Centre for Supply Chain Management
Project Report
Impact of Emerging Technologies on the Management of Future Supply Chains

Energy Efficiency and Sustainability

Research Project Report
Centre for Supply Chain management (CSCM)
The University of Auckland Business School
6/10/2008

ABSTRACT
As crude oil price has increased almost three fold between 2001 and 2008, organisations are faced with increasing operating costs. In order to sustain their operations, organisations look for alternative energy to fuel their businesses. Biofuel has been the popular alternative. This report discusses biofuel innovations that are much improved and cost effective to produce. While progress is being made to improve biofuel, organisations are beginning to look to improve their operations in terms of more energy efficient management of their supply chains. This report finds the following areas to be the first to achieve energy efficiency in New Zealand (NZ): high density storage area, order replenishment, container management, and farming machinery. In the supply chain area, customised applications incorporating the co-existence of data capture technologies will evolve. The emerging technologies for data input and other management applications are voice, touch, and display technologies. In the energy area, wind and solar innovations will continue to evolve, while around the globe interest is increasing in the use of biomass as an alternative energy source. As a result, there will be more fusion or hybrid innovations in the use of renewable energy.

Keywords: automatic identification and data capture, automatic storing and retrieving system, cold chain, energy, optical character recognition, sustainability, waste management

INTRODUCTION
The Centre for Supply Chain Management has undertaken a research project focused on the impact of emerging or future technologies — both hardware and software — on the management and operation of the physical supply chain, and on the information management of that supply chain.

The initial approach was two pronged:

1) The cataloguing of the existing state of the art in technology applicable to managing and operating supply chains and the extrapolation of those technologies into the future.
2) The search for, and identification of, emerging technologies that might be applicable to the management and operation of future supply chains.

With the increasing fuel prices, energy utilisation is becoming a major concern for businesses around the world. Therefore, this report will discuss the emerging technologies for energy efficiency and sustainability. The main driver of efficiencies in energy use is the increasing cost of fuel caused by the recent surge in oil prices. Logistics and transportation costs are still a significant cost for most businesses. Some firms seek to improve their ‘green’ image by using less energy or fossil fuels to improve the public perception of their company. The topic of sustainability in supply chains is a critical and timely topic (Jayaraman et al., 2007) and deserves special attention especially in the light of the unique dynamics of supply chains in New Zealand (NZ). For example, the New Zealand Institute points out that there is a potential need to reduce emissions significantly in the future and that NZ should begin now by reducing its emissions (The New Zealand Institute, 2007). The pressure to focus on the sustainability of supply chains is especially true for global market products (Brent, 2002).
RESEARCH OBJECTIVES

1) To identify which technologies might change dramatically in the next ten years.
2) To determine how those changes might affect the design of supply chains in the future.
3) To propose specific future supply chain designs that might be appropriate for major New Zealand industries over the next decade.

EXPECTED OUTCOME

1) Report on existing technologies and their roles in the future
2) Report on specific and/or emerging technologies and their roles in the future
3) Impact of these technologies on supply chains – two to three scenarios

RESEARCH METHODOLOGY

An exploratory study was carried out to identify potential technologies using online research as the primary method. There were three purposes of the online research. First, the purpose was to find out existing and emerging technologies used in NZ. Second, companies related to the technologies were identified and interviewed. Third, the research was expanded to the global context where technologies used in other parts of the world were investigated for this report (see Figure 1). Representatives from a total of 13 organisations in NZ were interviewed. The representatives were from various functional areas such as: logistics operations, consumer products, waste management, cold chain solution providers, manufacturing and engineering, and industrial automation. The interviews were carried out for a duration ranging from 45 minutes to two hours. Apart from the interviews, information about the organisations was collected from their web sites. A special focus was given to the role of energy efficiency while using these technologies.

There are five main research areas (Figure 2) in this study:

1) The Information & Communication Technology area. The aim is to study how automatic identification and data capture (AIDC) technologies are utilised for supply chain management.
2) The Fuel and Energy area. The aim is to find out the innovations of renewable energy and the alternatives to crude oil.
3) The Innovative Warehousing area. The aim is to study how organisations are utilising warehouse space and conserving energy.
4) The Cold Chain area. The aim is to explore how technologies can help improve cold chain management in order to be sustainable.
5) The Waste Management area. The aim is to find out how organisations manage effluent for environmental and sustainability concerns.

RESEARCH SIGNIFICANCE

This report provides information on the emerging technologies encompassing these five areas. The information is aimed at helping organisations in
identifying areas in which the technologies can be applied to improve their operations and, most importantly, to achieve energy efficiency. The research areas are specifically selected because (1) they fit into NZ’s geographical landscape, (2) primary production is a major industry in NZ, and (3) NZ has a small labour market.

