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Sustainability and the Future of Supply Chain Management

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Abstract

The global supply chain is embarking upon a new era of challenges and opportunities. Environmental protection, energy availability, and dramatic population increases are placing unprecedented pressure on the abilities of worldwide supply chains to efficiently and effectively provide goods and services. However, modern supply chains and the supply chain of the future also have unprecedented access to technology, particularly communication technology, enabling real-time connectivity to virtually anyone on earth. This paper describes the challenges and opportunities facing the supply chain of the future and describes the various effects these issues have on supply chain design, management, and integration.

Keywords: *Supply chain management, integration, energy*

1. Introduction: Forces of Change

There are strong indications that we are moving from a world of abundant, cheap energy to a world of limited and expensive energy (Hartmann, 2004). Commerce-driven societies have long emphasized growth over sustainability and consequently built massive transportation, communication, and production infrastructures on the assumption and seeming reality of a practically infinite energy supply. The vast majority of the energy that powers these societies, and therefore their supply chains, is based in fossil fuels. As or when we reach the peak of worldwide oil production, and remaining oil supplies become increasingly scarce and located in increasingly unstable parts of the world, the pressure will be on supply chains to produce the necessary food, water, goods, and services to support the world's increasing populations demanding energy in increasing amounts. Indeed, by current United Nations (UN) predictions, the world population will reach 9.2 billion by the year 2050 (an increase of 2.5 billion over the next 42 years), and the United States (US) Energy Information Administration predicts that worldwide energy consumption will simultaneously increase by an average of approximately one percent per year (United Nations, 2007; United States Energy Information Administration, 2007).

In addition to the energy challenges that lie ahead, we also face growing evidence that we are entering an era of potentially extreme climate change. As concluded by the Intergovernmental Panel on Climate Change, "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea levels (Intergovernmental Panel on Climate Change, 2007)." No one knows for certain what the effects of climate change will be, and these effects will differ by geographical region, but scientists have hypothesized a wide range of potential effects, such as increased flooding and coastal erosion, reduced quality and quantity of drinking water and food supplies, increased frequency and intensity of storms and wildfires, increased animal and plant species extinctions, and increased destruction of natural ecosystems. Since these changes would threaten transportation infrastructures, natural resources (and the supply of raw materials), and would change human settlement patterns, they would also dramatically affect supply chains' abilities to supply worldwide.

Besides the challenges of energy and climate change, the supply chain is also entering an unprecedented age of opportunity. In particular, the modern supply chain still enjoys relatively inexpensive and abundant energy inputs and raw material resources, and is also more connected than ever before. Improvements in telecommunications, including standardized communication protocols, have led to the creation of a "supply web", within which organizations and facilities across and within supply chain echelons have real-time access to information, vastly improving their ability to track item movement and customer demand patterns, while increasing opportunities for vertical and horizontal collaboration, communication, and synchronization. These advances have also created incredible opportunities for consumers, providing them with two-way communication capability with virtually anyone on earth, ranging from companies, community organizations, and consumer advocacy groups to other individual consumers. Even so-called third-world nations are finding ways to overcome the constraints of language, technology, and relevancy to gain access to the Internet in unprecedented numbers (Steffen, 2006).

With these new technologies and the emergence of external factors, customers are also changing. Customers, as stakeholders in the supply chain, may include governments, communities, and individuals. Local governments, under the strains of increased material disposal costs and public pressure, are implementing legislation to reduce the volume of post-consumer materials directed to landfills. Communities are demanding cleaner air, water, and soil. Individual consumers are demanding higher quality goods in greater variety, delivered with short lead times at a reasonable cost. A growing number of consumers are also making purchasing decisions, at least in part, on the bases of perceived environmental stewardship and corporate responsibility—not just cost, quality or service. Finally, emerging markets, most notably India (population 1.1 billion) and China (population 1.3 billion), will certainly place additional pressures on natural resources, and consequently, supply chain inputs and outputs (United States Central Intelligence Agency, 2008). These changes in customer characteristics, combined with the external challenges of constrained energy and natural resources, all within the environment of a competitive and expanding worldwide marketplace, pose an emerging set of challenges to the modern supply chain.

Figure 1. Supply Chain Integration

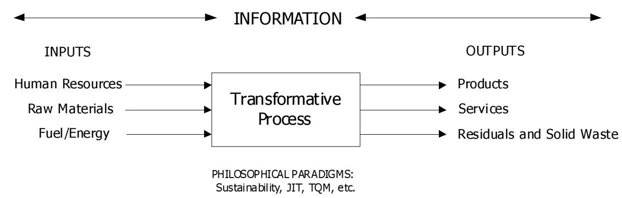


Figure 1 shows the integrative nature of the supply chain, transforming inputs into outputs. Information flows throughout the process, and philosophical paradigms, (such as sustainability, JIT, and TQM) permeate all stages of the chain.

This paper describes the effects of emerging challenges and opportunities on supply chains of the future, using the supply chain inputs and outputs as bases for the discussion. In particular, Section 2 describes emerging and future issues and trends in supply chain inputs, Section 3 describes the outputs, Section 4 discusses implications for two specialized supply chain examples, Section 5 describes approaches to supply chain design, management, and integration that are poised to lead the next generation of supply chains, and the paper is concluded in Section 6.

