the BOCR analysis.

4.2.3. Step 2.1 AHP weights for benefit analysis on criteria dimensions

In order to generate the weights and arrive at the local weights for the criteria dimensions, the management representative is asked, for example, "How much more important are the product deletion specific characteristics as compared to the internal operational characteristics in terms of organizational benefit?" In Table 3 we see that the answer to this question is 0.2 (1/5) which means that as compared to internal operational characteristics, product deletion specific characteristics contribute lesser to organizational benefit.

To calculate the relative ranking of a dimension/factor/sub-factor, a local priority vector w (eigenvector) for the pairwise comparison matrix A is calculated by finding a unique solution to equation (1).

$$A\,w = \lambda_{max} w \tag{1}$$

Where λ_{max} is the largest eigenvalue of A (Saaty, 2004).

Based on management responses, the weights in this paper are calculated using Web-HIPRE, a free, internet based software program for AHP calculations (Mustajoki and Hämäläinen, 2000).

Table 3
AHP weights for benefit analysis on criteria dimensions.

Benefits	Product Deletion	Internal	External	Weight
Product Deletion	1	**0.2**	0.25	0.097
Internal	5	1	2	0.570
External	4	0.5	1	0.333

Table 4
Weights for each dimension of the benefits hierarchy for decisions.

Weights for *Product deletion decision-specific characteristics* dimension			
	Product deletion decision-specific characteristics (PDC)		
	0.097		
	Resources	**Strategy**	**Financial Performance**
	0.111	0.444	0.444
Product Family A	0.648	0.163	0.540
Product Family B	0.122	0.297	0.297
Product Family C	0.230	0.540	0.163

Weights for *Internal operational characteristics* dimension			
	Internal operational characteristics (IOC)		
	0.570		
	Competencies	**Operations Activities**	**Lean Dimensions**
	0.540	0.297	0.163
Product Family A	0.163	0.163	0.500
Product Family B	0.297	0.297	0.250
Product Family C	0.540	0.540	0.250

Weights for *External environmental characteristics* dimension		
	External environmental characteristics (EEC)	
	0.333	
	Environmental Sustainability	**Stakeholders**
	0.667	0.333
Product Family A	0.726	0.333
Product Family B	0.172	0.097
Product Family C	0.102	0.570

4.2.4. Step 2.2 AHP weights for benefit analysis of factors within each dimension

Similar calculations are conducted for each factor and sub-factor groupings within the criteria dimension. Sample questions will be "How much more important is *impact on resources* than *impact on strategy* in terms of benefit to the *product deletion decision-specific characteristics*?" Based on these questions, there will be 11 pairwise comparison matrices for all levels under the benefits hierarchy. Similarly, 11 matrices each will be created for the O, C, and R elements of BOCR analysis. The relative importance weights are summarized in Table 4.

4.2.5. Step 3: AHP local and global relative importance and alternative evaluation

The third major stage involves determining the overall relative importance weights of the alternative product families for each of the BOCR elements. This forms the AHP portion.

To arrive at the overall weights the local priorities are aggregated by multiplication to arrive at global priorities (see equation (2)). The global priorities are then aggregated for each product family (see equation (3)).

$$AHP_{ij}^{P} = C_i{*}F_{ij}{*}RI_{ij}^{P} \tag{2}$$

$$AHP_P = \sum_{(i,j)\in P} AHP_{ij}^{P} \tag{3}$$

In equations (2) and (3), C_i represents the relative importance of the criteria dimension *i*. F_{ij} denotes the relative importance of a factor *j* within a criteria dimension *i*. RI_{ij}^{P} is the AHP local relative importance weights for a product family P with regard to a criteria dimension (*i*) and its factor (*j*). AHP_{ij}^{P} is the AHP global relative importance weight for each product family P with regard to a factor within a criteria dimension.