With a relatively large landscape and a small labour population, NZ companies have to operate with increasing transportation and labour costs. Although there is an abundance of land, organisations are faced with limited space for growth in terms of warehouse footprint. Expansion is constrained by the lack of availability of land for commercial use, and the challenges for NZ infrastructure to connect to her major ports. As NZ is a major primary production nation, most of NZ exports require temperature controlled freight forwarding. Products such as milk, kiwifruit, wine and cheese, require a cool environment whilst in transit to the international markets. As the world’s most remote developed country, it is critical for NZ to invest in energy efficiency and sustainability.

This report is organised as follows: The next section explains sustainability and its significance to NZ. The sections that follow discuss the findings of the research. The technologies and innovations are best examined by grouping them into five sections accordingly to the research areas. Each research area is discussed in terms of current and future technologies, and their impact on supply chains. In the closing of the report, the emerging technologies are discussed using supply chain scenarios. Three scenarios are described: the impact of data driven supply chains, the impact of energy driven supply chains, and the impact of virtual supply chains. The technologies are evaluated in terms of time savings, quality improvement, and cost reduction, across the various supply chain functions. Due to the confidentiality of some of the technologies, the evaluation results are not included in this report. They are available upon sending a request to the Centre for Supply Chain Management.

**SUSTAINABILITY**

The term sustainability is difficult to grasp as it encompasses different shareholders and processes. This concept can essentially be split into sustainability for the environment, for society, and for the business (McIntyre, 2007). The following definition of sustainable development clarifies this issue further:

- Social progress which recognises the needs of everyone
- Effective protection of the environment
- Prudent use of natural resources
- Maintenance of high and stable levels of economic growth and employment

From this definition, it can be concluded that the concept of sustainable development involves environmental, societal and economical issues, which are highly interdependent. For example, on the one hand, high economic growth cannot be achieved in the long run without protection of environmental and social needs. On the other hand, economic progress should not be sacrificed for altruistic environmental or worker rights protection. A balanced approach must be taken for long term viability of a business model. A business can only be sustainable if shareholders, suppliers, employees, and customers see a future in it (McIntyre, 2007).

Decision makers concerned with supply chain design or management have to consider the impact of their decisions on the quality of life, safety, health, and welfare of the public in order to act in an ethical manner. This can be extended to the requirement of environmental friendly conduct of business (World Federation of Engineering Organisations, 2000). 

Beamon (2005) points out that there is a gap in the supply chain research when it comes to the effects of decision on present and future ecosystems. It is also not clear what constitutes an appropriate balance between individual tastes, the rights of others and the collective good (Woodhouse, 2001). The interaction of sustainability and supply chains is a new critical step in examining operations and sustainability (Kleindorfer, Singhal, & Van Wassenhove, 2005). It is a pressing research topic which broadens the boundaries of sustainability adoption and development. In addition, sustainability focus is widened as supply chains incorporate product flow from the production

---

1 Source: Manchester Metropolitan University (http://www.ace.mmu.ac.uk/esd/Action/UK_Strategy.htm l)
through to the delivery process to the end customer, compared to a solely localised view on one particular company (Jayaraman, Klassen, & Linton, 2007).

The concept of sustainability governs the way businesses function in many aspects. The more recent developments in climate change are forcing a global change to a more sustainable business practice (Svensson, 2007). This will lead to the implementation of strategies for reducing the environmental impact of a company’s products and services. It therefore also has an impact on all business functions that are involved in the supply chain.

Suppliers are often forced to comply with environmental standards which are mainly driven by customer pressure (Hall, 2000). Business customers often demand compliance to environmental management systems (EMS) to improve their own environmental and social performance. Such demands can apply significant pressures on companies to adopt more sustainable operations. Several research studies suggest that organisations adopting EMS also implement greener supply chain practices more frequently (Darnall, Jolley, & Handfield, 2008). In production or manufacturing, the focus for more sustainable development is generally on supporting resource efficiency, as a very significant amount of today’s production output is actually waste (Senge, Carstedt, & Porter, 2001). Studies have shown that ecological damage can indeed be minimised by designing all production stages in an environmentally sustainable way (Lye, Lee, & Khoo, 2001). Cooperation upstream and downstream through a supply chain can therefore improve environmental performance for the whole supply chain and not just a single company (Zhu & Sarkis, 2006).

