

A Sustainable Manufacturing Strategy Framework: The Convergence of Two Fields

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ABSTRACT

Pressing concerns about the sustainability of products and processes have compelled the manufacturing industry to transition from making mere economic-based decisions to envisioning more holistic goals encompassing economic, environmental and social perspectives. The intriguing results of this transformation include the development of various sustainability programs and initiatives that has increased for three decades. The myriad of research in this area focuses on creating opportunities that would minimise, if not eliminate, the impact of manufacturing activities on the natural environment and society. However, previous approaches seemingly detach their association to the competitive function of manufacturing. Maintaining competitiveness while pursuing sustainability has drawn interest from practitioners, but this area is inadequately explored in the current literature. Current research directions on sustainability in the manufacturing industry lack foundations on exploring mechanisms that maintain or improve the competitive function of manufacturing. The integration of sustainability issues into manufacturing strategy (MS) implies complex decision-making in manufacturing. Thus, this paper proposes a framework in formulating MS that addresses sustainability issues while taking into account the competitive function of manufacturing. The framework integrates classical theories of MS and sustainability issues derived from previous works. The proposed framework provides guidance for the decision-making of practitioners and researchers in developing a sustainable manufacturing strategy (SMS). This contributes to manufacturing planning at the firm level.

Keywords: manufacturing strategy, sustainable manufacturing, framework

INTRODUCTION

Following the seminal work of Wickham Skinner (1969) published in the Harvard Business Review, manufacturing strategy (MS) has emerged as a mature field in the management literature. Generally, two important roles must be carried out by the manufacturing function: (i) support the business unit strategy, and (ii)

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develop a set of capabilities in creating and maintaining market position (Wheelwright, 1984a). These roles must be duly acknowledged by any manufacturing firm, as organisational competitiveness lies potentially in how manufacturing performs its intended functions. It has been further agreed that MS could only support business strategy if a sequence of decisions over structural and infrastructural categories becomes consistent over a long period of time (Wheelwright, 1978). When these decision categories are focused and consistent,

the manufacturing function develops a set of competitive priorities that must be aligned with the competitive advantage set out by the business function. This model of MS has been established and tested over decades of research and application in the field.

However, recent concerns on resource depletion, the destruction of natural resources, the unprecedented increase in global temperature due to excessive carbon emissions and increasing waste generation pose sustainability questions, especially to the manufacturing industry. It has been acknowledged by policy-makers and institutional bodies that sustainability must not be encapsulated merely in economic terms such as favourable GDP growth, but rather take care of the environment and the welfare of society (Brundtland, 1987). Manufacturing is regarded as a key sector in sustainability due to its high volume of resource consumption, increasing annual introduction of new products that require a relatively high amount and generation of materials, energy and wastes, an increasing volume of emissions throughout the product life cycle and the collective impact of manufactured products and manufacturing processes on the immediate community (Joung, Carrell, Sarkar, & Feng, 2013). The manufacturing industry captures one-third of world energy consumption and simultaneously generates carbon emissions, with projections in 2050 showing energy demand that doubles current figures (Nezhad, 2009; Mani, Madan, Lee, Lyons, & Gupta, 2012). Manufacturing thus occupies an important part of the sustainable development puzzle.

Confronted with issues with developing MS on one hand and sustainability issues on the other hand, manufacturing managers definitely face complex decisions. Currently, these issues are treated separately, such that individual actions are intended to promote competitive advantage, while others are aimed to address sustainability concerns. Adopting concepts such as life cycle thinking, eco-efficiency, green engineering, cleaner production, a 5R approach, ISO 14001 and ISO 2600 series (Ageron, Gunasekaran, & Spalanzani, 2012; Lozano, 2012; Rosen & Kishawy, 2012) tends to mobilise company systems and resources towards sustainability but fails to address how these approaches support the competitive function of manufacturing. Significant attempts to incorporate sustainability in manufacturing decision areas were present in the literature (Azapagic, 2003; Reich-Weiser, Vijayaraghavan, & Dornfeld, 2008; Subic,

Shabani, Hedayati, & Crossin, 2012); however, such attempts lack a comprehensive framework for developing a strategy that simultaneously addresses sustainability issues and improves the competitive position of the firm. The pivotal work motivating the development of our proposed framework, which was published by Johansson and Winroth (2010), incorporated environmental issues into manufacturing decision areas. These authors emphasised that incorporating environmental issues alters the policy areas of all decision categories and requires environmental performance as a competitive strategy. However, this framework failed to examine how other forces in sustainability affect the policy options of manufacturing in decision areas. Although such forces identified by previous works tend to increase the complexity of decision-making, they are essential to

embedding sustainability in the manufacturing function without sacrificing its ability to create competitive capability.

In this paper, a review of the fundamental concepts and approaches of MS from Skinner (1969) to current roundtable discussions is presented. A discussion on sustainability with a focus on sustainable manufacturing (SM) is also highlighted. A review of the frameworks is also presented to convey recent developments in these fields. A conceptual framework is then proposed to provide guidance for decision-makers in an attempt to incorporate sustainability issues in manufacturing decisions. This paper proposes an integrated decision framework in developing sustainable manufacturing strategy (SMS). This framework attempts to assimilate two seemingly independent theories of MS and SM. The objective of this work is to develop an MS framework that grounds itself on sustainability, incorporating significant issues such as firm size, the strategic orientation of firms and various interests of stakeholders. This work progresses knowledge in two ways: (i) the development of SMS by integrating MS and SM, and (ii) the development of a framework that guides decision-makers in SMS development, putting into context relevant issues that impact sustainability.