The results of these aggregations are shown in Table 5. According to Table 5, the AHP global relative importance weight, for the benefit to organization category, for Product family A is 0.360, Product family B is 0.241, and Product family C is 0.399. Thus, from the AHP portion of calculation, if the firm and management considers deleting a product family based only on benefits generated, Product family C should be the first product family to be considered for deletion. This exemplary calculation only concerns the "benefits" portion of the BOCR analysis, the product candidate with the highest score stands for "deleting this product will benefit the company the most when considering the influencing dimensions and factors".

4.2.6. Step 4: ANP analysis

The fourth major stage is completing an ANP analysis by only considering the alternative sets and their interrelationships with each other. This means conducting a series of pairwise comparisons amongst the interactions of the product deletion decisions. ANP analysis requires formation and convergence of supermatrices. There will be a supermatrix of the product deletion alternatives for each of the BOCR elements. The following section will only show the benefit portion of the ANP analysis as an example. The level of analysis here will be at the product level within a product family. The analysis will consider interactions and interdependencies amongst the product deletion candidates. For example, interdependencies may exist because the deletion of one product may free capacity and resources for another product to use. In addition, interdependencies may have a negative impact where the deletion of one product may hurt the sales or market share of another product. Thus, the ANP analysis is applied to capture all types of

Table 5
AHP local and global relative importance and alternative evaluation.

Criteria Dimension	Factors	C_i	F_{ij}	Local Relative Importance Weights (RI_{ij}^{P})			Global Relative Importance Weights (AHP_{ij}^{P})		
				Product Family A (RI_{ij}^{A})	Product Family B (RI_{ij}^{B})	Product Family C (RI_{ij}^{C})	Product Family A (AHP_{ij}^{A})	Product Family B (AHP_{ij}^{B})	Product Family C (AHP_{ij}^{C})
PDC	IOR	0.097	0.111	0.648	0.122	0.230	0.007	0.001	0.002
	IOS	0.097	0.444	0.163	0.297	0.540	0.007	0.013	0.023
	IOFP	0.097	0.444	0.540	0.297	0.163	0.023	0.013	0.007
IOC	Cs	0.570	0.540	0.163	0.297	0.540	0.050	0.091	0.166
	SCOA	0.570	0.297	0.163	0.297	0.540	0.028	0.050	0.091
	LD	0.570	0.163	0.500	0.250	0.250	0.046	0.023	0.023
EEC	ES	0.333	0.667	0.726	0.172	0.102	0.161	0.038	0.023
	Ss	0.333	0.333	0.333	0.097	0.570	0.037	0.011	0.063
				Product Deletion Decision Indices AHP_P			0.360	0.241	0.399
				Product Deletion Decision Alternative Ranking			2	3	1

interdependencies as one general interdependent set of relationships. An alternative to this process would be to develop ANP interdependencies based on the specific type of interdependency (e.g., capacity and cost savings). In addition, in this example interrelationships amongst the product candidates are assumed to exist not only within the product family itself but also across other product families. The level of interrelationships may be restricted within product families, if necessary.

The formation of the supermatrix requires an additional series of pairwise comparison matrices. Thus, the additional series of pairwise comparisons are conducted amongst the nine product candidates. A sample questions for management includes: "How much more beneficial is the deletion of product B1 as compared to product C1 for product A1?" There are 324 (9*9*8*0.5) pairwise comparison questions to complete these matrices. Table 6 is the initial 9 × 9 supermatrix.

The next step of the supermatrix evaluation is to determine the final ANP relative importance weight for each product candidate. A normalized importance weights matrix needs to be established by making the supermatrix column stochastic. The normalization is needed to have all the values in the column sum to 1. Given that each column should sum up to 2,[1] the normalization occurs by dividing each weight in the column by the sum of that column, which is 2. The normalized supermatrix is shown in Table 7.

For convergence to arrive at a final set of weights, the normalized supermatrix was raised to the 32nd power until a converged set of weights occurs. The final converged importance weights (ANP_p^P) are shown in Table 8. It shows that product B1 has the greatest overall benefit (0.146) if deleted, followed by product B2 and product B3. If only the interactions amongst product candidates from a benefits perspective are considered, product B1 should be deleted; in fact, arguably product family B should be deleted in this situation.