NZ has a reputation for her high quality food products. Due to NZ’s low population density and its remote location, many products can be grown or produced in an environmentally friendly manner. One example is the high standard aquaculture products which are exported fresh to overseas markets. Such ‘live’ products generally have to be transported via air-freight to ensure freshness of the product. This has been identified as a less environment friendly transportation method. A similar issue arises when looking at agriculture products, especially those produced for overseas markets. Agricultural products generally enjoy a reputation for being both high quality and ‘green’. This offers a great opportunity for NZ businesses considering that 15 percent of US customers routinely pay more for green products (Ginsberg & Bloom, 2004). However, considering the remoteness of New Zealand, all of these agricultural products require a substantial amount of food miles before they reach their final destinations. Thus, overall, it can be concluded that there are opposing forces at play here. NZ products are marketed as being naturally produced, thus sustainable, but require more travel distance to reach their final markets.

Transportation and storage contribute significantly to the overall sustainability of a supply chain. While freight rates are gradually increasing, the development in the carbon footprint issue will add further woes to the logistics and transportation industry. Most NZ made products are reasonably low value goods, are heavy, and have to travel long distances to their final markets (Skilling, 2007). This may become increasingly unsustainable in the future and the need for repositioning NZ business strategy may arise.

Our research also finds that there is no leading edge technology within NZ businesses. Most of the interviewed organisations are either studying their overseas counterparts or implementing technologies as part of their regional initiatives. Therefore it makes sense to extend our research to the global context.

It is thus timely that this report offers information on the emerging technologies and trends in supply chain management. The five research areas cover most of the important aspects in a supply chain. The following sections discuss the research findings in those areas.

INFORMATION & COMMUNICATION TECHNOLOGY
This section on information and communication technology is dedicated to Automatic Identification and Data Capture (AIDC) technologies. The recent developments in Radio Frequency Identification (RFID) and Optical Character Recognition (OCR) deserve to be reviewed for potential application in
supply chain management. AIDC technologies identify objects using some form of coding system. The coding systems represent information about an object that is used to identify it. The common AIDC technologies are barcode, OCR, biometric, magnetic stripe, smart card, and radio frequency identification (RFID). This section also looks at sensor technology and global positioning systems (GPS) application.

Barcode and RFID are used in the supply chains for identifying and tracking items. Biometric, magnetic stripe and smart card are used primarily in the banking and security industry. OCR was not widely used in the supply chain until recently. It was in fact introduced in the 1960s, almost twenty years after the emergence of barcodes. In OCR special characters that are legible to both humans and machines are used to present a series of unique codes. OCR is also used in the banking industry, production, and service and administrative fields (Finkenzeller, 2003). With the advancement in imaging, OCR is a reinvented technology in the field of image and data capturing. The photography sector is leading this technology by utilising the digital camera; for example, face recognition technology can now be applied.

GPS systems use the satellite positioning grids to pinpoint a location’s latitude and longitude mapping coordinates. GPS applications are integrated with Geographical Information System (GIS) applications to provide positions in a more meaningful representation – GIS provides the relevance of the coordinates that GPS systems provide. Incorporating GPS into a GIS solution means that real-time positioning data (for example the location of a truck or courier) can be mapped along with the optimum routes available. Consequently, GPS applications provide visibility for the containers and the products that are onboard. Thus the exact arrival times of containers at a port can be predicted, and the required arrangements related to documentation at the port can be made just in time.

**Telematic Solutions** GPS units now also provide integration with telemetry data such as speed, temperature, humidity etc. Some of the Telematic Solutions include temperature recording (also referred to as data logging), vehicle tracking, fleet management, and dispatch and load management, to name a few. In temperature monitoring solutions, sensors, such as RFID tags, are installed on the trailers/containers and coupled with temperature monitoring systems. Thus the vehicle temperature can be monitored. The sensing is not limited to temperature. Various sensors can be deployed to monitor door opening frequency, time period the door is left opened, change to humidity inside the truck, the weight of the truck, and liquid level in liquid transport vehicles. Recently, a local NZ company was awarded a contract to provide a major freight forwarding company in the U.S. with a telemetry monitoring device (Smith, 2008). Besides offering the ability to track assets, the system tracks tampering, detects hook and drop hook events, and also provides mileage information for maintenance purposes. The system also optionally supports digital inputs which can be used for monitoring the status of door switches, lamps, or other digital sensing equipment.

In terms of labour efficiency, these identification systems provide information such as who is driving which vehicle. The technology provides important information such as driver work hours, vehicle driven history, distance travelled, etc. There is a gradual trend toward devices that send the vehicle information through the General Packet Radio Service (GPRS) networks.