MANUFACTURING STRATEGY

Foundation

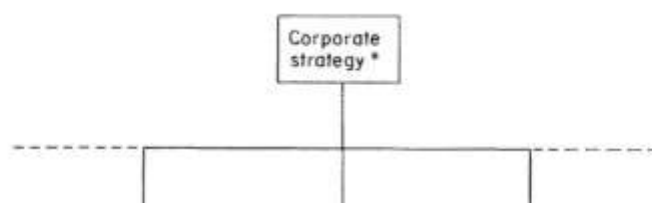
The pivotal work on MS research has been attributed to the 1969 seminal paper of Wickham Skinner (Skinner, 1969), whose framework is a hierarchical top-down approach that relates corporate strategy to business strategy and business strategy to MS. This approach, as shown in Figure 1, maintains that MS must be consistent with business strategy, which is also defined by corporate strategy. Wheelwright (1984a) and Kotha and Orne (1989) extended this approach by incorporating multiple business units with multiple functional areas and by adding industry to corporate strategy, respectively. The central theme is that

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manufacturing must not focus only on total productivity and efficiency (Skinner, 1969) or promise engineering perfection, but should be consistent in developing capabilities to support corporate goals (Wheelwright, 1984a). Skinner's (1969) argument is summarised as follows:

1. Different firms have different characteristics and, therefore, can choose to compete in different ways
2. The manufacturing function must develop a production system that reflects its priorities and trade-offs in its competitive strategy

The first argument contains the notion of defining a set of competitive priorities that a manufacturing firm could positively develop, and the second one provides decision-making in well-defined decision categories to achieve its set of competitive priorities. These two arguments are both well articulated and elaborated in the MS literature.



*Might also refer to group or sector levels in a large diversified organisation.

**Most often refers to a division or strategic business unit (SBU).

Figure 1. Skinner's levels of strategy as shown by Wheelwright (1984a)

Wheelwright (1984b) enhanced Skinner's hierarchy by defining each level of strategy. At the corporate strategy level, two areas are of interest in decision-making: the definition of the businesses with which the corporation would engage, together with the acquisition of corporate resources and the commitment of the corporation to each of the defined businesses. At the business strategy level, the interest is to specify the scope or boundaries of each business in a way that operationally links it to the corporate level and the basis on which that

business unit achieves and maintains a competitive advantage. At this level, two strategic orientations are common in the literature. These are market orientation and technology orientation (Hayes & Wheelwright, 1984). A business unit is market oriented if its goals advocate listening and chasing the demands of the market. Exploiting these demands requires business units to use a variety of products, materials and technologies. In a technology-oriented business, the orientation is to become the leader in technological advancement. A functional strategy, in contrast, specifies how that function will support the desired competitive advantage and how it will complement other functional strategies. Due to its potential to create capabilities, the manufacturing function has been given significant attention (Wheelwright, 1984a).

Aside from the top-down approach, embedding interrelationships on these levels has also become an interesting area. Skinner (1969) himself proposed a feedback loop by suggesting that corporate strategy affects MS and vice versa. This means that while manufacturing supports corporate strategies, the pattern of decisions and the resulting capabilities of the manufacturing function send signals to the corporate strategy in defining the kind of businesses it aims to involve. Fine and Hax (1985) and Pun (2004) also agreed that MS must be present on all three levels, which means that corporate and business-level strategies must likewise support

MS. Empirical studies have shown significant validity of these conceptual interrelationships (Ward, Bickford, & Leong, 1996).

Manufacturing Strategy – Decision Categories, Capabilities and Functional Support

Definitions of MS have been proposed by several works with high consistency. Skinner (1969) regarded MS as something that must exploit certain properties of the manufacturing function to achieve competitive advantages. Hayes and Wheelwright (1984) defined MS as a consistent pattern of decision-making in the manufacturing function that is linked to business strategy. Platts, Mills, Bourne, Neely, Richards and Gregory (1998) considered it as "a pattern of decisions, both structural and infrastructural, which determine the capability of a manufacturing system and specify how it will operate, in order to meet a set of manufacturing objectives which are consistent with the overall business objectives." Marucheck, Pannesi and Anderson (1990) defined MS as a "collective pattern of coordinated decisions that act upon the formulation, reformulation, and deployment of manufacturing resources and provide competitive advantage in support of the overall strategic initiative of the firm or the strategic business unit." A comprehensive review of previous literature was performed by Dangayach and Deshmukh (2001). From these definitions, several concepts are certain:

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1. MS is a pattern of coordinated and consistent decisions over a relatively narrow area.
2. MS determines capabilities of the manufacturing system and provides its competitive advantage.
3. MS is consistent with business strategy.

The details of each concept are discussed in the following contexts.

Inspired mostly by the work of Skinner (1969) and building upon theoretical and empirical works, succeeding literature agreed that manufacturing involves a number of decision categories. A manufacturing function could only support corporate strategy if a pattern of decisions on these decision categories is consistent over a long period of time (Wheelwright, 1978). Several works agree on the number and type of decision categories. Table 1 presents these decision categories with their corresponding policy areas.

Hayes and Schmenner (1978) and Miller and Roth (1994) grouped these decision categories into two broad categories: structural (facilities) and infrastructural decisions. The first four decision categories are structural and their impacts are long-term such that changing the decisions after they are made requires a significant amount of investment (Wheelwright, 1984a). The last five decision categories are infrastructural in nature and require a lower amount of investment at one point in time; however, they could be very costly if changes are made possible (Wheelwright, 1984a). While structural decisions are strategic, infrastructural decisions require complex decision-making because: (i) they involve longer time

periods in which the build up to decisions must be very specific, consistent and narrow, with relatively few choices and (ii) they consist of both objective and subjective judgements that are very difficult to validate quantitatively. This pattern of structural and infrastructural decisions over time establishes the MS of a business unit.

