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November 2009

CIRRELT-2009-53

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An Essay on Green Supply Chain Design and Dynamic Alignment

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Abstract. New developments in supply chain management bring attention to the fact that companies need to dynamically manage different supply chains together in order to properly respond to divergent customers' buying behaviour. In order to do so, some authors propose that four basic supply chain types exist: fully flexible, agile, lean and continuous replenishment. Each one of these supply chains has different requirements in terms of the structure of their network design. Some need a faster, more adaptive and distributed network of facilities, while others require a rather stable and centralized structure. Nowadays, with the emergence of the green supply chain management paradigm, when designing and realigning supply chains according to customers behaviours, one needs to consider several environmental issues related, for example, to energy use, greenhouse gas emissions, material consumption and waste generation. This paper investigates how different supply chain types serving different customers profiles can manage several network design tradeoffs in order to properly answer some relevant green supply chain management requirements. In order to do so, a theoretical framework combining these three concepts is proposed and discussed.

Keywords. Green supply chain, dynamic supply chain alignment, supply chain network design.

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Dépôt légal – Bibliothèque et Archives nationales du Québec,
Bibliothèque et Archives Canada, 2009

1 Introduction

Recent advances in supply chain management put forward the idea that unconscious aspects that define the leadership model, the organizational culture and the behaviour of the value chain's stakeholders are of fundamental importance in delivering superior value to customers (Bremer et al, 2009a). In this sense, by coining the term dynamic supply chain alignment, Gattorna (2006) suggests that it is important to configure value chains in a way to have the capacity to deliver an array of supply chain responses that align with the dominant buying behaviours of customers. Customers are different and have different value requirements.

Traditional approaches define only one servicing strategy for all customer segments (known as "one size fits all"), instead of multiple possibilities. However, companies obtain superior performance by recognizing these differences and by aligning value delivery accordingly (Gattorna, 2006). In practical terms, this concept implies the definition of different servicing strategies for each consumer group including, for example, different levels of communication intensity, collaborative approaches, prices, product quality, and so forth. The author proposes that four generic supply chain types exist: fully flexible, agile, lean and continuous replenishment type.

Value chain alignment can be obtained by rethinking the supply chain. Traditional works in the domain (Cooper et al., 1997) mention that supply chain design and transformation include a discussion on business processes, management components and network structure. For example, based on a practical and academic experience, Bremer et al. (2009b) propose an alignment model for collaborative value networks including a business process reference model and a set of management components comprising principles (e.g., organizational and technological) and a complete transformation methodology. Other interesting and recognized works discuss different business processes or management components, such as Azevedo et al. (2008), SCOR (2006), and Lambert (2004), but they do not explicitly consider the dynamic supply chain alignment principle.

In terms of network design, several works in the literature discuss how to structure supply chains considering decisions involving partners' selection, plant and warehouse locations, facilities capacity definition, products allocation and transportation modes selection (Klibi et al., 2008; Kettani, 2008; Shapiro et al., 2001; Lakhal et al ., 2001; etc.). Usually, analytical and simulation methods are employed. For example, Kettani et al (2008) propose a methodology for supply chain network design to maximize economic added value through optimization procedures, which were encapsulated through a solution called Supply Chain Studio®. This solution is able to deal with very large MIP with concave costs for answering questions related, for example, to how many distribution and production facilities the network should contain and where they should be located, what production/warehousing technologies should be adopted and how much capacity they should have, which transportation model should be employed, and so forth.

Today, these three issues (business processes, management issues and network design) are being discussed according to a new perspective emerging in the business area: the sustainable supply chain management. This concept enlarges the traditional supply chain management paradigm, taking into consideration objectives from the economic, environmental and social dimensions of sustainable development, both from the customers and stakeholders viewpoints (Seuring and Muller, 2008). Many works discuss how to identify best practices and performance indicators for sustainable business (e.g., Hutchins and Sutherland et al., 2008; Wilkerson, 2008; Aberdeen, 2008). In a recent literature review, Seuring and Muller (2008) demonstrated that this topic is gaining attention each day, but it is clear that many efforts are still necessary to transform this concept into a widespread and accepted notion.