The usage of GPS systems was largely related to the tracking of vehicles and fleet management. For the tracking of products at warehouse level, i.e., tracing the products at various stages in the production cycle, various other technologies, such as RFID and barcodes, are available. The product details on the RFID tag are transmitted to a reader whenever the product crosses a boundary or ‘gate’ – say when the product leaves the factory dispatch dock or is moved through a warehouse door. Rather than the barcode needing to be manually scanned, the product data is automatically gathered at ‘gate in’ or ‘gate out’. The uptake of RFID in NZ has been slow. In the present research study, the discussions with the participants also revealed that RFID technology, though technologically superior to the other AIDC technologies, is more costly and hence the industrial adoption will take time. There are technological solutions based on the co-existence of AIDC technologies that are in use in NZ. The Indoor
Positioning System that tracks the activities of vehicles such as forklifts within the warehouse is one such solution. The solution includes a server and software which displays in a CAD drawing format the warehouse layout with illustrations of forklifts or other indoor vehicles that move in real-time. This system is constantly recording and gathering data such as distance travelled without a load, the amount of downtime for each vehicle and when and where impacts have occurred, for auditing and analysing. A company in NZ is able to achieve the above by using a patented OCR reader called Sky-I\(^2\). The OCR reader is mounted on the top of the vehicle and pointed towards the ceiling where 2D barcodes, Sky-Markers, are positioned in grids. This tracking solution can determine the position, speed and direction of vehicles by references to the Sky-Markers.

The Sky-I optical reader is connected to a vehicle mounted mobile computer via any form of a wireless network. This technology can be combined with RFID readers mounted on forklift load backrests and RFID labels on pallets to track the position of pallets. The RFID tagged pallet can be traced to its exact location. An example of a monitoring system is the tracking of kiwifruit trays at EastPack\(^3\) pack houses.

In the monitoring user interface, the current display technology is based on 2D display. To improve visual recognition and management of a high density storage space, 3D graphic display of the storage space, a warehouse or a container, will enable a more efficient use of the space. It is especially beneficial in the freight industry to know the volumetric information. It helps to manage freight costs, loading plan and loading time, and effective resource allocation.

Sensors play an important role in the integration of various technologies such as GPS, RFID, OCR, and barcode. The use of sensors in tracking pallets at the production floor is now well established. Sensors form the basic detection technology in an automated supply chain. Some of the sensor types are discussed below:

- Photoelectric Sensors: Detection device based on the amount of light reflected from an object.
- Displacement Sensor: Used primarily for Dimension inspection of an object.
- Vision Sensor: Camera based sensing device. As robot based automation increases, the vision sensors become more important.
- Digital fine Scope: More sophisticated digital version of the vision sensors.
- Safety Sensors: Used primarily to ensure safety in the supply chain.
- Proximity Sensors: Used to detect the presence of an object using electromagnetic induction or capacitance principle. Used to detect the metallic and non metallic objects.
- Photomicrosensor/slot sensor: Miniature sensors used in automated vehicle devices to detect the position of vehicles
- Rotory Encoder Sensors: Indispensable part of robotic devices.
- Ultrasonic sensors: Sound based sensors used where photo electric sensors cannot be used. They are used for sensing liquid levels and clear objects.
- Pressure Sensors: They convert pressure into electrical signals and use an LED display.

**FUEL AND ENERGY**

The future sustainability of organisations, countries, and mankind is dependent on the availability of fuel which generates energy that provides us with heating, lighting, and the ability to operate man-made innovations. This has become such an important issue that governments around the world are collaborating in an effort to reverse global warming. In this section, the developments in biofuel and efficient use of fuel are discussed.

---


\(^3\) A NZ kiwifruit grower.
The NZ government spelled out its plan to move NZ to become a carbon neutral country in the New Zealand Energy Efficiency and Conservation Strategy (EECS) 2007. Of particular interest here is their vision for NZ businesses. The objective of the conservation strategy is for NZ to use more renewable energy and to emit less carbon dioxide (EECA, 2007). The government presented initiatives and programs towards achieving the goal of 90 percent of electricity generated from renewable sources by 2025. Examples of the initiatives are: direct assisting of businesses in energy conservation projects, encouraging best practices, teaching and training in energy efficiency, and implementing a building energy rating scheme. The programs include Energy Intensive Business where capital grants are allotted to energy intensive businesses and Emprove, where energy audits and action plans are designed to help businesses become more energy efficient.

Two key areas of research and work in this field are the development of biofuel and the improvement of efficiency in fuel use.

Figure 3. Pictorial Representation of Main Energy Conservation Areas (Source: EECA, 2007)

**Development of Biofuel**

There have been multiple research projects, even in a country the size of NZ, which have sought to end the reliance on petroleum based products. Early attempts were made by the NZ government in the mid 1980’s to convince motorists to convert to CNG or LPG use in their motor vehicles. (Approximately 50,000 used LPG during the peak period. In the early 2000’s LPG was being used by approximately 10,000 vehicles.⁴)

---

Converting a motor vehicle to use LPG requires significant adjustment to the existing vehicle. In contrast biofuel should be used in the place of petroleum based fuels. This means that it is a substitute and requires no extra effort on the part of the motorists.