4.2.7. Step 5: synthesis of the AHP, ANP, and BOCR results from individuals

The next major stage is the synthesis of the AHP and ANP relative importance weights with respect to the BOCR analysis. This synthesis will occur through a desirability index matrix for each AHP/ANP BOCR element result. A final BOCR ratio will then be calculated to arrive at the ranking of product deletion alternatives. Equation (4) represents the calculation for a given BOCR category.

$$Dp = AHP_P * ANP_p^P \tag{4}$$

Where D_p represents the adjusted global relative importance weight for a specific product candidate deletion, AHP_P is the AHP global relative importance weight for a product family and ANP_p^P is the converged relative importance weight for a given product p within a product family P.

Similar calculations need to be performed for all four BOCR elements after which, a ratio can be computed for each product candidate. Equation (5) is used to determine the final BOCR ratio for each product candidate.

$$\text{BOCR ratio} = \frac{Benefit*Opportunity}{Cost*Risk} \tag{5}$$

When comparing the BOCR ratio for each product candidate, the candidate with the highest BOCR ratio should be first considered for deletion. The results are shown in Table 9.

According to Table 9, product A3 has the highest BOCR ratio (105.236) and is the one that should be initially considered for deletion. If more than one product is to be considered for deletion, the likely candidates are the three A3, B1, and B2, in that order.

[1] Note that to help in convergence the diagonal elements have a value of 1 assigned which means that the deletion of a product has significant impact on itself.

Table 6
Initial supermatrix.

	A1	A2	A3	B1	B2	B3	C1	C2	C3
A1	1.000	0.097	0.028	0.036	0.236	0.311	0.112	0.069	0.058
A2	0.062	1.000	0.053	0.061	0.125	0.089	0.098	0.075	0.076
A3	0.117	0.240	1.000	0.116	0.223	0.145	0.034	0.069	0.059
B1	0.114	0.089	0.076	1.000	0.345	0.167	0.067	0.212	0.213
B2	0.092	0.096	0.400	0.134	1.000	0.077	0.071	0.209	0.203
B3	0.116	0.157	0.400	0.235	0.011	1.000	0.012	0.164	0.159
C1	0.140	0.071	0.011	0.179	0.006	0.096	1.000	0.108	0.099
C2	0.143	0.132	0.009	0.123	0.034	0.112	0.231	1.000	0.133
C3	0.215	0.118	0.023	0.116	0.019	0.003	0.375	0.095	1.000

Table 7
Normalized supermatrix.

	A1	A2	A3	B1	B2	B3	C1	C2	C3
A1	0.500	0.049	0.014	0.018	0.118	0.156	0.056	0.034	0.029
A2	0.031	0.500	0.027	0.031	0.063	0.045	0.049	0.037	0.038
A3	0.059	0.120	0.500	0.058	0.112	0.073	0.017	0.034	0.030
B1	0.057	0.045	0.038	0.500	0.173	0.084	0.034	0.106	0.107
B2	0.046	0.048	0.200	0.067	0.500	0.039	0.036	0.104	0.102
B3	0.058	0.079	0.200	0.118	0.006	0.500	0.006	0.082	0.080
C1	0.070	0.036	0.006	0.090	0.003	0.048	0.500	0.054	0.050
C2	0.072	0.066	0.005	0.062	0.017	0.056	0.116	0.500	0.067
C3	0.108	0.059	0.012	0.058	0.010	0.002	0.188	0.047	0.500

Table 8
Final importance weights for products.

	A1	A2	A3	B1	B2	B3	C1	C2	C3
A1	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113
A2	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074
A3	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114	0.114
B1	**0.146**	**0.146**	**0.146**	**0.146**	**0.146**	**0.146**	**0.146**	**0.146**	**0.146**
B2	0.139	0.139	0.139	0.139	0.139	0.139	0.139	0.139	0.139
B3	0.138	0.138	0.138	0.138	0.138	0.138	0.138	0.138	0.138
C1	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083
C2	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097
C3	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096

Interestingly, if we only considered the AHP benefit perspective, product family C should have been deleted. If only the ANP interdependency analysis for benefits is used, product B1 should be deleted. Whereas, the holistic analysis of BOCR likely provides a more realistic and complete result to satisfy individual management's goals that include lean and sustainability concerns, stakeholder interests, and strategic and financial performance. It recommends deletion of product A3 if we consider inputs from an individual manager. In the next section, an aggregated BOCR ratio will be introduced by integrating inputs from group decision makers composed of four key organizational functions, respectively marketing, supply chain, sales and finance.