Our interest in this paper is to discuss the network design aspect in the context of the dynamic supply chain alignment from a green perspective. To our knowledge, this is an important gap in the academic and professional literature. Also, this combined perspective has not gained enough attention from practitioners. Many questions need to be answered, such as: what are the main trade-offs between green requirements, different supply chain types and network topology? Which supply chain type is more environmental, social and cost effective? How different supply chain types and network topology adhere to the notion of sustainability? Other relevant questions could also be included in this list. For our part, the objective of this essay is to raise some hypotheses and provide some initial understanding concerning the first question. In order to do so, we propose a first conceptual model combining green supply chain, dynamic alignment and network design issues. This is a first step toward a more complete model.

This paper is organized as follows. First, Section 2 presents a general overview on the concept of dynamic supply chain alignment. Then, Section 3 presents the concept of supply chain network design, while Section 4 discusses the green supply chain management paradigm. A discussion combining these three concepts is provided in Section 5. Next, Section 6 explains how the proposed framework will help us in some future practical applications. Finally, Section 7 outlines final remarks and conclusions.

2 Dynamic Supply Chain Alignment

According to Gattorna (2006), successful enterprises are those whose strategy, translated into a value proposal, are aligned with the customers' buying behaviour. This alignment occurs when the leadership style and internal capacities (organizational culture, infrastructure, etc.) satisfy different costumers' attributes.

The author explains that managers need to go beyond traditional customer segmentations approaches that typically consider mainly the elementary customers characteristics related to the geographic location and the annual customers' purchase volume. These aspects do not allow for understanding relevant behaviours such as demand variation, required order urgency, sales forecast reliability, changes in terms of allocated orders, willingness to establish long-lasting partnerships, and so on. All these aspects are important for the management of the value chain and for the alignment of the value proposal with the value delivery.

The translation of this concept into practical terms involves the definition of a service package for each identified customer group. This package includes the service differentiation, communication alternatives, the level of collaboration and information sharing, prices, the offered products and their quality, etc. The innovation proposed by Gattorna (2006) consists in the concept that different supply chains types must be set in order to create distinctive service packages for different customer groups.

In this sense, based on the seminal work on personality types from Carl Jung (Jung, 1983), and other complementary works such as Adizes (1985), Gattorna (2006) identified four key behavioural types or 'logic sets' that might exhibit a dominant tendency in the specific interaction between buyers and sellers in supply chains: Producer – P (the force for action, results, speed and focus); Administrator – A (the opposing force to "D" that represents stability, control, reliability, measurement, logic and efficiency); Developer – D (the force for creativity, change, innovation and flexibility); and Integrator – I (the opposing force to "P", which represents cooperation, cohesion, participation and harmony).

Additionally, based on a research comparing several real case studies, the author concludes that four basic supply chains exist to serve these four basic consumer types: fully flexible, agile, lean and continuous replenishment. Figure 2.1 schematizes these supply chains.

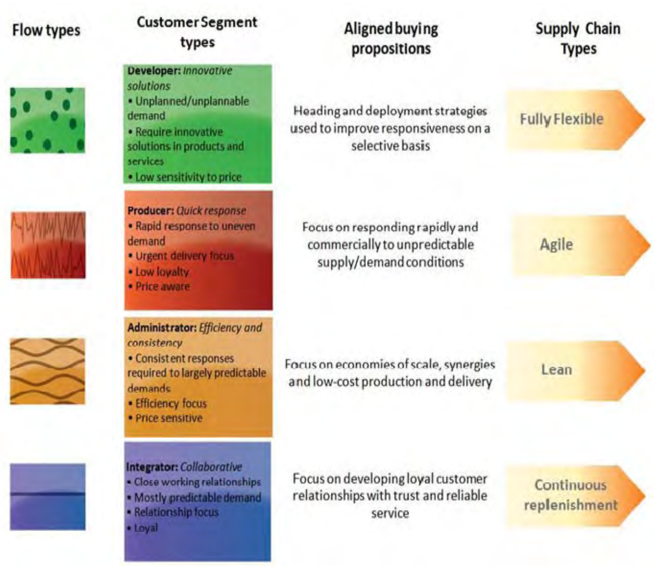

Figure 2.1: Supply chain types (Gattorna, 2006)

The basic idea of Gattorna (2006) is to put people at the center of all supply chains as the key to successful supply chain management. This gives some distinctive characteristics for each supply chain type:

✓ Continuous replenishment supply chains: where relationships matter most;
✓ Lean supply chains: where the focus is on efficiency and lowest cost-to-serve;
✓ Agile supply chains: where quick response is paramount;
✓ Fully flexible supply chains: where nothing is impossible.

When configuring different supply chains, several elements need to be considered. At the strategic level, the supply chain network design is of fundamental importance, as explained in the next subsection.