Depending on the decisions and actions made within decision categories, a MS correspondingly develops a set of capabilities (Hayes & Pisano, 1994). Manufacturing capabilities or objectives, which are often referred to as competitive priorities (Ward et al., 1996), are a portfolio of strategic assets that have been accumulated through a flow of consistent patterns of investment in different decision categories over time. Kotha and Orne (1989) provided four basic assumptions why manufacturing must be involved in creating such capabilities:

1. The basic reason for existence is to produce something of value.
 2. Manufacturing has a critical and indispensable role in the creation of that value.
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3. There are different ways to compete.
 4. An explicit well-defined strategic planning process is essential in generating competitive position.

Table 1
Manufacturing decision categories

Manufacturing decision categories	Source	Policy areas as adopted by Wheelwright (1984a) and Hallgren and Olhager (2006)
Process technology		
Facilities		
Capacity		
Vertical integration		
Wheelwright (1984a); Fine & Hax (1985); Ward et al. (1996); Hallgren &	Process choice, technology, integration	Olhager (2006)
Skinner (1969); Fine & Hax (1985); Wheelwright (1984a); Ward et al. (1996); Hallgren & Olhager (2006)	Size, location, focus	
Wheelwright (1984a); Fine & Hax (1985); Ward et al. (1996); Hallgren & Olhager (2006)	Amount, timing, type	
Fine & Hax (1985); Wheelwright (1984a); Ward et al. (1996); Hallgren &	Direction, extent, balance	Olhager (2006)
Organisation	Skinner (1969); Wheelwright (1984a);	Structure, reporting

	Ward et al. (1996); Hallgren & Olhager (2006)	levels, support groups
Manufacturing planning and control	Skinner (1969); Wheelwright (1984a); Ward et al. (1996); Hallgren & Olhager (2006)	System design, decision support, systems integration
Quality	Wheelwright (1984a); Fine & Hax (1985); Ward et al. (1996); Hallgren & Olhager (2006)	Defect prevention, monitoring, intervention
New product introduction	Skinner (1969); Fine & Hax (1985); Hallgren & Olhager (2006)	Rate of innovation, product design, industrialisation
Human resources	Skinner (1969); Wheelwright (1984a); Fine & Hax (1985); Ward et al. (1996)	Skill level, pay, security

The literature is consistent in the types of these four competitive priorities on which an MS could possibly develop. These are cost, quality, dependability and flexibility (Wheelwright, 1984a; Fine & Hax, 1985; Ward et al., 1996). Competing on cost requires a manufacturing strategy that minimises inefficiencies in manufacturing operations so that products are offered at a low cost (or low price) . A manufacturing strategy that establishes quality as a dominant capability requires higher quality among standard products or offers

wider features or performance characteristics compared with other competitors with similar products. Dependability involves a manufacturing system that is able to do work as specified and delivered on time, and the firm makes sure that its resources are able to ensure that any failures are corrected immediately. Flexibility, on the other hand, comes in two forms – product flexibility and volume flexibility – and denotes a strategy that could enable firms to introduce new products more quickly in the market or to rapidly change its capacity to address sudden demand fluctuations (Wheelwright, 1984a). A comprehensive discussion of these four capabilities was outlined by Ward et al. (1996).

It should be noted that the competitive strategy maintained by the MS must support the competitive advantage defined by the business strategy, as depicted by Skinner's (1969) hierarchical framework. Wheelwright (1984a) strongly emphasised that it is both difficult – if not impossible – and potentially dangerous for a manufacturing firm to try to excel in these four capabilities. Firms must "attach definite priorities to each, and those priorities determine how that business will be positioned relative to its competitors – in terms of its competitive advantage" (Wheelwright, 1978; 1984a). Different manufacturing firms emphasize each of the four competitive capabilities to varying degrees (Wheelwright, 1984a). If these priorities are not explicitly considered in a consistent manner, it is unlikely that the firm can achieve an effective MS (Wheelwright, 1984a).

Advancements in Manufacturing Strategy Research

Some areas of interest in MS research involves defining content and process strategies, determining MS types, and several empirical studies following the framework of Skinner (1969) and Wheelwright (1984a). Research on strategy differentiates an MS according to its content and process (Voss, 1995; Gonzalez,

Quesada, & Mora-Monge, 2012). The content comprises what specific structural and infrastructural decisions must be made to support competitive priorities, while process focuses on how strategy is implemented (Dayangach & Deshmukh, 2001). Various conceptual and empirical studies have both been devoted to this area.

Identifying types of MS involves a range of empirical studies. Miller and Roth's (1994) famous taxonomies of MS, which were also validated by Frohlich and Dixon (2001), identified three types of MS: (i) caretakers, (ii) marketeers, and (iii) innovators. Caretakers place low emphasis on capability building, which sets minimum standards for competition. Cost is the dominant competitive capability for caretakers. Marketeers, on the other hand, are the largest group of manufacturers that employ a particular type of MS. In this type, dominant capabilities are quality and dependability, as firms listen to and pursue customer

demands. Last, innovators are known to have an ability to make quick product design changes and rapidly introduce new products. A comprehensive list of these taxonomies was presented by Sweeney (1991), which shows that there is consistency of MS types.

Research on MS has been noted over time for a lack of progress in theory building, empirical studies and incorporation with current research findings (Gonzalez et al., 2012). A growth of clarity has decreased following the development of different views and approaches (Voss, 1995). Knowledge about key relationships among manufacturing tasks, manufacturing choices and business strategies remain small (Miller & Roth, 1994). Some important empirical findings were published in several journals on operations management. Despite certain advancement in this field, MS research has often been regarded as being disintegrated with today's emerging concerns, especially in sustainability.