2. Supply Chain Inputs

The supply chain transforms inputs into goods and services. Supply chain inputs include human labor, raw materials, and (renewable and non-renewable) fuel sources.

2.1 Human Resources

At a time when the earth's natural resources are becoming increasingly scarce, human resources are simultaneously increasing. One effect of scarce natural resources is an increase in the cost of material inputs to the supply chain. Ironically, a primary cost center in many supply chains is human labor, so when supply chain managers look to reduce cost, they often reduce human staffing levels, at a time when human resources are increasing! It follows, therefore, that as supply chains begin to experience increases in material resource costs and seek to reduce overall supply chain costs, they will inevitably reduce staff, while emphasizing abundant, cheap, and/or renewable material inputs. As an alternative to staff reductions, many firms in industrialized countries have turned to outsourcing labor from developing countries (such as India, China, and southeast Asia), where laborers are willing to work for much lower pay. Indeed, some organizations have even positioned outsourcing as a strategic initiative, called "transformational outsourcing". Transformational outsourcing allows companies to grow their businesses by more closely matching employee skills to tasks, thereby freeing up skilled labor and monetary resources to apply to other projects, programs, and investments (Engardio, et al., 2006).

2.2 Raw Materials

Supply chain managers often try to improve input efficiency by looking for ways to use fewer (or cheaper) inputs to generate the same (or greater) outputs ("getting more from less"). In addition to labor cost reductions described above, reducing the expense of raw material inputs has also been used as a strategy to reduce overall costs for many years. The objective has been to control the expense of raw materials in such a way that cost is minimized while ensuring quality. Sometimes an organization gets "caught" reducing that cost at the expense of quality. Some high-profile examples include toothpaste (toxins) and toy (lead paint) toxicity in products from China (2007) and the Ford Motor Company's inadequate fuel tank straps (Hightower, 2008, The Associated Press, 2005).

2.3 Fuels

As previously mentioned, fossil fuels provide the bulk of the inputs to modern supply chains. However, there is a finite amount of oil in the world, and there is growing evidence that we have reached or are nearing worldwide peak oil production (Hartmann, 2004). Also, or maybe in part because of this, the market price per barrel of oil has topped $100 (The Associated Press, 2008). So, there is renewed interest in alternative ways to power modern society and its supply chains. This sub-section discusses alternative fuels and residual "fuels".

2.3.1 Alternative Fuels

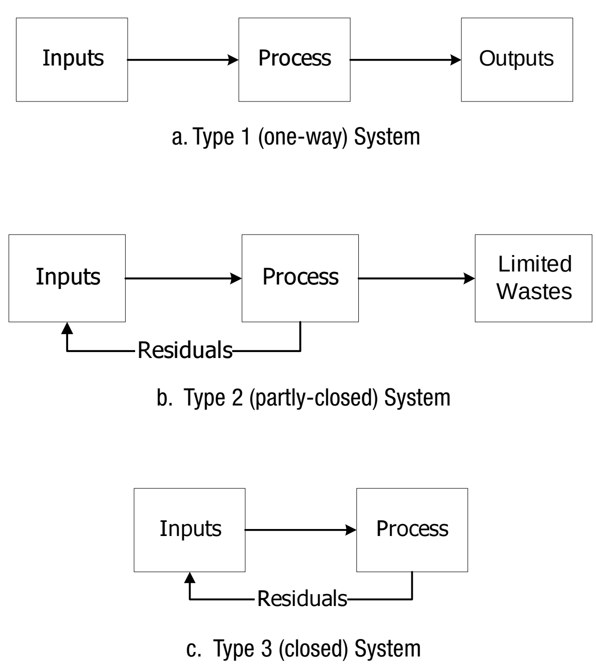
While worldwide energy consumption is increasing and expecting to continue to increase, it is important to note that this increase is in the demand for non-renewable *and* renewable energy. In fact, one of the economically and environmentally positive consequences of rising energy costs is that it makes renewable energy more cost-competitive (Esty and Winston, 2006). This serendipitous consequence supports improvements in input efficiency in the long run, and environmental sustainability now and in the future.

The supply chain of the future will emphasize renewable fuel sources, as non-renewable sources become more scarce and expensive. There are many different technologies being forwarded for different applications, including those based on hydrogen, solar, wind, and ethanol. Ethanol power, in particular, is gaining momentum, but burning ethanol may produce more greenhouse gas emissions than burning fossil fuels because: (1) corn-based ethanol requires significant amounts of energy to fertilize, harvest and refine and (2) fuel plants may not be as effective as other vegetation in absorbing greenhouse gases (Markman, 2008). Other renewable sources have some significant barriers to implementation as well. Solar power is still relatively expensive (though prices continue to fall) and solar cells still currently require fossil fuels to manufacture. Hydrogen power is challenging to produce efficiently on a large scale, difficult to store, and difficult to transport (Wise, 2006). While wind power is clean, its price remains relatively high for the resultant (and often intermittent) power output, and opponents are quick to note that wind farms are eyesores in natural environments (Steffen, 2006). If and when these and/or other alternative fuels become scalable and cost-competitive, they will play critical roles in powering future supply chains.

2.3.2 Residual "Fuels": Outputs as Inputs

A source of renewable fuel sources will also likely be found in outputs from other processes. Some supply chain outputs traditionally classified as waste (material for which there is no further use) will be newly-classified as residuals (materials that may have further use somewhere within or outside of the process or firm that originally generated or used the material). Formally, this type of process would tend to close the loop between supply chain outputs and inputs, ultimately moving supply chains from Type 1 systems to Type 2 and Type 3 systems, as shown in Figure 2.