3 Supply Chain Network Design

The globalization phenomenon and the increasing complexity of business processes greatly contributed to the emergence of network design as a key discipline in supply chain management. By designing and redesigning networks, companies are able to reduce costs and delivery lead-times dramatically, to effectively establish themselves in current and new markets, to properly perform long-term investment plans, as well as to establish solid partnerships with clients and suppliers.

In fact, the supply chain network redefinition is of fundamental importance in some cases, such as:

✓ Companies facing opportunities of expansion and market growth need to make clear decisions concerning the setting up of additional manufacturing capacities, suppliers' selection, and facilities location.
✓ Acquisitions and merges can be seen as interesting opportunities to rationalize resources allocation, to improve efficiency and reduce redundancies.
✓ When facing relevant uncertainties capable of disrupting the supply chain, companies are forced to develop network structures and business practices insuring them with enough robustness and reduced risks (Snyder et al, 2006).

The literature presents many interesting works. Some focuses only on distribution networks (e.g., Syarif et al., 2002), i.e. outbound supply chain network considering lead times, location of distribution facilities and choice of transportation mode. Other works also include manufacturing facilities and supply network (e.g., Lakhal et al., 2001). In this paper, we are mostly concerned about network of factories instead of distribution networks.

In all cases, the supply chain network design represents an important opportunity for companies to reposition their assets, business processes and practices in order to better respond to the requirements of the four supply chain types previously mentioned (Gattorna, 2006). In addition, supply chain network design and redesign can be used to lighten carbon footprints associated with product movements and manufacturing, as well as other green supply chain management requirements, as it will be discussed in the next subsection.

4 Green Supply Chain Management

The sustainable supply chain management phenomenon is nowadays gaining attention worldwide. Supply chains stakeholders (i.e., investors, shareholders, employees, suppliers and customers) are asking whether their organization and the supply chain in which they participate are environmentally and socially responsible.

According to Seuring and Müller (2008), sustainable supply chain management is the "management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements". Another interesting definition is provided by Pagell and Zhaohui (2009): "sustainable supply chain management is the specific managerial actions that are taken to make the supply chain more sustainable with an end goal of creating a truly sustainable chain". Therefore, for a supply chain to be really sustainable it should provide good results as proposed by the triple bottom line model (Elkington, 1998).

Figure 4.1 represents the nature of some relevant actions to promote sustainable practices across single supply chains and also towards multiple supply chains (Svensson, 2007). It is interesting to note that already existing supply chain management practices also serve as an effective basis for sustainability improvements. However, traditional practices tend to value innovations that are incremental in nature. This strategy is appropriate to make the supply chain "more" sustainable, preferably than "fully" sustainable, as a fully sustainable approach may require a complete reengineering of the whole supply chain.