While there has always been extensive interest in their use, biofuel initiatives are often impractical to implement on a large scale. The existing infrastructure is currently set up for a liquid fuel. Indeed, for biofuel to replace petroleum fuels it must be liquid in order to provide a high energy density, be readily transportable, and be able to utilise existing distribution infrastructure with minor conversion required. However it is possible to provide a mix of ethanol (derived from a bio-mass source) and petroleum fuels. This form of biofuel has recently been introduced to the NZ market by Gull. Their Gull Force 10 product is a mix of 10% bio-ethanol and high octane gasoline.\(^5\)

In the history of such biofuel there have been three key phases in the research and development. The first generation utilised existing and standard processes to extract useable material. Often the raw material is a food stock which could otherwise be used to feed people (hence wide-spread public criticism of the use of biofuel – it is perceived to draw food out from the human food chain!). In the case of seeds or grains, contents can be fermented to produce an ethanol for fuel use; sunflower seeds can be pressed to form a vegetable oil that can then be converted into a biodiesel.

The second generation of biofuel was developed while recognising the difficulties in using a raw material that could otherwise be used to feed people. As a result it uses ‘waste’ biomass from a variety of food crop sources. Examples of biomass are wood pellets, firewood, wood chips, plants, and animal matters. Biomass is used to produce biofuel in gas or liquid form. Investigation into non-food crop sources continues, however these processes have proven to be more difficult to implement.

A third generation is based on producing a biofuel from algae. This appears to be a promising approach as the energy output is higher than other types of biofuel for the amount of land used (Hartman, 2008). Algae are believed to produce more energy per gross energy requirement (GER) compared to other living biomass, such as corn. Therefore less land is required to grow algae. Algae are also easier and faster to grow than other plants for biofuel.

In the aviation industry, biofuel is already in use. This is largely due to the recent surge in crude oil price which has forced airlines to expedite alternative fuel. The aviation industry would also be the first to use biofuel made from algae.

In other countries, there is research into using animal waste, such as poultry litter, mixed with woody biomass to produce alternative energy.

The biggest drawbacks to biofuel approaches are:

- Diversion of food crops from the human food chain
- Existing infrastructure is designed to support distribution of petroleum based products
- Use of considerable amounts of land or other resources to support production
- High transportation costs due to bulky biomass

**Efficiency in Fuel Use** NZ has a high intensity of forests and rivers where biomass and geothermal energy sources, respectively, are readily available. In recent years, a more popular biofuel, ethanol, is produced from corn plant. Although such innovation is proven, it has been criticised for its sustainability in production. The ethanol produced is less than the gross energy requirement (GER). In other words, the production process requires more energy to produce a unit of ethanol. As NZ has many forests, the primary biomass could be the forestry residue, often referred to as ‘woody biomass’. The NZ government plans to replace the wood burners with biomass.

The revised EECS 2007 Act included the primary produce sector. Knowing that a number of farms are tenanted, the NZ government are assisting with on-farm energy costs and related emissions challenges. In other countries, there are examples of self-sufficient farms where the energy produced from farming residue is able to power their manufacturing

---

\(^5\) Source: Gull Petroleum website (http://www.gull.co.nz/html/fuel_products.htm)
processes. A good example is sugarcane energy farming. The crushed sugarcane residue, bagasse, is used to power the mill and factory operations. Using efficient machinery, the process is able to produce excess energy for production of by-products such as “chemicals, animal feed, ethanol, fibre board, and electricity” (Twidell, Weir, & Weir, 2006, p. 357). A NZ company is planning an organic power plant in which the owner is allowed to upgrade existing equipment over time to meet the changing needs of their business.

Some disadvantages of biomass are the bulky density, the competition with food production, and pollutant emissions from poorly controlled processes.

Geothermal technology uses heat from the earth to produce energy. At present, due to the higher risk and heavy engineering required to turn the geothermal resources to energy, this option is restricted to rural enterprises and local power grid.

Another renewable source is wind. Wind turbine technology has been around for decades. Recent developments in wind turbine technology have enabled it to be used in a much smaller scale – making it feasible to use in homes. A simple installation of wind turbine and a battery tank, which can power an average house for up to five days, is all that is required to supply power to a home in Waiuku, South Auckland. Beside the investment cost, the only operating cost is a few dollars on distilled water for the battery tank (EECA, 2007).