Figure 2. Supply Chain System Types (modified from Allenby, 1999)



In Type 1 (traditional, one-way) systems, raw materials and energy inputs enter the process, are used once, and exit the system as products and waste outputs. In Type 2 (partly-closed) systems, raw materials and energy inputs enter the process, but a fraction of the process outputs (residuals) are re-used as inputs. Type 2 systems produce a limited amount of waste. Type 3 systems are completely closed, as no waste is generated from the process. All process outputs (residuals) are immediately or eventually re-used as inputs to the producing process or to an external process. An example of a proximal Type 3 system is Subaru of Indiana (SIA). All of SIA's non-automobile outputs are reused, recycled, or burned to generate steam power (Inman, 2006). Type 2 and Type 3 systems are likely to become increasingly common in future supply chains.

3. Supply Chain Outputs

Anticipated changes in the natural and supply chain environment will have a significant effect on supply chain outputs. Physical outputs from the supply chain include products, services, and waste (here we will focus on solid waste).

3.1 Products

Supply chain products of the present and future will be designed from a life cycle perspective. This is a fundamental shift from just the recent past, when even if a product were to be recycled, for instance, it was likely never designed to be recycled. To illustrate this point, McDonough and Braungart (2002) provide an example from the paper recycling industry. The authors note that since chemically-treated paper is not designed to be recycled, recycling it actually results in *downcycling*, since the resultant paper is of significantly lower quality/value than the original (Mayfield, 2003). The modern supply chain will need to consider the lifecycle of products beyond their traditional end-of-life and design products accordingly. Product design is the key to tying manufacturing outputs to manufacturing (and other process) inputs. The dual purposes of closing the loop are to extract more value from precious natural resource inputs and to reduce the amount of material directed to landfills. Lifecycle product design facilitates the processes applied to a product after it reaches its traditional end-of-life.

With the emergence of new legislation requiring manufacturers to collect post-consumer products, manufacturers are beginning to think of ways in which they can turn this cost into potential profit. Schultmann et al. (2006) present two motivations for why companies would implement a product take-back program: profit motivation and legal motivation. Profit motivation arises from collecting materials that may be of value as manufacturing inputs. The legal motivation arises from the aforementioned legislative imperative to collect. The authors astutely point out that, in many instances, companies are motivated by both reasons. The motivation for product take-back in the supply chain of the future will likely shift more towards profit, as take-back legislation becomes increasingly mature, and begins to be seen as a standard cost of doing business. Coupling this with the expectation that raw materials will become more expensive, modern supply chain managers will have incentives to consider alternative streams for supply chain inputs. In this way, the supply chain outputs could potentially merge, or at least overlap, with supply chain inputs. To this end, the emphases in product design will be on repairability (products will once again be designed to be repaired rather than discarded), modularity (products will be designed in modules, which will facilitate repair and disassembly), and re-use (products will contain durable, reusable components).

3.2 Services

The discussion thus far has primarily focused on product-based supply chains, but given the importance and prevalence of service-based enterprises, it is important to note the service supply chain. Some services are provided in addition to physical products, such as product information and customer service. Other services exist as separate supply chains, for example government services, healthcare, and education [World Bank (2000)]. Baltacioglu, et al. (2007) identify four distinguishing characteristics of the service sector, which are summarized in Table 1.

Table 1. Distinguishing Characteristics of the Service Sector (summarized from Baltacioglu, et al., 2007)

Heterogeneity	The "product" cannot be standardized.
Perishability	If not consumed when available, the "product" cannot be stocked for future use.
Simultaneity	Customers must be present to receive the "product".
Intangibility	The "product" cannot be perceived with the senses, since services are not "things".

Today's technology challenges (or is beginning to challenge) all of the above service characteristics. Before the Internet age, most services were performed in person and delivered by an individual. Today, many services that were previously only available in person or by telephone are now available online. Examples of such services include: product ordering, customer support, membership renewals, medical diagnostics, and journal articles. Table 2 describes how modern service providers are challenging the characteristics given in Table 1.

Table 2. Emerging Changes to Service Sector Characteristics

Heterogeneity	While customer experiences cannot be standardized, online services allow service products to be standardized (e.g., standardized web presence, standard communication protocols).
Perishability	Service products can be downloaded (e.g., users manuals, FAQs), so service is no longer necessarily perishable.
Simultaneity	Service providers can communicate asynchronously to customers (e.g., by providing health profiles, medical diagnoses, customer support) via email. So, while customers must still be present when actually experiencing the service, customers need not be present to receive the service.
Intangibility	So far, online services are limited to reaching customers via sound and vision. However, researchers are hard at work to provide digital smell, touch, and taste, with smell being the most promising so far (Gupta, 2002). Finally, personal services such as massage and aromatherapy have always been perceptible by the senses.