In this illustrative example, BOCR analysis uses an equal weighting for the BOCR elements. While in practice, different scenarios may have different relative importance weights amongst benefits, costs, opportunities and risks depending on industry, firm type, time, so on and so forth. The synthesis of composite priorities on BOCR that obtained from separate AHP/ANP model and its validity needs to be carefully facilitated by the firm and its management.

4.2.8. Step 6: aggregating BOCR ratios to arrive at cross-functional group decision making results

The previous five steps illustrate the model application for individual decision makers. The decision environment is compounded by the fact that product deletion decisions typically require inputs from multiple or a group of decision-makers. The final major step recommended is an aggregation of BOCR ratios from four KOLs (Key

Table 9
BOCR ratio for product deletion.

Product Deletion Candidates	B			C			O			R			BOCR Ratio
	AHP global weights	ANP	Adjusted Global weights for product deletion	AHP global weights	ANP	Adjusted Global weights for product deletion	AHP global weights	ANP	Adjusted Global weights for product deletion	AHP global weights	ANP	Adjusted Global weights for product deletion	
A1	0.360	0.113	0.041	0.231	0.123	0.028	0.167	0.087	0.015	0.086	0.065	0.006	3.723
A2	0.360	0.074	0.027	0.231	0.065	0.015	0.167	0.005	0.001	0.086	0.124	0.011	0.139
A3	0.360	0.114	0.041	0.231	0.012	0.003	0.167	0.201	0.034	0.086	0.055	0.005	105.236
B1	0.241	0.146	0.035	0.176	0.011	0.002	0.555	0.023	0.013	0.123	0.076	0.009	24.779
B2	0.241	0.139	0.034	0.176	0.127	0.022	0.555	0.276	0.153	0.123	0.145	0.018	12.875
B3	0.241	0.138	0.033	0.176	0.321	0.056	0.555	0.046	0.026	0.123	0.231	0.028	0.530
C1	0.399	0.083	0.033	0.593	0.176	0.104	0.278	0.211	0.059	0.791	0.122	0.097	0.192
C2	0.399	0.097	0.039	0.593	0.088	0.052	0.278	0.111	0.031	0.791	0.022	0.017	1.314
C3	0.399	0.096	0.038	0.593	0.077	0.046	0.278	0.040	0.011	0.791	0.160	0.127	0.074

Opinion Leaders) including those representing marketing, supply chain, sales and finance organizational functions. Product deletion decisions involve strategic cooperation and communication across functions; and each function is likely to have differing influence over this critical decision. The influence weights depend on firm type, organizational culture, product category, and managerial characteristics.

The following exemplary calculation is based on an in-depth interview with an Australian beverage company. The approximate decision power/influence allocation across the four functional areas are marketing 40%, supply chain 30%, sales 20% and finance 10%. The summation of multiplying individual KOL BOCR ratios to its allocated influence weight within the target organization, will be the aggregated BOCR ratio (See equation (6)).

$$BOCR^{Agg} = \sum_{k=1}^{m} w_k BOCR_k \tag{6}$$

Where, w_k stands for the influence weight of a function k. m is the number of key decision maker functions involved in the product deletion decision making process. In this illustrative scenario, $m = 4$. Table 10 presents the aggregated BOCR ratio for all product candidates from the illustrative example from step 5.

We assumed that the results from the individual BOCR assessment was for the marketing function. The Marketing BOCR ratios, second column of Table 10, has the same results as the final column of Table 9. The aggregated results show that A3 is the best candidate from the set of candidates for deletion. B1 and B2 follow closely. This result is due to the influence of the marketing function. A sensitivity analysis on the influence scores can show the robustness of this situation.