Sustainable Manufacturing

A more explicit definition of sustainable development was presented by Ragas, Knapen, van de Heuvel, Eijkenboom, Buise and van de Laar (1995), stating that "sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and the institutional change are in harmony and increase the present, as well as the future, possibility to accommodate human needs. The relation between the society and its physical environment should be such that a natural carrying capacity is ensured for future generations." While various sectors in the economy have a responsibility to address sustainable development, the manufacturing sector is undeniably one of the forerunners in bearing this responsibility (Mani et al., 2012). With expected five-fold increase in GDP per capita over the next fifty years, a corresponding ten-fold increase in total impact in energy consumption, material resource usage and wastes production is however expected (Rashid, Asif, Krajnik, & Nicolescu, 2013). These impacts are obviously attributed to the manufacturing sector as producers and users of materials, energy and wastes. As the leading employment sector and the main contributor to GDP, the manufacturing sector serves as the "backbone" of the well-being of nations and societies (Rashid et al., 2013). In this regard, sustainable manufacturing (SM) has

emerged, and it is defined by the US. Department of Commerce as "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound" (Joung et al., 2013) . Central to this approach is the design of products and processes in relation to stakeholders along product life cycle stages. SM has gained interest in both industry and academia for a couple of decades and has inspired leading developed economies, such as the US and UK,

to focus research directions on SM (Kovac, 2012); this has gained momentum around the world (Tsai & Chou, 2009).

While implementing SM strategies is undoubtedly beneficial (see discussions of Azapagic, 2003), there is increasing discussion on the motivations of manufacturing firms to adopt SM. In contrast to traditional cost and quality performance, which are tangibles for a firm, the presence of intangibles such as community well-being, product responsibility and employee career development in SM creates doubts about investment decisions. Complexity arises primarily because of the difficulty in quantifying the benefits firms could gain from this initiative brought about by longer time horizons and a higher degree of uncertainty in the results. Counteracting firms' difficulty in making an initial move towards sustainability, different stakeholders play the role of drivers in pushing them to the frontline of SM (Theyel & Hofmann, 2012). Contrasting former approaches in MS formulation where stakeholders are merely limited to stockholders and the market (Wheelwright, 1984a), sustainability is difficult to achieve without holistic consideration by different stakeholders. Along with their organisational culture and values, manufacturing firms tend to brand themselves into specific strategic responses to sustainability. There are enough consistencies published in the literature defining the responses of firms towards sustainability. Table 2 shows sustainability responses of firms in increasing their degree of acceptance.

Table 2
Strategic responses of firms toward sustainability

Roome (1992)	Winn & Roome (1993)	Meffert & Kirchgeorg (1991)	Azzone (1998)	Brockhoff, Chakrabarti, & Kirchgeorg (1999)	Castka & Balzarova (2008)	de Ron (1998); Heikkurinen & Bonnedahl (2013)
Noncompliance			Unresponsive			
Compliance	Compliance	Defensive strategies	Reactive	Portfolio defenders	Coercive perspective	Stakeholder -oriented
Compliance plus	Compliance plus	Reactive strategies	Responsive	Escapists	Strategic perspective	Market-oriented
Leading edge	Excellence	Active strategies	Proactive		Altruistic perspective	Sustainability-oriented
			Evangelist	Dormant activists		

Table 2 implies that firms are initially stakeholder-oriented and that their strategies are directed at superficially complying with stakeholders' requirements. As firms

evolve around meeting these requirements, they transform their responses from a stakeholder orientation to a market orientation, developing

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strategies that extend stakeholder requirements into exploiting sustainability to create competitive advantage. At this stage, firms view sustainability as a way to enhance market leadership in their industry. As firms enhance this, they evolve by achieving the sustainability-oriented stage wherein a goal extends from merely complying with stakeholder requirements and attaining market leadership into genuine care for the environment, the economy and society. Sweeney (1991), with his work on generic MS, which includes caretaker, marketeer, reorganiser and innovator strategies, explored transition routes to achieve innovator strategy. This concept of transition could be similarly applied to the transition of strategic responses of manufacturing to sustainability. Because sustainability is enhanced by stakeholders' participation, transition from one strategic response to another requires changes in the degree of stakeholder participation.

One of the significant issues prevalent in the literature is how firm size affects the strategic responses of firms towards sustainability (Hassini, Surti, & Searcy, 2012; Caniato, Caridi, Crippa, & Moretto, 2012). Implementation of some SM approaches requires relatively high investment in the short run, and quantifying the return of investment has not been well established in the literature (Ageron et al., 2012; Law & Gunasekaran, 2012) because of the high degree of uncertainty caused by intangibles. Following this argument, compared with large firms, small and medium-sized enterprises (SMEs), those having no more than 250 employees with annual sales of less than US\$50 million (Barad & Gien, 2001; Gonzalez et al., 2012), are affected by this large amount of investment (Ageron et al., 2012). Tsai and Chou (2009) argued that sustainability raises questions on how SMEs can achieve sustainability, as a shortage of resources such as time, manpower and money is relevant for most of these firms. Although empirical studies show a positive relationship between drivers and the willingness/readiness of firms in adopting SM (Salzmann, Ionescu-Somers, & Steger, 2005; Law & Gunasekaran, 2012), the link between drivers and SMS has not been fully explored in the literature (Schrettle, Hinz, Scherrer-Rathje, & Friedli, 2011). The significance of exploring how these drivers and their changes affect strategic manufacturing responses and therefore affect the development of SMS lies in:

1. providing a finer understanding of how specific drivers and their interactions affect strategic responses,
2. serving as a guide for policy development to enhance sustainability in a particular manufacturing industry, and
3. providing a framework for manufacturing firms for MS formulation.