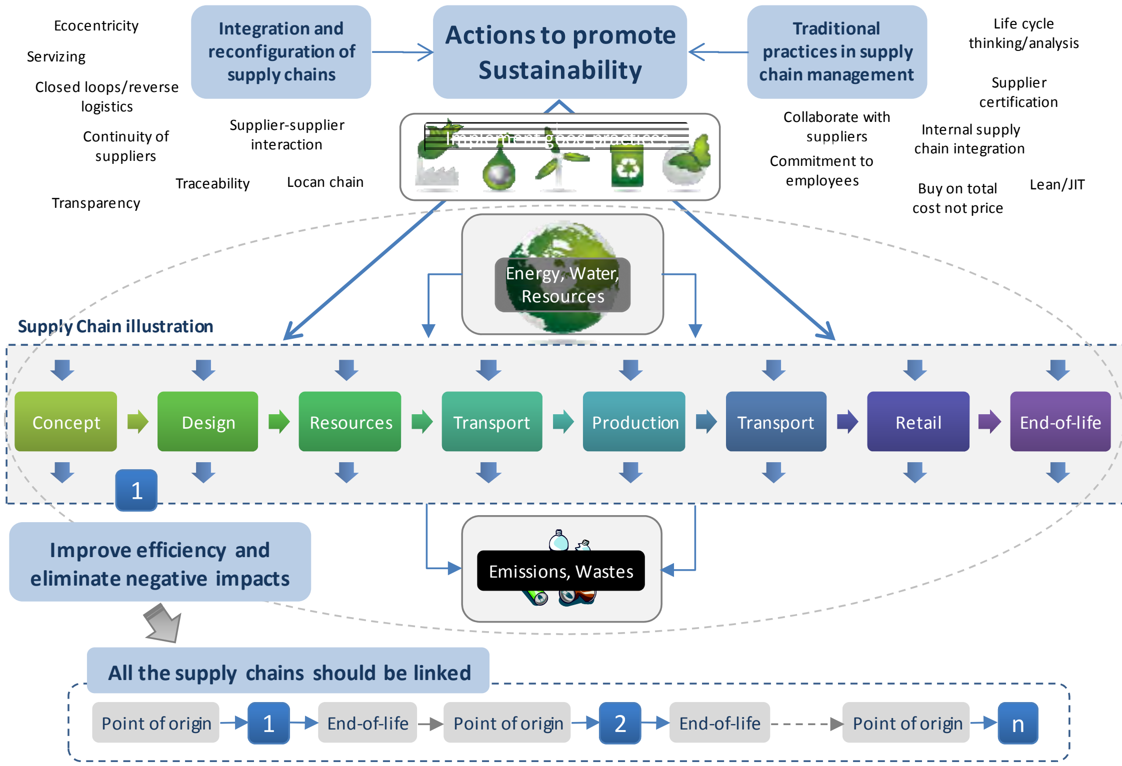

Figure 4.1: Actions to promote sustainability in consecutive supply chains

Initiatives involving supply chain reconfiguration and integration are more effective to "fully" improve the supply chain sustainability. The idea is to transform or change supply chain partners, the way value is generated across the supply chain, and how results are measured.

Seuring and Müller (2008) put the responsibility of designing sustainable supply chains in the hands of companies known as "business leaders". Leading companies are companies that usually rule or manage the supply chain, which may or may not have direct contact with consumers.

The advantages of sustainable supply chain initiatives are intrinsically related to the creation of real and sustainable business value. Sustainability can contribute to re-examine processes, materials and operational concepts, which will ultimately increase productivity and support innovation. Thus, more sustainable corporations have better chances to compete and stay in the market on the long run than traditional companies (Pagell and Zhaohui, 2009).

One of the main issues in sustainable supply chain management is the ability to take into account a wide range of subjects across the entire value chain in order to favour all stakeholders to think out of the box. This is considered the main barrier to implement sustainable practices.

The following subsection discusses how supply chain reconfiguration adheres to this context, according to some new studies related to multiple and dynamic supply chain design and alignment perspective.

5 Green SC Design and Dynamic Alignment

Before discussing these three elements together (i.e., dynamic alignment, network design and green aspects), we first combine two domains at a time. First, we inspect how some relevant aspects concerning network design can be related to green issues.

5.1 Green Aspects versus Network Design Criteria

In order to select the main issues affecting the network design, we were inspired by Baglin et al. (2007). Essentially, these authors mention four relevant criteria: supply chain integration, sourcing, economies of scale and technology. We add capacity utilization to this discussion.

Supply chain integration essentially refers to vertical integration. A company can be vertically integrated by owning and managing alone all the different aspects of a product's manufacturing from raw material to distribution. In this case, a vertical company controls all parts of the business. On the other side, less vertical businesses prefer to make use of the outsourcing strategies by transferring some functions not related to the company's core competence to third-party providers. By doing so, one can concentrate on its strength and gain access to specialized partners. This integration degree varies according to the continuum "vertical integration – outsourcing" and diverse levels of verticalization are possible (see Figure 5.1).

In terms of sourcing, it refers to whether the company is being supplied from local or global suppliers. Local suppliers are closely located to the facilities, while global ones are usually found overseas. Local suppliers allow for a faster and more flexible procurement strategy, whereas global ones are more cost-effective and less flexible regarding procurement strategy. In this case, the suppliers' pool can be defined according to the continuum "local – global".

As for the third criterion, i.e. economies of scale, firms can concentrate all of their activities in one or few large facilities to obtain economies of scale and reduce marginal costs. On the other side, smaller production facilities can be created and scattered across the market, thus being closer to clients. Similar to the previous criterion, several degrees of economies of scale exist inside the continuum "centralized – distributed" facilities.

The fourth criterion refers to the employed technology. In this case, the continuum is defined between the extreme cases "specialized – polyvalent". Specialized facilities are more efficient, but less flexible. On the contrary, polyvalent facilities are much more flexible, but less efficient.

Finally, the last criterion is capacity utilization, which varies in the continuum "full capacity – idle capacity". In this case, full capacity means that we try to better occupy all resources, but we limit the ability to absorb possible demand variations. Idle facilities allow for the absorption of eventual demand picks, but they incur additional costs.