To determine the robustness of the aggregated group decision, a sensitivity analysis based on the influence weight for Marketing as a referent group is completed. The sensitivity will cover the range of 0%–100% influence by marketing. The values for the other three functions, similar to previously published AHP/AHP sensitivity analyses and software (e.g. Mustajoki and Hämäläinen (2000)), will keep the ratio of the influence weights the same, as marketing weights change. The sensitivity analysis results are summarized in Table 11. Figs. 3 and 4 provide a visualization of the sensitivity of the BOCR group decision results for the product deletion decisions. Fig. 3 plots the results from Table 11 directly. Fig. 4 are the plots of the logarithmic scores of Table 11, allowing the decision maker to more easily visualize the lower valued weighted alternatives at different levels; in case a broader set of product deletions are to be considered and ranked.

Product A3 is the most appropriate candidate for product deletion as long as Marketing has a greater than, approximately, 5% influence. Product C3 would be the best product to delete if Marketing had 0% influence on the decision. If Marketing had 100% influence, product C3 would be the most likely to be kept in the product portfolio. Overall, the ranking of product C3 is the most sensitive as the Marketing function influence varies. If the company was seeking to delete more than one product, at the baseline level of Marketing at 40% influence, two products are good candidates for deletion (A3 and B1). Two remaining products may be additional good product deletion candidates, with both (B2 and C3) having essentially at equal aggregated scores. Currently B2 is slightly better for deletion than C3. Looking at Fig. 4, if Marketing's influence is lessened, C3 becomes more attractive for deletion. If the company is not seeking to delete more than one product, the decision is relatively clear, when seeking to delete a set of products, the decision becomes very sensitive as product sets vary.

5. Conclusion

Product deletion is a strategic decision for all firms. A strategic decision making process may become complex and involves both internal and external firm characteristics, such as resources, strategy, financial performance, supply chain processes and performance competencies, and stakeholders. The strategic decision model proposed in this

Table 10
Aggregated BOCR ratio for cross-functional group decision making.

	MARKETING		SUPPLY CHAIN		SALES		FINANCE		*AGGREGATE BOCR RATIO*
	BOCR ratio	Influence %	BOCR ratio	Influence %	BOCR ratio	Influence %	BOCR ratio	Influence %	
A1	3.723	40%	1.03	30%	5.21	20%	0.235	10%	2.864
A2	0.139	40%	9.32	30%	2.23	20%	9.352	10%	4.233
A3	105.236	40%	9.25	30%	19.25	20%	3.65	10%	49.085
B1	24.779	40%	12.01	30%	9.36	20%	16.89	10%	17.076
B2	12.875	40%	13.11	30%	4.11	20%	2.54	10%	10.159
B3	0.530	40%	7.25	30%	10.26	20%	13.74	10%	5.813
C1	0.192	40%	2.11	30%	17.84	20%	6.31	10%	4.909
C2	1.314	40%	17.33	30%	7.21	20%	7.153	10%	7.882
C3	0.074	40%	13.62	30%	20.1	20%	19.451	10%	10.081

Table 11
Sensitivity analysis.

Marketing	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
A1	2.291	2.434	2.577	2.720	2.864	3.007	3.150	3.293	3.436	3.579	3.723
A2	6.962	6.280	5.597	4.915	4.233	3.551	2.868	2.186	1.504	0.822	0.139
A3	11.650	21.009	30.367	39.726	49.085	58.443	67.802	77.161	86.519	95.878	105.236
B1	11.940	13.224	14.508	15.792	17.076	18.359	19.643	20.927	22.211	23.495	24.779
B2	8.348	8.801	9.254	9.706	10.159	10.612	11.064	11.517	11.969	12.422	12.875
B3	9.335	8.455	7.574	6.694	5.813	4.933	4.052	3.172	2.291	1.411	0.530
C1	8.053	7.267	6.481	5.695	4.909	4.123	3.336	2.550	1.764	0.978	0.192
C2	12.261	11.166	10.071	8.977	7.882	6.787	5.693	4.598	3.504	2.409	1.314
C3	16.752	15.084	13.416	11.748	10.081	8.413	6.745	5.077	3.409	1.741	0.074