Solar power has been around for many years. The development in solar panel, or Photovoltaic (PV), has made it affordable for homes. Such applications are stand-alone, off-the-grid sources that provide electricity that can be more cost effective particularly for remote locations. In order to sustain the electricity supply, batteries are used to store excess power. In a recent development, PV systems are connected to the utility grid. This allows the excess power supply to be powered back to the utility grid and used only when the power supply from PV is low. In the US, power companies in many cases offer net metering where the excess power “spins the electricity meter backwards, effectively banking the electricity until it is needed and [provide] the customer with full retail value for all the electricity produced” (Kutscher, 2007, p. 59). Recognising the value of renewable energy, utility companies are moving away from centralised power generation to distributed power supply.

PV systems, which are man-made, require a wide, unobstructed area to receive direct sunlight energy. As a result, a system uses up valuable land which could otherwise be used for cultivation. This leads to the idea of creating solar islands. A solar island can exist on reclaimed land, or on a platform that floats in the ocean and turns according to the position of the sun. Thousands of solar panels are installed on the island to absorb direct sunlight. Energy convertors are used to convert the energy to electricity which is then powered to an inland station for distribution. In a more sophisticated technology, artificial trees are developed to mimic how plants absorb and reflect sunlight to overcome the need for direct sunlight exposure. The leaves of a tree are grown in such a manner that almost every leaf receives the sunlight. Leaves are translucent and therefore sunlight filters through them. They can also reflect sunlight so that surrounding leaves receive enough sunshine. The Solar Botanic Energy Systems⁶ use nanotechnology to allow tiny photovoltaic generators to be planted onto the artificial leaves (nanoleaves) where solar and heat energy are absorbed and converted to electricity. There are also plans to generate wind power from the same artificial tree. At present, there are 20 species of artificial tree designed in an undisclosed Middle Eastern location.

While there are increasing sources of renewable energy, the tools that leverage those sources provide a potential area for energy efficiency improvement. As noted earlier, efficient machinery allows more energy for the production of renewable by-product. Motors are used in the generation of energy. Energy efficient motors using variable speed and control devices are available in NZ to power machinery of various sizes. A new technology for supplying high voltage direct current (HVDC)⁷ uses an energy efficient motor to run wind turbines on an offshore site at Borkum, Germany. The energy produced by

⁶ Source: Artificial tree (http://www.solarbotanic.com)
the HVDC transmission technology can be used in mainland grids.

That the use of biofuel has been favoured ahead of other types of energy, such as electricity, may be due to the widely available infrastructure for petroleum and gas. The use of electricity to run motor vehicles and airplanes will be disruptive. Petrol stations will have to install power outlets, power generators, and airports will have to cater special charging units for docking airplanes. However, innovative use of electricity has some success stories. In the U.S., a cable link allows large ships in the sea port to draw power supply from the mainland grid instead of using diesel or coal engines while docked. This reduces the emission of carbon dioxide. In a NZ farm, a wind turbine is used to power a hydrogen production unit. The hydrogen produced is stored and used later to produce electricity when needed.

Beside the above mentioned energy alternatives, the NZ government is funding research into marine energy from tides and waves.

### INNOVATIVE WAREHOUSING

In this section, the research undertook to study how organisations are utilising warehouse space and conserving energy. At present, most warehouse operations are using basic warehouse management systems (WMS) to manage their inventory levels in the warehouse. Although this is integrated with the ordering systems to enhance visibility for warehouse planning, most WMS do not have the capability or flexibility to maximise the utilisation of storage locations. As a result, warehouse operations do not have full visibility of their inventory in stock. In NZ, some organisations are utilising third party applications to help optimise warehouse storage space. The application requires input such as product profile, warehouse layout, and order profile to determine the slottig sequence for each product. Although the application optimises product locations and pick-faces, integrating the application with existing WMS is still not seamless. The optimisation is as good as the data provided.

---

8 Source: High Voltage Shore Connection (http://www.abb.com).
9 Buildings contribute to 40 percent of the total carbon emissions. Source: Kutscher (2007).

Other forms of warehouse operations optimisation include the use of Optical Character Recognition (OCR) technology, smart entry methods, web communications, and a centralised data store. A logistics service provider in NZ has developed a WMS that utilises these technologies to improve inventory visibility, smarter picking, and allow supply chain members access to data online. Warehouse order picking applications that are gaining wider adoption in NZ use voice technology and pick-to-light systems.

The increasing labour cost and limiting warehouse space have been a growing concern in the warehousing or physical storage domain. Countries with limited land resources, while they can reclaim land through land-fill, are finding it difficult to expand their business operations horizontally in terms of space. In order to maintain a sustainable growth, organisations have to increase their capacity and/or turn-over rate of their holding stocks. A logical solution is high density storage, and the solution is to go vertical. To achieve this, machines are deployed to stack and retrieve products in the units of pallets and containers. Such devices are known as automatic storing and retrieving systems (ASRS).