Frameworks for Manufacturing Strategy

In this section, a review of partially and individually developed areas of MS and SM is presented. The most fundamental framework developed in MS formulation

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is the hierarchical framework presented by Skinner (1969). This framework establishes a unidirectional influence of corporate strategy on business strategy and the influence of business strategy on MS. Wheelwright (1978) emphasised the significance of the four manufacturing capabilities as mediators of manufacturing decision categories and corporate objectives, together with external objectives. It supports the former notion that MS develops a capability, and this capability is consistent with business and corporate strategies.

Later works explored how process and content strategy formulation must be performed. Fine and Hax (1985) proposed a framework relating MS and decision categories with other business functions as media. This framework guides decision-makers towards the functional areas with which to interact to address each decision category. Kotha and Orne (1989) presented a synthesised framework for differentiating generic MS based on three dimensions: Process structure complexity, product line complexity and organisational scope. The framework strengthened earlier frameworks that linked MS to business strategy. Sweeney (1991) discussed a framework relating each MS type with its competitive strategy. It proposed that strategy formulation is easily understood when an MS type is identified. Once the MS type is identified, a corresponding set of capabilities is directed, and decision-making within each decision category must be aligned and consistent with the set of capabilities.

Williams, D'Souza, Rosenfeldt and Kassae (1995) proposed a framework relating business strategy and manufacturing and its impact on business performance (return on sales). MS is then developed from a business strategy, and the effectiveness of this strategy is measured using business performance. Barnes (2002) described a theoretical framework that extended the work Skinner to include external factors and ownership factors within both internal and external contexts. This is consistent with the notions of Ward et al. (1996) and Hayes and Pisano (1996) regarding the function of MS in aligning internal capabilities and market opportunities. Drawing upon seemingly interacting frameworks of previous works, both theoretical and empirical in approach, Pun (2004) presented a synergy model of MS formulation and configuration. This framework integrates the process and content of strategy from an abstract view to a more detailed view. It also incorporated strategy outcomes as a result of a complex integration of strategy processes and content. This relation is allowed to interact with an external context and market forces. The framework is expected to help managers and policy makers identify competitive priorities, determine key process components of strategy formulation and monitor the execution of strategies in their respective organisations.

Although several empirical supports have emerged in the literature, quantitative models are scarce. A commendable guide on quantitative strategic decision-

making was presented by Hallgren and Olhager (2006). These authors identified several types of quantitative approaches in the strategy research: measuring, linking, comparing and modelling. Measuring involves identifying variables in terms of dimensions and how they are measured. Linking establishes relationships

between variables. Comparing explores levels of conjunction between manufacturing capabilities and market requirements. Modelling involves setting up the variables, including the relationships and conditions that govern these variables. The framework draws upon describing MS content based on decision categories to achieve manufacturing capabilities that support market requirements. The framework is able to distinguish between what the market needs and what the manufacturing function can provide. Figure 2 presents this framework.

The following discussion, a seemingly separate concept, presents approaches to sustainability. The most widely accepted framework for sustainability in general and for SM in particular is the triple-bottom line (TBL) approach (Seuring & Muller, 2008; Adams & Frost, 2008; Jain & Kibira, 2010) introduced by Elkington (1997). This approach maintains that SM is achieved by considering simultaneously the three pillars of sustainability, i.e., environmental stewardship, economic growth, and social well-being (Joung et al., 2013). SM can be viewed as the intersection of these three pillars. The intersection of any two pillars could represent sets of programs that address specific issues that may not be truly sustainable at all, as described by Rosen and Kishawy (2012) in Figure 3.

This framework has been adopted by various works in operations management (Placet, Anderson, & Fowler, 2005; Baumgartner & Ebner, 2010; Kashmanian, Wells, & Keenan, 2011; Danciu, 2013). Unfortunately, current approaches to SM have diverted from Skinner's (1969) framework. Conceptual frameworks are developed in the literature on SM and environmental sustainability. Central themes of these models revolve around supply chains (Olugu, Wong, & Shahrour, 2010; Duflou et al., 2012), life cycle (Reich-Weiser & Dornfeld, 2008; Dhingra, Naidu, Upreti, & Sawhney, 2010), material, energy and wastes (Yuan, Zhai, & Dornfeld, 2012; Despeisse, Oates, & Ball, 2013; Smith & Ball, 2012) and planning and monitoring SM implementation (Fiskel et al., 1999; Azapagic, 2003; Chen, Heyer, Seliger, & Kjellberg, 2012).

These conceptual frameworks are based on the TBL approach. These can be summarised as follows:

1. Sustainability is further achieved through collaboration in the supply chain (Ageron et al., 2012; Giovanni & Vinzi, 2012; Gimenez, Sierra, & Rodon, 2012)
2. A comprehensive approach to sustainability is achieved through a life-cycle approach (Yuan et al., 2012; de Brucker, Macharis, & Verbeke, 2013)
3. Different stakeholders have significant roles in sustainability transformation (Kronenberg & Bergier, 2012; Matos & Silvestre, 2013; de Brucker et al., 2013)

While research on SM has gained increasing attention in the current literature, its integration with MS research remains unclear. Baumgartner and Ebner (2010) attempted to explore relationships between sustainability strategy profiles in the

form of introverted, extroverted, conservative and visionary strategies against competitive forms of strategy, such as a cost leadership strategy, a product differentiation strategy and a hybrid strategy. In exploring relationships, four levels were introduced: force, pressure, option and forbiddance. Force means that a sustainability strategy is supportive of a competitive strategy. Pressure means that a sustainability strategy is very helpful for a competitive strategy, whereas option shows that a sustainability strategy is one possibility for the firm. Forbiddance shows that there are conflicting objectives between a sustainability strategy and a competitive strategy. The discussion is conceptual and does not have enough empirical support. Kashmanian et al. (2011) presents a framework relating elements of corporate sustainability strategy. An important notion of the framework is on relating sustainability strategy to internal and external stakeholders. A more recent work that attempts to integrate these two fields was presented by Johansson and Winroth (2010). These authors presented a framework describing how concern for environmental issues affects the MS formulation process. This shows the interrelationships between drivers of environmental concern, effects on the competitive priorities, implications for the decision criteria and how these factors may affect the MS selection process. Figure 4 shows the framework proposed by Johansson and Winroth (2010).