These five criteria and their possible variations within their respective continuum are summarized in Figure 5.1.

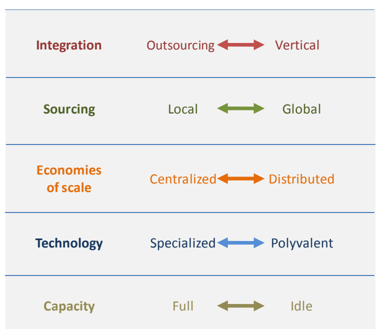

Figure 5.1: Supply chain network design criteria

Those criteria can be understood from the green point of view. Diverse authors (e.g., Araujo and Oliveira, 2008) support that some of the most important aspects used to evaluate the "greenness" of a given supply chain are greenhouse emissions - GHG (e.g., CO_2), materials use (e.g., raw materials), energy consumption, waste generation and biodiversity conservation. In spite of the relevance of biodiversity, it cannot be generalized and one needs to discuss it on an individual basis because it depends on the regions where facilities are to be placed. Additionally, as energy consumption and gas emissions are closely related (Stokes, 2009), they will be considered together in our discussion to simplify the logic of it.

This provides us with three green aspects to be considered: Energy/GHG, Materials and Waste. These aspects are used to construct three "conceptual" KPI (key performance indicators) which make a relative dimension, as explained in (1):

$$KPI_i = \frac{(Green\ Aspect_i)}{\sum(value\ added)} \qquad (1)$$

where,

- ✓ *i ∈ {Energy/GHG, Materials, Waste}*
- ✓ *value added = (contribution of the factors of production, e.g. land, labour, and capital goods, to raise the value of products and service generated)*
- ✓ *Green aspect ∈ {Energy/GHG generation, materials consumption, waste generation}*

The relative dimension allows for a fairer analysis. By doing so, when comparing a supply chain type against another one, the same basis is used, that is the value being added across the supply chain.

Figure 5.2 is an attempt to compare the five network design criteria previously discussed from a green point of view.

KPI	Energy/GHG	Materials	Waste		Energy/GHG	Materials	Waste
Integration	(+)	(+)	(+)	Outsourcing ⟷ Vertical	(-)	(-)	(-)
Sourcing	(+)			Local ⟷ Global	(-)		
Economies of scale		(+)	(+)	Centralized ⟷ Distributed		(-)	(-)
Technology	(+)	(+)	(+)	Specialized ⟷ Polyvalent	(-)	(-)	(-)
Capacity	(+)			Full ⟷ Idle	(-)		

Figure 5.2: Supply chain network design and some green tradeoffs

In Figure 5.2 the (+) sign means that the aspect evaluated has a positive impact. For example, outsourcing tends to have a positive impact on energy consumption and GHG emissions since more specialized and efficient partners are used in the network. On the contrary, (-) denotes that the aspect is negative. For example, highly verticalized firms managing everything from the source of raw materials to the final consumption tend to be less efficient in terms of energy and GHG emissions. The main reason for that is related to the fact that companies that focus on their core competence tend to have more efficient business processes and resources. As efficiency is tightly related to energy consumption and gas emissions, we raise the hypotheses schematized in Figure 5.2. Note that in this case, we are not discussing whether the verticalization process will require more transportation or not.

At this point it is important to make two relevant remarks. The first one is that these hypotheses show that businesses tend toward this situation in general terms, but several exceptional situations may exist. The second one is related to an important property of this logic: the three green criteria are mirrored in regards of the continuum between the extreme cases. For example, if on the right hand side we have a positive impact, on the left hand side the impact will be the opposite, thus negative. Both logics employed are valid for the remaining criteria and the green point of view. In what follows, we present the remaining issues.

Similarly to Energy/GHG, firms making an intelligent use of outsourcing practices can be more efficient, which can importantly contribute to obtain proficient business processes and resources, thus reducing waste generation and material burning ups. By being responsible of all processes through the supply chain, like in vertical businesses, firms tend to be less efficient, hence increasing the probability of generating larger quantities of emissions and waste.

In terms of sourcing, we argue that local sourcing favours less transportation use, since suppliers are closer, therefore reducing energy consumption and GHG emissions. We cannot make the same hypothesis for materials consumption and waste generation since we are not able to identify direct correlations. This is due to the fact that one of the most important reasons for going global is to reduce costs through the use of the well known LCC (low cost countries), which does not necessarily imply more process efficiency.