When ASRS is implemented, direct replenishment planning can be integrated into the systems. Thus the ASRS is capable of replenishing the staging area where ‘loose’ orders are picked and packed. Two types of ASRS are identified. Both types of ASRS are fully automated.

The first type of ASRS is used in a warehouse environment for storing and retrieving pallets. This type of ASRS uses a moving crane to move pallets to their slots or locations. An advantage of ASRS is high density stacking. A 6,000 sqm storage floor area with nine high and double-deep pallet racks has a capacity of approximately 31,500 pallet locations. Besides operational efficiency, a huge advantage of ASRS is in energy savings. The storage area does not require lighting as it is fully automated.

The second type of ASRS is for stacking containers. An overhanging crane, known as the Automatic Stacking Crane Arrangements (ASC), may be used in
A sea port operation to stack and retrieve containers according to a computerised shipping plan. Current sea port operations may use straddle or container lifters to move containers. This type of vehicle is operated manually and the containers are stacked by precise manoeuvre of the straddle. The straddles can stack the containers to a ‘One over three’ level. Straddle operations provide an area where there will be technological intervention directed towards full automation. ASC technology is being considered as an advanced solution to the straddle based stacking. ASC is a crane based system. The fully automated cranes are installed at the designated locations at the port. The containers, once delivered to the port, are stacked using cranes. The crane uses a laser identification technology to detect the appropriate stacking levels. This detection can also be done using other AIDC technologies such as RFID or OCR. Some of the organisations that are using such a technology are Altenwerder (Germany), Kaohsiung, Oslo (Norway), Port of Antwerp (Belgium), Euromax, and Wan Hai Lines (Tokyo). Apart from the technologies related to Container Stacking, discussions reveal that a lot of new technologies will be available in the areas related to scanning the containers for security purposes. Certain containers at the port are required to be maintained at a particular temperature. Presently the tracking of a container’s temperature uses a modem based technology, i.e., containers are provided with a modem through which the temperature of the container is transmitted to a central repository. This can be done via a power cable. It is also expected that the technology will be available to track the container temperature at various stages of a supply chain.

For efficient port operations, efficiency in moving the containers with accuracy is of paramount importance. Thus, the container loading problem has attracted a lot of attention in the optimisation literature. It is amongst those mathematical problems referred to as the “hard” problems. Efficient container loading problems have two aspects: the mathematical and practical. From the mathematical point of view, the container loading problem is a difficult problem and the optimal solution is not easy to derive. Even if the optimal solution is achieved, it would not be easy to implement in most cases. The problem seeks to find the best arrangement for boxes to be loaded into the container while maximizing the capacity utilisation (and in some cases minimising the operation time). Apart from considering the size of the container, and required loading time for each container in each position (and therefore total loading time), a buffer space between containers should be considered for manoeuvre space for lift trucks and other material handling equipment. The container loading problem contains the classical knapsack problem, in which weight limitation forces the solution to include only certain combinations of the goods to be loaded. Container loading can be thought of as a 3D version of the knapsack problem (Bischoff, 2006) although in practice, when the 3D limitations are also taken into consideration, it is more complicated than that.

Although, for the container loading problem, many different factors have been taken into consideration, there are additional important issues that are essential in real-world requirements which have not attracted enough attention in the literature. These factors, as explained by Bischoff, make the container loading problem far more complicated and different from just an extension of the classical knapsack problem. Such real-world requirements include: orientation constraints, load bearing strength of the items, handling constraint, load stability, grouping of items, multidrop situations, shipment priorities, weight distribution within a container, etc. (Bischoff, 1995). The best algorithms and approaches for handling the container loading problem should be the ones that try to maximise the usage of the container capacity and at the same time address these factors based on a given situation. Many different heuristics and meta heuristics have been suggested for handling the container loading.
problem such as Genetic Algorithm, Tabu search, greedy heuristics etc. The container loading optimisation will see more heuristics computation as well as 3D modelling.

The stages preceding and succeeding the storing and retrieving processes are at present labour intensive. Forklifts and other material handling equipment are utilised to move pallets or cartons within the staging areas. A university is working on Inductive Power Transfer (IPT) technology to power such movers. Also known as Automatic Guided Vehicle (AGV), the technology does not require storage of power in the unit. The technology enables the unit to be powered by electric current either from a cable embedded on the floor, or wirelessly using a transmitter. The inducted power is converted into electricity that powers the unit. It is therefore carbon neutral and low maintenance. In some cases, the unit can be programmed to recharge itself.