3.3 Solid Waste

As mentioned in Section 2.3.2, some supply chain outputs will be classified as residuals and therefore re-used in another process or in the originating process. Still other supply chain outputs will be recycled, based on the market, suitability, and quality of the materials to be recycled (Beamon, 1999). Finally, other materials will be simply discarded and either sent to landfills or incinerated. It is difficult to estimate worldwide waste production, in part because the word "waste" holds different meanings for different countries and many countries do not keep accurate waste statistics (Research on the Scientific Basis for Sustainability, 2006). However, in 2006, the United States produced 251 million tons of trash, of which 32.5% (or 82 million tons) was recycled (United States Environmental Protection Agency, 2008). Residential waste comprises between 55 and 65 percent of the total municipal solid waste, while the remaining 35 to 45 percent is comprised of waste from schools and commercial facilities (such as hospitals and businesses), with paper comprising the largest percentage of waste stream material (33.9 percent) (United States Environmental Protection Agency, 2006).

In manufacturing, there are obvious wastes that are created by the manufacturing process itself, including product scrap, spent ancillary production materials, and so on. Through product and process re-design, many of these wastes may be avoidable. There are also many types of solid waste that are created outside of the manufacturing process. These wastes include wood pallets and crates (which are commonly discarded after a single use), virgin-material cartons, and excess packaging. Many supply chains have begun reducing these waste streams using a variety of methods. One method is to use durable, re-usable plastic, metal, or composite pallets (instead of wood), though any strategy for pallet and/or crate re-use would require the firm to manage the material flow of the materials/equipment being re-used. Other waste-reduction strategies include using cartons and packing material made from post-consumer (recycled) content. For packaging, which is often passed on to the customer for him/her to dispose, reduction strategies would include eliminating or reducing packaging, implementing refillable or reusable packages, and producing recyclable packages and packages made of recycled materials (California Integrated Waste Management Board, 2007).

The waste problem is becoming more complicated, however, as landfill contents increase and landfill services become more expensive. E-waste, or waste comprised of discarded electronic components and products, is a significant issue. As the cost of technology decreases, and the obsolescence rate on new electronics increases, an increasing number of electronic products is discarded, leading the European Environment Agency to conclude that the volume of e-waste is increasing at a rate of approximately three times the rate of municipal waste (BBC News, 2007). In response to the e-waste problem, the European Union (EU) recently passed legislation that places restrictions on the materials that can be used in the production of electronics and also requires manufacturers to recover used electronics from the field (European Commission, 2008). Many predict the world economy will adapt, realizing that in order to participate in the EU market, firms will need to adhere to the new requirements. There is some evidence that other markets are indeed recognizing the e-waste problem, and many are following the EU's lead. In the United States, the largest producer of e-waste, the Environmental Protection Agency estimates that between 1.9 and 2.2 million tons of e-waste were produced in 2005, of which between 1.5 and 1.9 million tons were landfilled (approximately 345,000 to 379,000 tons were recycled) (Mayfield, 2003; United States Environmental Protection Agency, 2006). States in the US, such as California, Maine, Maryland, and Washington have passed product recovery legislation, and many other states are in the process of developing similar laws. As a result of, or perhaps in anticipation of the take-back movement, major electronics manufacturers, such as Microsoft, Ericcson, Dell and Hewlett-Packard, are instituting their own take-back programs (BBC News, 2007). Environmental concerns have also caused manufacturers to reduce the amount and potency of toxins in manufactured electronic products, which reduces the products' environmental impact during manufacture and disposal, and also makes recycling cleaner and easier (Greenpeace International, 2006).

The supply chain of the future will be pressured by disposal costs, governments, and markets to reduce the amount of solid waste it generates by changing the processes and materials used in manufacturing and transportation, reducing the environmental impact of packaging materials, and by changing the product itself, including design for reuse, remanufacturing, and recycling.

4. Specialized Supply Chains

There are two types of supply chains that deserve special mention here, as their unique characteristics set them apart from many other types of supply chains. These specialized supply chains are food and humanitarian relief.

4.1 The Food Supply Chain

Due to the complexity of its products, the food supply chain is poised to face some of the future's most compelling supply chain challenges. As of 2005, 840 million people were undernourished across the world, and the demand for food is expected to increase by 50% per generation (Medical News Today, 2005). Beyond population increases, environmental and industry trends will play a major role in shaping the future for worldwide food delivery.

Farming has undergone a rapid transformation over the past several decades. Modern commercial farms often rely on chemical pesticides, chemical fertilizers, and large equipment to get the job done. Lax crop rotation, industrial machinery, and chemicals damage the topsoil, creating a need to use even more chemicals to improve yields. Much has been written about the effects of such practices on long-term topsoil quality and thus its future productivity, in terms of food volume and quality. To combat this, an increasing number of farms are beginning to adopt sustainable agriculture practices as a way to ensure the long-term viability of farm land and the safety of the environment and consumers.

A specific challenge/opportunity for the food supply chain is the use of bioengineered crops. Genetically modified (GM) crops are extremely controversial. On the positive side, GM crops have been shown to dramatically increase yields, providing large quantities of food in areas that may otherwise have been famine-stricken. One example is the bioengineered New Rice for Africa (NERICA). The pest-resistant NERICA lines have shown higher yields, shorter growing time requirements, and higher protein content (Africa Rice Center, 2006). The negative side is that scientists still do not know the potential health and environmental impacts of farming GM crops. GM farming introduces new, self-reproducing species that simply have not existed long enough to be thoroughly studied (Steffen, 2006). GM crops also require (sometimes specific) chemical herbicides and/or pesticides in order to grow. Attacking pests and weeds chemically increases pest and weed resistance to these chemicals, which then leads to the need for more chemicals to be effective.