The third criterion, i.e. economies of scale, is known to be strongly correlated to process efficiency. From this, we suggest that larger facilities tend to provide superior performance in terms of materials consumption and waste. In contrast, highly distributed networks tend to have less efficient manufacturing processes, consequently generating more environmental impacts for these two aspects. As for Energy/GHG, we believe that it is also another criterion that has to be discussed on an individual basis because it may induce an important trade-off, considering manufacturing processes efficiency and transportation. For example, a distributed model typically requires less transportation because all facilities are closer to the market, while in centralized models more transportation is required. On the other hand, centralized models are more Energy/GHG efficient, but require more transportation. Thus, this criterion cannot be generalized appropriately.

The fourth criterion is related to whether technology is specialized or polyvalent. Specialization is also strongly associated with efficiency, making us believe that specialized facilities generates less waste, employ relatively less materials per value added and are more Energy/GHG efficient than polyvalent ones. However, specialized facilities cannot react properly to market variations.

Finally, we hypothesize that capacity utilization can also have an environmental impact from the network design perspective. By better managing capacity, meaning favouring its maximum utilization[1], one is supposed to consume less energy and emit less GHG per value added than the idle capacity. As it will be discussed in the next subsection, the problem with this criterion is that sometimes idle capacity needs to be considered in some supply chain types to obtain superior flexibility. As for the two other aspects (materials and waste), we believe that they are much more correlated to production rates rather than to the network structure.

The following subsection discusses how these network design criteria can be understood from the dynamic alignment perspective.

5.2 Dynamic Supply Chain Types versus Network Design Criteria

This section combines the five network design criteria (Subsection 4.1) with the notion of supply chain alignment discussed previously in Section 2. Figure 5.3 summarizes the basic idea.

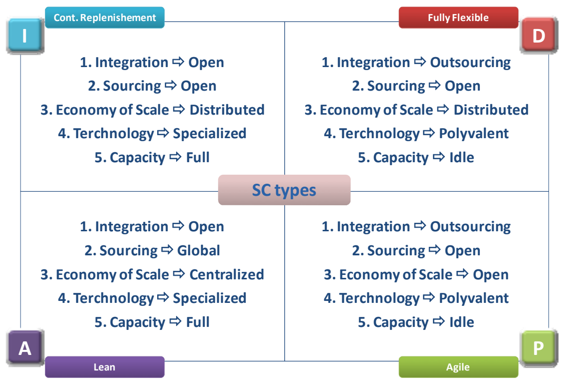

Figure 5.3: Dynamic Supply Chain Types versus Network Design Criteria

In Figure 5.3, the "open" criterion refers to a situation where one needs to evaluate the situation on an individual basis.

We hypothesize that the fully flexible supply chain tends to have the following structure:

- ✓ Integration: "outsourcing" is largely used in order to obtain flexibility in terms of i) different competences to support the development of a creative value proposal for customers as well as a fast time to market and ii) capacity to support demand variations.
- ✓ Sourcing: in some situations, when the supply chain value proposal is the most important parameter, the supply chain tends to be rather "global", because a fully flexible supply chain needs to use a wide net of partners and suppliers to support different requirements from an unpredictable environment. Those suppliers and partners are very often far away from each other and the company has to look for the required competences where they exist. On the other hand, when response time is crucial, "local" sourcing is preferred for faster requirements adjustments. Thus, fully flexible supply chains have their sourcing criteria "open", decided on an individual basis.
- ✓ Economy of scale: fully flexible businesses tend to be close to the client, so they are rather "distributed" when the market is distributed. Also, a distributed structure can be useful to accommodate different modals requirements and variations in terms of volume and specification. In this case, economy of scale gains and efficiency are not critical to this type of supply chain. The capacity to react creatively is the most important issue.
- ✓ Technology: tendency to be "polyvalent" to accommodate different customers' requirements and better support innovations.
- ✓ Capacity: "idle" to accommodate demand variations and demand picks. Capacity works as a buffer for fully flexible supply chains.

Exactly on the opposite hand of a fully flexible situation, the lean supply chain has the following network design structure:

- ✓ Integration: this attribute can be considered "open". A lean supply chain may be "vertical" in order to obtain cost reductions and economies of scale. However, if there are other suppliers that can provide the same product at the same quality with reduced costs and similar reliability in delivery, then "outsourcing" may be a better option.