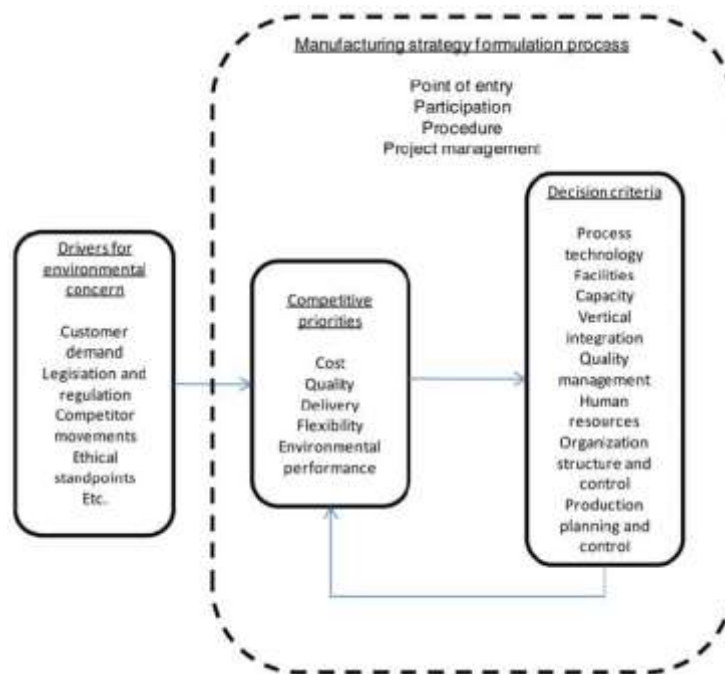


Figure 4. A framework for strategy formulation process incorporating environmental concerns (Johansson & Winroth, 2010)

The recursive relationship between decision categories and competitive priorities in this framework was patterned from early works of Wheelwright (1984a) and Hayes and Pisano (1996) and was portrayed with the framework of Hallgren and Olhager (2006). There are at least two interesting ideas embedded in this recent framework. The first shows how environmental concerns affect competitive

priorities. Former approaches in MS are merely market-centred, not stakeholder-centred, where inputs from other stakeholders are barely considered. In a stakeholder-centred approach, competitive priorities are motivated by stakeholder requirements. This approach is holistic, as it encompasses internal and external entities that affect or are affected by manufacturing products and processes. The significance of this approach lies in addressing a more diverse audience, which is an important characteristic of sustainability. With attempts to address stakeholder needs, it is assured that decisions characterising an MS are aligned not only with traditional market needs but also with inclusive, wide subjects. The second important feature of the framework is incorporating environmental performance as an additional competitive priority. Although this concept is not widely accepted in current literature, as more concrete findings need to surface, the significance of having environmental performance as a competitive priority lies in forcing manufacturing firms to incorporate environmental issues in every decision category. Johansson and Winroth (2010) explored some of the changes or revisions in policy areas of each decision category if environmental performance is a competitive priority. In summary, the frameworks of MS and SM have gone in separate directions, except for the work of Johansson and Winroth (2010), which attempted to integrate sustainability and MS. A review of the literature on these frameworks shows that an integrative framework that could propel an SMS is lacking. An SMS must be anchored on integrating these two fields: SM must have concrete foundations on the elements of the MS field. Although the work of Johansson and Winroth (2010) already exists, major revisions have to be made. First, the framework is rooted merely in environmental and economic dimensions and not in a TBL approach. Second, more elements must be added to the framework to capture details of formulating an SMS. For instance, the elements of firm size and strategy types are essential factors that have a substantial impact on strategy formulation. The significance of meeting these two areas of SM and MS is to gain finer insights on the development of an SMS, which are necessary to address environmental, economic and social issues.

However, the approaches developed by Griffiths and Petrick (2001), Johansson and Winroth (2010), Pham and Thomas (2012) and Theyel and Hofmann (2012) placed great emphasis on the role of stakeholders in motivating and enhancing sustainability in manufacturing organizations. Traditional organizations tend to focus only on a limited number of stakeholders, particularly shareholders (Pham & Thomas, 2012), such as board of directors and investors; therefore, the firms

failed to develop stakeholder integration (Griffiths & Petrick, 2001). Stakeholders are those who are influenced, either directly or indirectly, by the actions of the firm (Pham & Thomas, 2012). Stakeholders are composed of employees, suppliers, customers, industry associations, universities, consultants, governments, community organizations, and the media (Theyel & Hofmann, 2012). Stakeholders may play an important role in a manufacturing firm's sustainability efforts because if managed well, they can offer valuable assistance and resources beyond simply exerting pressures on companies (Perrini & Tencati, 2006; Clemens & Bakstran, 2010; Paloviita & Luoma-aho, 2010). In addition to exerting pressures, stakeholders can help companies decide which environmental and social activities to adopt because of the perspectives, experiences, and resources already built up

by these stakeholders. Firms can build trusting relationships when they include stakeholders in their decision-making processes and their management (Harrison, Bosse, & Philips, 2010). Relationships with stakeholders can produce insights necessary for deciding how to allocate limited resources to satisfy stakeholders.