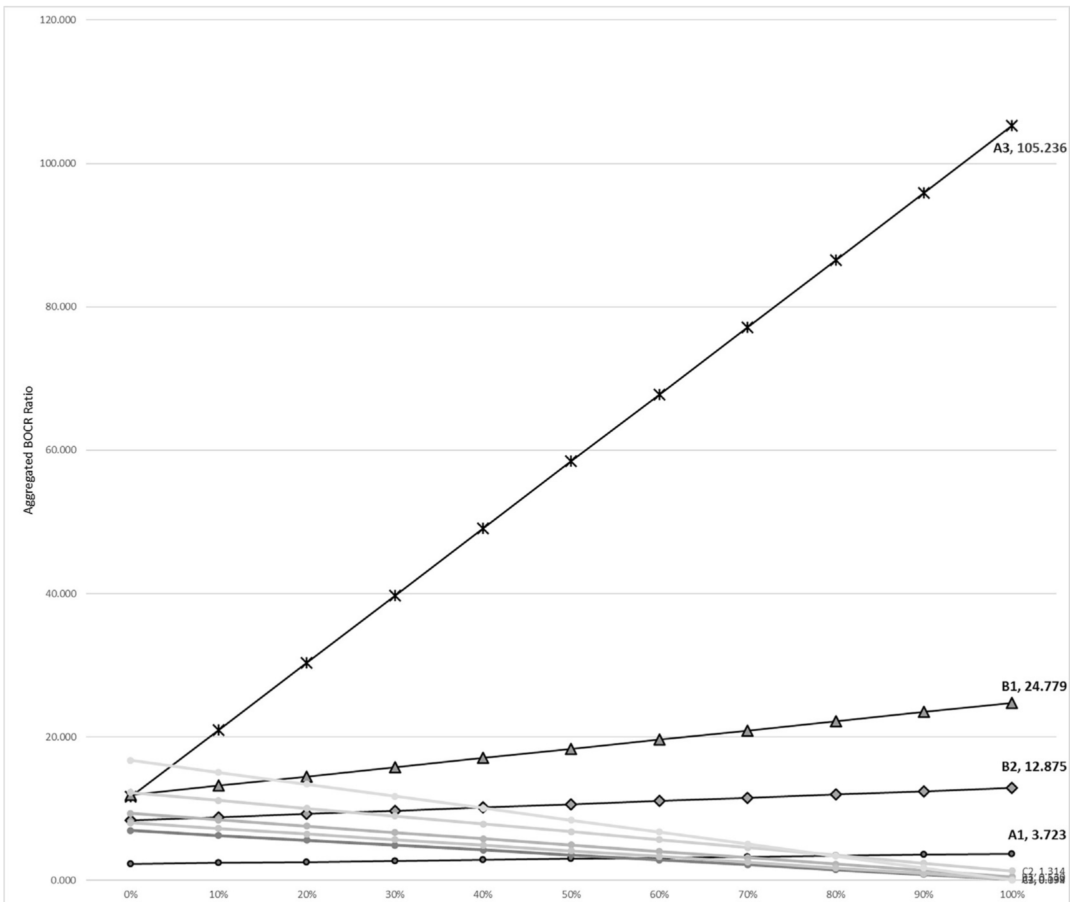

Fig. 3. Aggregated BOCR group decision results.

paper is designed to facilitate the product deletion decision for firms that aim to achieve lean and sustainable supply chains within a broader strategic perspective. The model presented incorporates multiple levels of factors to help structure the decision in a way that guides decision makers. Utilizing AHP, the model can be applied from benefits, opportunities, costs, and risks perspectives. ANP becomes valuable in the model by explicitly considering the interactions amongst the deletion alternatives. Together these model characteristics help arrive at a strategic and systemic decision on deleting a product and optimizing a product portfolio.