[1] *In this case we are not considering a situation where capacity is occupied to its maximum limits, for example 99%. In this situation, very frequently performance tends to decrease significantly.*

- ✓ Sourcing: the main attributes are costs and reliability in delivery. As lead time is not a critical attribute to supply, the sourcing tends to be "global".
- ✓ Economy of scale: tends to be "centralized" to obtain high volumes and cost reductions, the focus being efficiency.
- ✓ Technology: tends to be rather "specialized" with very limited flexibility. Due to demand stability, lean supply chains do not need to be very flexible.
- ✓ Capacity: facilities tend to have high occupation levels, so a "full" situation is desired and little waste is allowed.

The third supply chain type refers to the agile approach, whose network structure can be described as follows:

- ✓ Integration: tends to perform "outsourcing" in order to obtain flexibility to support demand variations. Compared to the fully flexible situation, the agile supply chain is a less radical situation, but outsourcing remains an interesting option. A typical example would be Dell, which employs outsourcing strategically for faster market responses.
- ✓ Sourcing: "open" is probably the general situation. For example, in some cases sourcing tends to be "local" to allow for supply lead time reductions in regards with high value or strategic components. Dell can be considered a good example, because all of its main suppliers are closely located to its facilities (less than 40 km in US), which allows a fast response to demand changes. Sometimes a hybrid approach ("global" and "local") is necessary and Zara is an interesting case. In this situation, suppliers of commodities are located in China, due to the fact that they provide lower prices for non critical raw materials. On the contrary, suppliers for specific ones (normally related to fast-paced innovation) used in new products are close to the facility in Spain.
- ✓ Economy of scale: we believe that it is rather "open". The examples provided in the last paragraph also illustrate this situation. Zara basically follows a centralized approach with a single plant in Spain, whereas Dell decided to locate its facilities worldwide, in the USA, Morocco, Brazil, Ireland, Poland, China, Malaysia, and India. Both are known agile cases, according to Gattorna (2006).
- ✓ Technology: more polyvalent" due to demand instability.
- ✓ Capacity: tends to be rather "idle" to accommodate demand variations and demand picks. Capacity works as a buffer for agile supply chains, as for fully flexible supply chains.

On the opposite side, there is the continuous replenishment situation, which usually has its network structure defined as follows:

- ✓ Integration: in this type of supply chain it is critical to maintain a good service level, as agreed with customers. Decision about which level of vertical integration can be used depends on the suppliers' reliability, thus the integration strategy is believed to be "open". When a reliable suppliers' base is available in the vendors' market, the "outsourcing" option can be quite interesting. Otherwise, it is important to keep operations under control and the "vertical" option may be better suitable.
- ✓ Sourcing: similar to the vertical integration logic, the sourcing strategy tends to be "open". As lead time is not a critical attribute to supply, the sourcing may be "global" if this option is acceptable in terms of reliability. If it is not the case, the sourcing shall be "local".
- ✓ Economy of scale: can be both, but is generally close to the client. It is "distributed" when the market is distributed.
- ✓ Technology: rather "specialized" due to demand stability. Besides, as the customers are well known and decisions can be made together, the acquisition of a new technology can be part of an agreement between both players.
- ✓ Capacity: tends to be rather "full" due to demand stability, but is usually planned collaboratively.

It is important to remember that the discussion about these network design criteria represents just a trend according to the authors' points of view and that several exceptional cases are possible.

The following subsection examines some possible green tradeoffs for each supply chain type.

5.3 Basic Tradeoffs in Green Supply Chain Design and Dynamic Alignment

This subsection provides a first general framework towards combining green aspects with network design criteria in order to verify which environmental tradeoffs companies will probably have to face when dealing with multiple supply chains according to the dynamic alignment theory proposed by Gattorna (2006). Figure 5.4 schematizes these main tradeoffs.

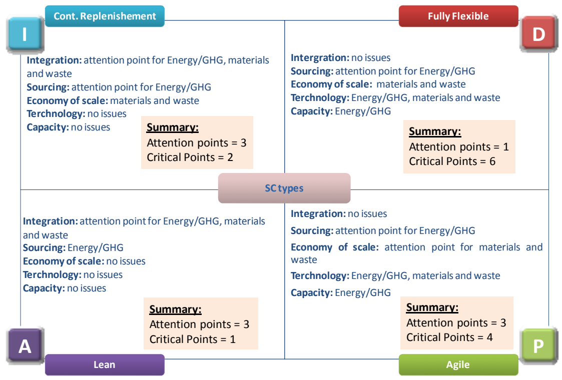

Figure 5.4: Main green tradeoffs to be managed

Two possible situations exist in Figure 5.4:

1) Attention points: refer to a situation where the network design criterion being inspected is considered “open”. In this case, the network designer will have to evaluate it on an individual basis and should not leave this criterion too close to the negative side of the continuum, if a green situation is desired. For example, for a fully flexible supply chain, there is no typical “sourcing” strategy. In this case, one can navigate between local and global approaches, but it is known that global sourcing is usually less efficient in terms of energy/GHG emissions. In this case, the network designer will have to deal with this issue carefully. This is a situation where only one attention point exists (see Figure 5.4).