In addition to the controversial technology, the legal ramifications surrounding the use of bioengineered food products are substantial. Seeds, of course, are the life blood of agricultural farming, and one of the most compelling legal issues in GM farming centers around seed patents. Proponents of seed patenting say GM seeds are new products and deserve a patent; opponents say seeds are living things and should not be patented. Indeed, living things are different in the sense that they can mutate, cross-pollinate, travel on their own, etc., unlike inanimate (conventional) products (Garcia, 2004). In fact, someone could use or be part of a patented living object unknowingly (Garcia, 2004). The output volumes and fiscal opportunities afforded to the food supply chain by new technology will need to be balanced by the need to ensure the safety and diversity of current and future plant and animal species.

Finally, it is important to highlight the effects of energy and climate change pressures on the food supply chain. Any scarcity in future energy supplies will drastically affect food production, since energy powers the food supply chain. It has even been said that "oil equals food". New issues surrounding Ethanol as a possible alternative energy source has highlighted another wrinkle in the energy-food equation: "energy *versus* food". There is an opportunity cost of using farmlands to raise corn earmarked for ethanol production, since this will reduce the land available for growing food. From a climate change perspective, food supplies (or at least farming practices) will be affected, since climate change will affect growing seasons and growing conditions. For example, it has been hypothesized that a warmer climate could shift the wheat belt of the Midwestern United States into the Canadian plains. Such shifts could apply even more pressure to use bioengineering to create crops that could grow in conditions that would otherwise no longer be native to a species.

We are already beginning to see changes in United States agricultural markets that may be a window into the global future for food distribution. These changes are, in large part, caused by the "local food movement", in which consumers favor locally-grown food over food that comes from industrial growers or retail giants (Hopkins, 2003). The philosophy is that by buying food that is grown locally, consumers support local economies, support local farmers, and reduce sprawl (Flint, 2004). Local food purchases also potentially reduce environmental impacts, since they shorten the transportation requirements and reduce or eliminate many of the chemical food additives that would otherwise be necessary to preserve foods across their long journey. There are barriers to local food distribution, however, as described by Michael Rozyne, founder of Red Tomato, a local food broker:

> The transportation and distribution systems [are] stacked in favor of large agribusiness suppliers and long-haul trucking. Thanks to the global distribution system and its resulting economies of scale, it can be easier and cheaper to buy fish from South America or tomatoes from California. We have a global food system that is accustomed to handling truck-sized quantities and not much else. There's tons of small-farm activity, but when you want it on demand, it's hard to find a truck to take it from point A to point B. All across the US, there's resounding new interest in eating things locally grown. But we're all waking up to the fact that [there is little infrastructure to support it]. (Flint, 2004)

While future energy implications lead to a prediction that food distribution systems will become increasingly decentralized, changes in growing patterns may favor more centralized systems. As mentioned above, existing infrastructures do not currently favor the local food movement (and decentralization), but this may not be true in the future. Either way, the challenge to the global food supply chain is and will continue to be one of ensuring high volume, high quality food production and delivery to the world's ever-increasing populations.

4.2 The Relief Supply Chain

A disaster is an event that "results in a serious disruption of society, involving widespread human suffering and physical loss or damage, and stretches the community's coping mechanisms to [the point of failure] (Davis and Lambert, 2002)." Disasters may be human-caused or natural, but as we saw in the case of Hurricane Katrina, this line can be blurred. A natural disaster may be caused by human failures (for example, inadequate levy design and maintenance) or human action (extreme weather events exacerbated by global climate change) and/or worsened by human failures (inadequate relief response).

The numbers of natural disasters and the people affected by disasters have increased dramatically during this century. Balcik and Beamon (2008) report that the average annual number of disasters between 2000 and 2004 was 55% higher than during the previous four years (Balcik and Beamon, 2008). As the frequency and impact of natural and human-caused disasters increase, there has been a simultaneously increased level of interest by practitioners and researchers to study and improve material flows in the specialized environment of the humanitarian relief chain.

Relief chain management differs considerably from commercial supply chain management, in terms of objectives, stakes, and constraints. The objective of the relief chain is to rapidly deliver the appropriate types and amounts of relief supplies to people in need following a disaster. Such supplies can, and often do, mean the difference between life and death to those affected. The constraints are financial (relief organizations funds are generally program or project-specific, with limited funds for improving infrastructures), organizational (techniques and technology lag behind those of the commercial sector), and cultural (logistics has only recently become recognized as a value-added, core function of humanitarian relief). Relief chains have been more closely compared to the military supply chain, whose focus is also on readiness, and which also plays significant roles in relief efforts. However, the amount of funding available for operations and infrastructure differ greatly between the military supply chain and the relief supply chain.

The relief chain operates in an environment in which the focal events are classified as high-risk, but low probability. Therefore, there are issues related to the practice of pre-positioning stocks (readiness is more secured and per-unit costs are lower, but holding costs and obsolescence risks are increased) versus real-time procurement and distribution (higher readiness risk, likely higher per-unit costs, but no holding costs). Most large relief organizations use a combined strategy of stock pre-positioning and real-time procurement and enter into framework agreements with real-time suppliers to reduce readiness risk.