5.1. Theoretical contribution and implications

Being one of the first initiatives of integrating product deletion, supply chain management and sustainability literature, this work, is meant to investigate product deletion relationships of supply chain management leanness and sustainability. This paper challenges the traditional perspective that marketing objectives drives all product deletion decisions. Whereas it investigates how goals related to supply chain management can influence product deletion decisions. Specifically, the goal is to consider the sustainability and leanness of the supply chain while deleting a product. This investigation builds on the relationship between the product deletion, supply chain management, and sustainability and lean management literature. The conceptualized model serves as a contextual tool to facilitate firms' product deletion decision-making process; and sets both, a conceptual and practical, foundation for further investigation of product deletion and its impact on organizations.

One of the major theoretical implications of this study is that the decision making exercise is more complex. Complex decision tools, methods, and behaviors theoretical developments are needed. Group decision making tools and relationships play a critical role in effective implementation. The consensus building aspects for these strategic decisions are needed with appropriate study designs. There are a

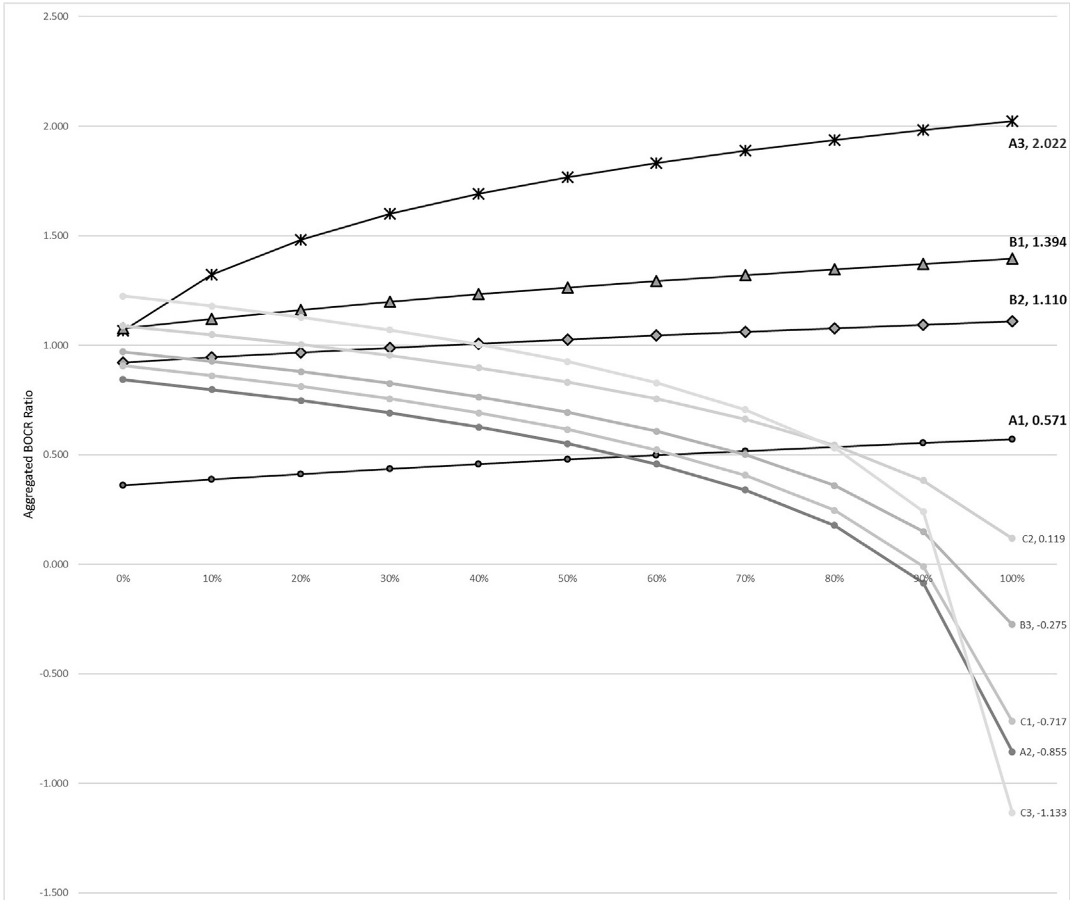

Fig. 4. Logarithmic aggregated BOCR group decision results.

number of directions for future research, outlined later in this section, that need to be further investigated related to some of the modeling and behavioral concerns. In addition to the decision modeling theory, there are application theoretic concerns. Much of the research on product portfolio management is on new product development and product proliferation. The further investigation of product deletion within product portfolio and lean project/product management is thoughtfully required.