2) Critical points: in this case, the option considered suitable for the supply chain type is conflicting with some green requirements. For example, a fully flexible supply chain tends to employ polyvalent technologies, but this kind of technology is generally less efficient in terms of energy/GHG, materials consumption and waste generation. In this situation, three critical points exist (see Figure 5.4) and the issues at stake will have to be managed accordingly. Perhaps alternatives to compensate and balance environmental impacts will be needed.

As one can observe in Figure 5.4, the fully flexible supply chain is probably the most complex situation to be managed, due to the fact that six critical points and one attention point exist. Attention points are more flexible and network designers can work on them in order to reduce their impact. On the contrary, critical points are more complex because they refer to important requirements to serve very flexible clients, thus they are difficult to change. In this case, more radical green initiatives may be envisaged. For example, since critical points related to Energy/GHG are present three times in fully flexible environments (see Figure 5.4), the company will probably have to evaluate the possibility of employing alternative energies including solar, wind, biomass, biofuel and others to reduce environmental impacts and better attain green requirements. Other initiatives can also be evaluated, such as buying carbon credits, promote the use of clean technologies, etc.

The agile supply chain is also a complex situation to manage since three attention points and four critical points are present. Polyvalent technology and idle capacity are normally correlated to lower green performance. Some attention points related to vertical integration and sourcing strategies also exist, but supply chain designers have more flexibility to deal with them.

The continuous replenishment and lean supply chains represent less complex situations, because in general terms it is easier to create a network of facilities respecting green requirements. Despite the fact that three attention points are present for each supply chain type, only a few critical points exist, i.e. two for continuous replenishment and one for the lean supply chain.

Hence, two groups of supply chain types exist: on the right hand side, fully flexible and agile supply chains, considered the most complex situations to manage in order to attain superior green performance; on the left hand side, continuous replenishment and lean supply chains stand for an easier situation to manage, where there are fewer critical points. We strongly believe that this is related to one characteristic of these supply chain types: demand is rather instable and less predictable, so they require more flexibility and produce less efficiency.

Next subsection explains how the proposed theoretical framework will be validated and will help the team with business transformation projects.

6 Future Applications

Together, Axia Consulting and Modellium Inc. are working on transformation projects in Latin America, using both the network design approach and the multiple supply chain dynamic alignment theory. Large quantities of information are being gathered and a database is built for diverse supply chain structures in various industrial sectors. Up to now, a database for the cosmetics industry has already been created and is currently under study. The researchers and consultants are looking for other distinctive sectors of possible use, such as electronics and consumer goods.

With several industrial sectors mapped together and enough information gathered, the team will use simulation to create several supply chain scenarios. Simulations will be performed using a network design optimizer, the Supply Chain Studio®. The framework proposed in this paper will help the team to identify possible scenarios to be created in terms of network design structures and multiple supply chain alignment options. It will be possible to combine the five criteria with the four supply chain types studied in this text. By performing simulations, the three green aspects (Energy/GHG, materials and waste) will be considered in evaluating the hypothetical tradeoffs raised in the last subsection.

By doing so, this study will help to better understand these tradeoffs and validate the proposed framework, using real data from different industry sectors. Improved versions of this paper are to be published shortly.

7 Final Remarks and Conclusions

We strongly believe that the proposed theoretical framework is an innovation in the domain, since it is, to our knowledge, the first work combining network design principles with the multiple and dynamic supply chain alignment theory, from a green supply chain perspective.

By combining these concepts, we intend to bring attention to the fact that several tradeoffs exist when designing different supply chains serving distinctive customers that also try to better preserve the environment. The proposed framework is a first step towards a more definitive discussion.

The next stage in our work is to proceed to simulations and validate through experimentation the basic premises of this framework. In order to do so, we are using real data from different industry sectors. The framework will support the team in creating scenarios which will allow for the quantitative evaluation of the discussed green supply chain tradeoffs.

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