Relief organizations are becoming increasingly interested in improving the effectiveness and efficiency of their relief operations, and in measuring these improvements (Beamon and Balcik, 2008). Current and emerging challenges in relief chain management include: improving information sharing and collaboration across agencies, improving material management, using technology and borrowing best practices from (and partnering with) industry to improve logistics operations. Umbrella organizations, such as NetHope, have emerged as helpful in these areas. There are recent successful examples of relief collaboration, particularly private-public partnerships. One such example is the partnership between the World Food Programme (WFP) and TNT (Thomas and Fritz, 2006); Van Wassenhove, 2006). This partnership was successful, in large part, because both organizations were able to capitalize on the strengths of the other (Thomas and Fritz, 2006). As organizations begin to witness the benefits of collaboration, they become more interested in exploring the possibilities of sharing resources and expertise to improve the relief mission. Interactions across relief organizations have been traditionally focused on the operational (post-disaster) level, in terms of sharing resources and information in the field, but the WFP-TNT collaboration is one indication that relief collaborations may be moving towards more tactical relationships. Indeed, as pointed out by Balcik and Beamon (2008), pre-disaster efforts have significantly greater impact on effective relief delivery than post-disaster efforts (Balcik and Beamon, 2008). As resources become increasingly tight and the intensity and frequency of disasters increase, relief organizations will have greater incentives to increase their relief capacities through tactical and strategic collaboration.

Certain aspects of relief chain management have direct relevance to risk management in commercial supply chains. Indeed, all supply chains are subject to some amount of risk, including supply disruptions and delays, demand fluctuations, and price fluctuations (Chopra and Meindl, 2007). A few recent examples of supply disruptions, ranging from the 2000 Royal Phillips Electronics wafer plant fire to the 2004 US flu vaccine shortage, have highlighted the need to build resilience into the supply chain (Chopra and Meindl, 2007). Much work has been done recently in this area, focusing on operational- or tactical-level mitigation strategies (e.g., capacity building) and robust strategic network design (e.g., risk-pooling/aggregation and redundant supply). An excellent summary, detailing the types of risks and their associated mitigation strategies can be found in Chopra and Sodhi (2004). Finally, Hopp (2008) observe that operational-level strategies, such as maintaining additional resources, come with additional costs, and so should only be used when events have relatively high likelihood of occurring or are potentially disastrous. These ideas are of particular importance to relief chain management, which often operates in a low probability, high impact environment. The importance of risk management in the commercial supply chain is also likely to increase, based on the aforementioned predicted uncertainty in the supply chain environment, particularly associated with energy, natural resources, and weather.

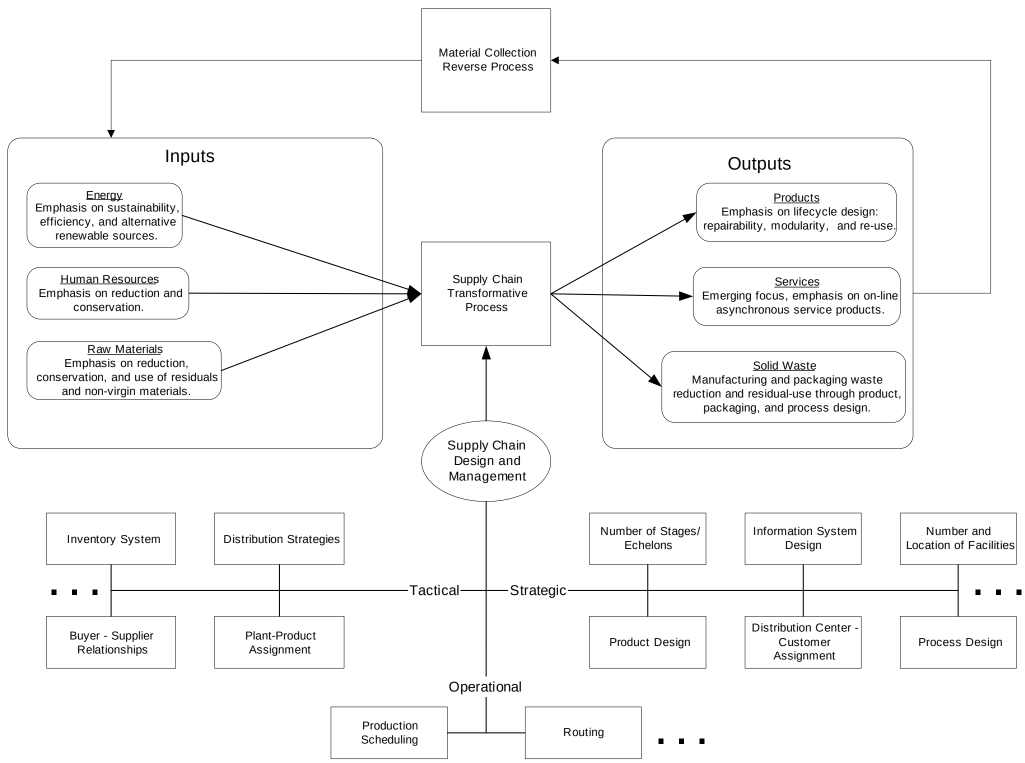
5. Supply Chain Design, Management, and Integration

The emerging challenges for designing the supply chain are accompanied by unprecedented levels of information technology. These new technologies and practices will give rise to significant opportunities in supply chain communication and, therefore, supply chain management and integration. The supply chain of the future will be challenged on all fronts. All aspects of the chain will have new considerations that will likely change the way we view supply chain management. Future supply chains will still need to identify a supply chain strategy that provides direction on how the chain will compete (Chopra and Meindl, 2007). However, the environment in which these chains will operate will change, thereby affecting the strategies, tactics, and operations that support the overall supply chain strategy. The supply chain operates within a dynamic environment comprised of a set of supply chain objectives, an overall supply chain strategy (that must adapt to a changing market), and a performance measurement system (that measures the extent to which the objectives are met). The relationships among the various supply chain design elements and the transformative process of the physical supply chain are shown in Figure 3. Strategic, or long-term decisions, include decisions related to supply chain structure. Tactical, or medium-term decisions, bridge the gap between the structural supply chain decisions and the day-to-day, operational decisions.