THEORETICAL FRAMEWORK

A theoretical framework that integrates the fields of MS and SM is presented in this section, as shown in Figure 5. As indicated, the two fields were exclusive, and significant attempts were made to provide some links on the two fields. The upper-right -hand corner of the framework shows the top-down hierarchical framework proposed by Skinner (1969) and primarily supported by Wheelwright (1984a). The feedback loops of MS to business and corporate strategies were proposed by Fine and Hax (1985) and Pun (2004) and were empirically supported by Ward et al. (1996) and Gonzalez et al. (2012). These loops provide mechanisms that update both levels of strategy regarding the status of the manufacturing function.

MS has been known to have generic types, and each type has, to a certain extent, particular sets and policy areas considered in decision-making. These generic types of MS were comprehensively reviewed by Sweeney (1991) but were popularly known in the work of Miller and Roth (1994). Further evaluation and support were performed by Frohlich and Dixon (2001) following similar taxonomies developed by Miller and Roth (1994). These taxonomies are discussed in the previous section. A particular MS type forges a set of policies that characterizes manufacturing decision categories. Consistent patterns of decisions over these nine decision categories develop a set of manufacturing capabilities or competitive priorities that is also consistent with the business strategy. The four competitive priorities; cost, quality, dependability and flexibility; were also discussed in the previous section. The set of competitive

priorities a business strategy identifies comes traditionally from market requirements.

The second part of the framework introduces the SM field. Some important concepts are relevant in this field. For instance, the TBL approach embodies the framework of sustainability (Elkington, 1997). A manufacturing organisation is barely sustainable if upstream suppliers and downstream customers are not present in the equation (Ageron et al., 2012). Materials, energy and wastes must be critically analysed throughout supply chains, not on individual manufacturing plants alone. This enhances collaboration and an economy of scale with regards to the efforts of manufacturing firms to drive SM. Likewise, product and process design for sustainability must be considered throughout the product life cycle stages (Yuan et al., 2012). The environmental and societal impact of a product and its manufacturing processes must not be contextualised within manufacturing gates alone, but must extend from cradle to grave so that all stages are considered. Last, following the TBL, considerable effort has been made with regard to research on the impact of stakeholders' interest in the sustainability of manufacturing firms (Theyel & Hofmann, 2012; Matos & Silvestre, 2013; de Brucker et al., 2013).

Theyel and Hofmann (2012) emphasised that aside from pressures imposed by stakeholders on the firm, stakeholders, on the other hand, help manufacturing firms in decision-making, especially on environmental and societal issues, through their perspectives, experiences and resources. These TBL approaches, supply chain and product life cycle perspectives and the stakeholder approach constitute a systems approach to sustainability that analyses sustainability from wider and more inclusive viewpoints.

Hallgren and Olhager (2006) provided significant advances in the MS field by introducing a quantitative framework in its formulation. However, the framework fails to consider the impact of sustainability issues on MS formulation. Significant attempts were made to link the two fields, such as the works of Thomas, Francis, John and Davies (2012), Pham and Thomas (2012), Baumgartner and Ebner (2010) and Kashmanian et al. (2011). The most commendable framework that relates the frameworks of Skinner (1969) and Wheelwright (1984a) to SM was proposed by Johansson and Winroth (2010).

Their findings can be succinctly summarised into two areas: (1) to embed environmental concerns into MS, environmental performance should be a competitive priority, and (2) when environmental issues are to be linked with MS, manufacturing decision categories should be altered to accommodate policy areas that should be aligned with environmental performance. However, the framework of Johansson and Winroth (2010) lacks a quantitative approach in

modelling decisions when considering sustainability concerns. Reviewing the theoretical framework, significant research gaps are known. Current knowledge lacks a quantitative unifying framework that systematically integrates the SM and MS fields. This framework would attempts to explore several issues, such as the impact of firm size, competitive priorities, strategic response and stakeholders' interests on developing an SMS.

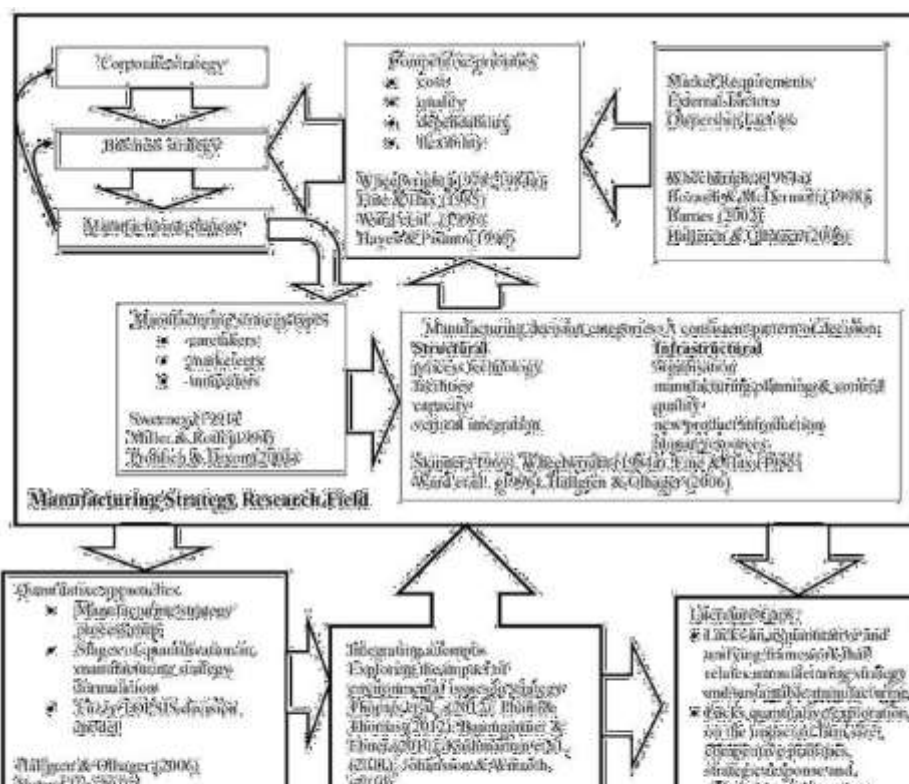


Figure 5. Theoretical framework

CONCEPTUAL FRAMEWORK

Because the current literature provides little information about the integration of the two fields of MS and SM, a conceptual framework that links these two fields is provided in this paper. The framework systematically integrates important concepts of MS and SM, with the goal of effectively providing comprehensive guidelines about making decisions in developing an SMS. The conceptual framework proposed in this work is shown in Figure 6.