5.2. Practical contribution and implications

The proposed model in this paper is a network decision hierarchy to help facilitate the product deletion decision across multiple organizational functions or departments. Managers from marketing, finance, operations, and environmental sustainability can cooperate under the guidance of this model to make a comprehensive and strategic product deletion decision. The integrated efforts and the decision can meet organizational goals while considering social and environmental sustainability impact. The model is flexible and replicable, i.e., it can be modified to suit different organizational objectives and contexts. Firms and management can assign different relative importance weights among the three criteria dimensions and factors. Firms with specific organizational goals can simulate different scenarios by assigning different weights to factors to arrive at a product deletion decision in different business scenarios and situations.

The model presented in this paper can address various strategic and operational concerns. The model is flexible enough to incorporate fewer or more factors depending on the level of complexity acceptable to managers. For example, in this illustrative example, AHP only has been applied to the general dimension criteria and major factor level of analysis. If time, resources, and more detailed evaluations are needed, managers can incorporate the identified determinants as sub-factors into the decision making process. A practical implementation design may require a decision support system that can provide flexibility and ease in application.

Further practical implications will relate to how to effectively implement this decision model such as actual data acquisition. Whether separate individuals or groups settings should be used for data gathering may be a concern. One of the advantages of the AHP/ANP process is that it provides a comprehensive structure for factor evaluation. In a group setting, discussion around the factors and their relationships and relative importance should occur. It can be a guide for a rich and comprehensive discussion associated with the decision environment. Of course, in a group team decision setting various group dynamics, e.g. power dynamics, may also cause a distortion of the decision. Thus, practical concerns on fair and logically supported inputs in the decision environment is necessary.

5.3. Limitations and future research directions

First, in the model development stage, only certain dimensions and factors were included. Even though they are from highly cited works in the literature, they still may not represent and capture all business situations and practical cases. In various product deletion decision environments, variations in factor incorporation for the model might be needed; this study does not provide a required set of factors and models and these will have to be determined. The AHP model with a limited set of characteristics involves constructing a number of pairwise comparison matrices. Some of these matrices are relatively large. There exist difficulties of getting opinions from decision-makers for AHP matrices.

A group decision making approach may be used to alleviate effort from individuals by dispersing the data collection process amongst firms, organizations and individuals. Studies on the decision effectiveness of this dispersion approach to ameliorate decision maker effort is required.

Second, the ANP models add more complication to the AHP model. Though the illustration uses just three products per product family, in practice, a larger number of products will be likely shortlisted. Hence, constructing the supermatrix can be challenging in practice. For future application, decision makers might consider to filtering a limited number of product candidates to be deleted by using their personal or team judgement; and then apply the proposed model in this paper. This will result in a product deletion ranking at the product level. And then replicate the same process on the top five selected product groupings. A study for the filtration process and/or the iterative AHP/ANP approach can be a future research direction.

Third, there is an issue of AHP's rank reversal concerns. When alternatives are deleted from alternative set under consideration, the ordering of the remaining alternatives may change. This occurs when there is no independence of irrelevant alternatives (Dyer, 1990). But, some evaluation of when independence does or does not exist can be evaluated to help determine if this is an issue (Harker and Vargas, 1990). Also, some of these concerns may also be mitigated with ANP inclusion with AHP in the final ranking (Schenkerman, 1994), which we do in this model. Clearly, this issue should be carefully monitored in multiple applications with changing alternative sets, in all AHP applications.

Finally, only AHP/ANP and BOCR are used to construct the model. The application of other methodologies to model development may provide another future research direction from a methodological perspective. Model verification through an actual application and feedback is still needed to determine the feasibility, reliability, accuracy, and validity of the model.

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