5.1 Supply Chain Design and Management

Sections 2 and 3 described emerging and future issues in supply chain inputs and outputs, respectively. This sub-section describes emerging and future issues in supply chain design (strategic

Figure 3. Supply Chain Design and Integration



and tactical) and management (tactical and operational). Important future research in supply chain management will mirror the challenges to practitioners. In particular, practitioners will be looking for new ways to maximize profit while minimizing resource use and the lifecycle environmental impact of their products and services. Research will be focused on incorporating all new aspects of the supply delivery problem, and designing resilient, collaborative, residual-based, closed-loop systems to accomplish these goals.

5.1.1 Strategic Decision-Making

Due to the anticipated increases in transportation costs, supply chain structures of the future are likely to become more decentralized. Future supply chains will emphasize local manufacturing capability and short transportation links. Thus, future storage and distribution systems will tend to move away from centralization (in which production occurs in a distant location, goods are shipped to a central DC, and distributed to many demand points) and towards decentralization. While in a typical modern supply chain, decentralized storage tends to increase inbound transportation costs, building local manufacturing capacity may become more cost effective than centralizing storage, given recent and projected increases in fuel costs.

Product and process design will be critical in reducing resource use. As described in Section 3.1, products will be designed from a life cycle perspective. So, all material and energy inputs and outputs will be considered from the point of raw material extraction through the end of product life. Efficient production will take on new cost dimensions that include material extraction, raw material cost, energy use in manufacturing, disposal fees, collection costs, compliance costs, and all other costs associated with the product's entire lifecycle.

5.1.2 Tactical Decision-Making

Along these lines, we are also beginning to see, with increased frequency, organizations sharing transportation and storage capacities to improve efficiency. Emerging distribution systems will be focused on decentralized production/distribution sub-systems whenever possible, and then on economies of scale, emphasizing fewer deliveries and shared resources in cases where a more centralized system is necessary. As tactical decisions enable operations to achieve strategic goals, new analytical models and techniques for these systems will need to incorporate the strategic, tactical, and operational implications of key trade-offs to achieve the best balance between resource use (efficiency) and distribution speed (effectiveness). These tradeoffs will become more complicated when considering sustainability. Government/public pressures and material costs will likely lead future supply chains to incorporate new functions into their production and distribution systems that support closed loop systems, including material collection, residuals (outputs fueling inputs), and renewable energy and materials.

5.1.3 Operational Decision-Making

Supply chain operations enable the supply chain to execute its tactical objectives en route to achieving strategic goals. As energy and resources become more constrained, the day-to-day operations of the supply chain will likely move more towards efficiency on the agility-efficiency spectrum. If supply chains become more decentralized, as described above, transportation lot sizes from individual facilities would decrease. Coupled with rising fuel costs, the operational reaction would be to either consolidate by sharing transportation capacities with other small-lot facilities or by incorporating transportation milk runs to increase carrier density.

5.2 Supply Chain Integration

Globalization, outsourcing, and advances in communication technology have enabled the supply chain to be more connected than ever before. This sub-section describes trends in business-to-business (B2B) relationships, business-to-customer (B2C) relationships, customer-to-customer (C2C) relationships, and the emergence of the Open Source Movement.

5.2.1 B2B, B2C, and C2C Relationships

Globalization and outsourcing also play crucial roles in service-based and product-based supply chain integration, in particular, B2B and B2C relationships. For many years, information technology (IT) services have been outsourced. For example, Procter & Gamble has outsourced IT, human resources, and office management (Engardio, 2006). Recently, Royal Dutch Shell has outsourced its technology and telecommunications infrastructure in a deal reportedly worth $4 billion (Perelman, 2008). The list of outsourcing examples goes on and on, including automobile companies, such as BMW, that are currently outsourcing the design of entire product lines, to pharmaceutical companies forming international partnerships for research and clinical testing (Engardio, 2006).

As the price of fuel continues to increase, firms are engaging in collaborative methods to reduce transportation costs. Supply chains of the future will focus on developing creative ways to collaborate vertically and horizontally to increase supply capacity and improve efficiency. Standard communication protocols facilitate this collaboration and will likely continue to do so in the future. Currently, electronic data interchange (EDI) allows automatic standardized computer-to-computer communication, replacing the need for paper documents that would otherwise execute the same function (United States Department of Commerce, 1996).