first part of the framework incorporates the top-down hierarchical approach of Skinner (1969) and Wheelwright (1984a) relating corporate strategy, business strategy and MS. Embedding sustainability in an organisation requires top management support, and thus, the drive to embrace it must come from corporate directives. Aside from the top-down approach of Skinner (1969) and Wheelwright (1984a), the framework also incorporates the feedback loops introduced by Fine and Hax (1985) and Pun (2004). Business strategy is classified as either market-oriented or technology-oriented. Unlike former taxonomies of MS, the proposed framework subscribes to the three strategic responses of Heikkurinen and Bonnedahl (2013), which were identified as stakeholder orientation, market orientation and sustainability orientation, and these responses are arranged according to an increasing degree of acceptance of sustainability approaches. The framework introduces two routes toward sustainability similar to the routes defined by Sweeney (1991): the first is the stakeholder-oriented → market-oriented → sustainability-oriented route, and the second is the stakeholder-oriented → sustainability-oriented route. Each of these strategic responses

characterises a set of manufacturing decision categories. The framework maintains the nine (9) decision areas but incorporates the insights of Johansson and Winroth (2010) on the impact of sustainability issues on decision categories. Unlike former approaches that consider decision areas to be independent of each other, the proposed framework considers causal relationships between these areas. For instance, the direction of vertical integration, either up or down the supply chain, has an impact on the structure of the organisation.

Different from previous notions that MS and business strategy are motivated by market requirements, SMS must incorporate the interests of different stakeholders, as described by Theyel and Hofmann (2012). These interests impact the strategic responses of manufacturing firms towards sustainability. For instance, demanding interests of the government, such as regulations, policies, penalties and taxes, with increasing demands of customers and consumers could motivate manufacturing firms to transition from a stakeholder-oriented stance to a market-oriented stance. The interaction of stakeholders' interests also frames the set of competitive priorities that must be satisfied by the manufacturing function. Thus, decision categories are not only affected by the strategic responses of firms but also motivated by the set of competitive priorities developed by this interaction. For instance, increasing environmental government regulations could enforce quality as the competitive priority of an industry. To address this priority, manufacturing firms must make a pattern of decisions that improve the monitoring of the environmental impact and performance of products. Furthermore, firm size could have a significant impact on these manufacturing decision areas. SMEs, with constraint primarily on the amount of resources available, would certainly make different decisions compared to their large company counterparts. Last, the proposed framework attempts to provide a

relation between a developed SM and the best practices in SM explored in the literature and embraced in practice.

CONCLUSION AND FURTHER WORK

The proposed conceptual framework provides contributions to advancing our understanding of developing an SMS. First, previous studies embarked on initiating sustainability programs that support the indicators of the TBL. This direction helps decision-makers in updating relevant information that truly promotes sustainability. However, such approaches provide an inadequate platform in supporting the competitive functions of manufacturing. Without this platform, the challenge of how to integrate sustainability initiatives in key manufacturing decision areas remains. In our conceptual framework, we present a harmonious relationship between the two significant fields, MS and SM, in developing strategies with a foundation in supporting the competitive advantage of the firm. This approach could guide managers and manufacturing decision-makers in formulating a strategy that addresses both firm competitiveness and sustainability. Second, the former notion of satisfying customer requirements is insufficient in structuring a sustainability framework in decision-making. The proposed framework extends this traditional market perspective of strategy to a

holistic approach that incorporates the interests of stakeholders in addressing sustainability.

We build upon several studies that emphasised the role of stakeholders in promoting sustainability not only at the regional level but also at the micro or industry level. The framework brings the interests of stakeholders together to the drawing board of decision-makers. Third, as we build upon several works that differentiate large firms and SMEs, the proposed framework explores the impact of firm size, providing opportunities to researchers and practitioners to take a look at how this factor impacts manufacturing decisions and, eventually, an SMS. This guidance will aid decision-makers in developing policies that direct action for firms in relation to their respective size. Fourth, previous studies suggest generic sustainability programs without a mechanism to evaluate their coherence with the strategic direction set forth by a manufacturing firm. As a probable result, programs tend to be not supportive of this strategic direction, and a firm would likely let go of either promoting sustainability or enhancing competitiveness. Thus, to strengthen the relationship between these two fields, the framework explores bilateral options in key decision areas that would promote sustainability but relate such decisions to the competitive strategy set forth by the firm. Last, the framework relates an SMS to best practices developed today, thus allowing some comparisons on how such business practices provide competitive advantage to the firm.

Two empirical studies can be generated from the conceptual framework. The first study is a statistical validation approach that would investigate the relationships directed by the framework. The results of these statistical tests through multivariate techniques could provide empirical proofs and explanations that strengthen the arguments proposed in this work. Further enhancements of the model are highly invaluable to refine or funnel down several concepts, contributing to a better understanding of sustainable manufacturing strategies. The second empirical work could be directed towards dissecting the framework into decision models that represent specific arguments. Decision models, using multi-criteria decision-making tools, could be integrated with expert judgements to formulate specific policy options numerically in key manufacturing decision areas. The results of these decision models may be significant for managers and decision-makers as guidance in developing an SMS.

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