The Internet has provided new ways for companies to communicate with their customers. A web presence not only is a means for marketing a firm's existence, it also allows organizations to quickly inform customers of their mission, products, contact information, and history. Of course, online ordering has also opened up new markets for countless firms and has allowed customers to shop without the constraints of transportation and business hours; customers can order products from the comfort of their homes 24 hours a day, seven days a week. The Internet also provides two-way communication between customers and businesses via email or live text chat. Customers can also post online product reviews and testimonials. These new methods for communication have changed and will continue to change the way that supply chains operate, from the importance of web-based marketing and B2C communication protocols, to re-designing the supply chain structure to include new distribution channels for web-based ordering. One of the current limitations of e-commerce is that customers cannot experience a product in the same way that they might if shopping at a traditional brick-and-mortar store. However, new technologies may provide such possibilities through digital touch, smell, and taste. We are already also seeing the use of "virtual models" by clothing manufacturers to allow customers to "try on" clothing in a virtual environment.

Communication among customers has improved dramatically through the Internet. Product review websites, such as consumersearch.com and epinions.com provide customers with on-demand reviews of hundreds of products. Customers are also able to communicate with one another through companies' own websites by posting reviews of products they have purchased. The emergence of the blogosphere has also provided a connected community (and therefore a forum) for anyone with an Internet connection to communicate with others (and/or other consumers) in unprecedented ways. These types of communication have provided new avenues for supply chains to gain information about potential consumers, and use this information in product design, customer service, and marketing.

5.2.2 The Open Source Movement

Open sourcing, which is applicable to B2B, B2C, and C2C relationships, is a collaborative philosophy that allows people to contribute to and share online products and information. A common application of open sourcing is software. Open source software allows registered users to modify (with the goal of improving) software code (a moderator is assigned to ensure the validity of the changes) that benefits all. The idea is that the more people who lend their expertise and experience to a problem (in this case, developing software), the better the software will be. Because the software is open source, it is free and available to everyone, thereby maximizing its proliferation. All individual modifications are not necessarily incorporated, and if they are not, the contributor is free to start their own version. Open source software development builds bridges across communities while producing a product that is highly functional and meets the needs of many. An excellent example of open-source software is the Linux operating system. Originally developed in 1991, Linux (or more specifically, the Linux kernel) has been modified many times since then, and many versions of the software are available online (Linux Online, Inc., 2007).

Open sourcing has also made its way to other domains. Perhaps the most famous of all open source applications is Wikipedia, the online public domain encyclopedia. Wikipedia is written by volunteers around the world and provides information on many topics in at least 16 different languages. Although its factual accuracy has been challenged on many occasions, Wikipedia uses a combination of volunteer oversight, software, and its own editors to help correct errors (Wikipedia, 2008). The new Journal of which this article is a part, *Operations and Supply Chain Management*, is open source. The Journal is free and available to anyone via the Internet.

The open source movement could have a substantial effect on the supply chain of the future. Beyond basic information that can be widely shared and used by many industries, widely available software/information systems that perform common business functions could be potentially useful. The stability and interoperability of such products could further improve communication and opportunities for collaboration. Furthermore, open sourcing has the potential to develop and distribute supply chain management solutions more rapidly and effectively than traditional information and software product pathways.

Of course, a potential hurdle to the proliferation of open source supply chain management solutions is the basic business need for profit-making on such information and solutions. However, the spirit of open sourcing in supply chain management would be to move at least some aspects of business away from strict competition and towards collaboration with the understanding that everyone could and would benefit in the long run (by being able to do more with fewer resources) using the new collaborative tools and information. In cases where the competitive hurdle cannot be overcome, there are still opportunities for supply chain managers to take advantage of limited open source models for supply chain partners. Such models would allow relatively small business communities to collaborate on limited open-source projects, such as software and information. These projects would still retain some of the spirit of the open-source movement, by allowing participants to share and modify content, but they would differ in the sense that the participants would be limited to specific supply chain partners.

5.3 Implications for Research

New research in supply chain design and analysis will reflect the new environment in which supply chains will operate. For example, quantitative models for supply chain design will need to address the energy, cost, and sustainability trade-offs described above, as well as closed-loop resource use (outputs as inputs). Although the new supply chain environment will be highly uncertain, existing and emerging communication technologies will ease this uncertainty somewhat by allowing for real-time data availability. Therefore, the analytical tools required to model systems within this new environment will also differ. New agent-based techniques that allow real-time decision making in a stochastic operational environment will more accurately reflect these new and emerging supply chain systems. Finally, as we have seen, the emerging supply chain environment is becoming increasingly global, touching on a wide range of geographical, political, social, and even philosophical issues. Therefore, new research in supply chain management will become increasingly multi-disciplinary. Quantitative models will no longer be constructed in a vacuum. New models will need to be built and analyzed within the context of an increasingly complex environment requiring the talents and expertise of a wide range of individuals.

6. Conclusions

A common theme in our discussion of the future of supply chain management is energy: what will be the new sources, will the new sources be scalable and adequate, can we bridge the energy gap by conserving fossil-based sources until then, and how will all of this affect our ability to supply goods and services to a growing population? Of course, no one knows for certain the answers to these questions, but in our discussion, we examined the indicators and trends, and began to suggest emerging impacts. In the midst of energy and resource supply uncertainty, we also identified unprecedented opportunities provided by dramatic improvements in communication technology, in particular. Emerging technologies imply a future in which we will have the ability to collaborate on levels never before available. Future supply chains will be challenged to leverage these technologies to improve efficiency in resource use, material storage, material movement, and product design. Moreover, all supply chains of the future will likely focus their efforts on achieving success through process improvement and collaboration on strategic, tactical, and operational levels.

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