In terms of energy efficiency, most newly built warehouses in NZ are specifically designed with roof skylights for natural light and remote operated shutter door to keep the inside temperature of the warehouse constant. Warehouse roofs are notorious for soaking up solar heat. While a facility’s ability to absorb heat might be advantageous for some facilities in the winter, a poorly insulated roof requires more energy to control the ambient temperature of the warehouse. With global warming, cool roof technologies that cut down on energy costs are a potential climate control technology for the warehouse. Cool roof systems have two critical properties: a high solar reflectance, which means they absorb less energy from the sun, and a high thermal emittance, which means they radiate a large percentage of the energy they absorbed back to the sky. Regardless of climate, cool roof technologies are highly beneficial for warehouses with refrigeration storage as these facilities demand consistent year-round cooling. Cool roofing technologies can improve energy efficiency for these facilities by five to ten percent. Dry storage warehouses that typically do not have refrigeration year round but still require a consistent temperature can still use cool roof technologies to control the temperature (otherwise known as a heat recovery system). In buildings with no air conditioning, cool roof systems make the building more comfortable for workers by regulating the air temperature. Since refrigeration and air conditioning are heavy drains on the power grid, cool roofing technologies can reduce peak demands and improve the load balancing on the utility grid.

As most warehouses in NZ are built on relatively flat and open land, they are exposed to solar heat during most of the day. Thus an alternative to insulation is putting the solar heat to good use by generating electricity such as photovoltaic as discussed earlier.

In a heating, ventilating, and air-conditioning (HVAC) environment about 30 to 50 percent of all air conditioning energy is used to remove moisture from incoming air. Using a desiccant wheel to dry the air before it enters the HVAC system is one way to improve energy efficiency. As the desiccant wheel spins, it absorbs moisture, drying the air before it enters the facility. Dry air is easier to cool than moist air. Oversized ceiling fans also help to reduce cooling bills, particularly in buildings prone to stratification, where hot air settles on top and cold air settles at the bottom. Ceiling fans, which can range from six to twenty feet in diameter, stir the air to keep the temperature even. At dock operations, dock shelters which enclose the entire back of a truck are more energy-efficient than roll-up dock doors, due to the reduction in outside air exchange

COLD CHAIN

This section on cold chain management looks at how organisations manage their products along their cold chains. Most of the technologies used in cold chain management are already discussed in the ICT section. They are primarily the AIDC and sensor technologies. Thus this section will focus on the machinery in maintaining the cold chains.

Thermometers used in cold chain management come in various forms. They vary in the type of sensory methods. There are infrared thermometer, thermocouple, and RFID tag, to name a few. Thermocouple is widely in use. It can convert thermal potential difference into electricity potential difference. The ability to control temperature is another primary monitoring application in cold chain. Computer systems regulate and alert a central monitoring centre of any cold chain breach. Software that changes the regulation method of a refrigerated
container (reefer) is claimed to save energy and reduce carbon emission\textsuperscript{10}. The main principle is to allow the air temperature to fluctuate by having the compressor stop and start, while ensuring that the average temperature equals the desired cargo temperature. This regulation method differs from the traditional method for chilled cargo where a constant temperature is maintained and the compressor is running even when no capacity is needed. Energy is conserved by giving downtime to the compressor.

Another method for controlling temperature is to insulate doors. Current technologies offer high speed freezer doors to minimise the air loss as a result of opening the door. Modern freezer doors are equipped with improved insulation and energy efficient mechanisms.

In the freight area, there are self-contained reefers that are capable of maintaining a certain temperature for up to 96 hours in year-round conditions. In the packaging area, well insulated isothermal or refrigerated storage boxes can now hold up to 96 hours at various temperatures. With advancement in materials, there is no need to use ice which may lead to accidental freezing of vaccines. Removing ice increases capacity.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{high_speed_freezer_door.png}
\caption{High Speed Automated Freezer Door}
\end{figure}

\begin{itemize}
\item Produces a sterile and pathogen free product that will comply with a Class ‘A’ biosolids regulation
\item Produces no offensive odour
\item Dries dewatered sludge to 90-95 percent solids content
\item Produces biosolids that are granular in nature and have been subjected to temperatures of 500-600\textdegree C
\item Provides options for a variety of beneficial disposal options such as fertiliser
\end{itemize}

Composting is an entirely natural biological process\textsuperscript{14}. However, it can be unpleasant, slow, and may even contain harmful bacteria. Composting is shifting from bottom-of-the-garden to an industrial sources to sustain the cold chains. One key source is solar energy. Battery-free solar refrigeration has been demonstrated in Indonesia and Senegal\textsuperscript{11}. With the need to track individual cartons for breach of cold chain, RFID will play a greater role in the future in cold chain management.

WASTE MANAGEMENT
Waste is an important source of energy and the environmental cost of not addressing this resource may be substantial. In this section, some new technologies for the management of waste which can be adopted for reuse, recycle, or to generate energy, are highlighted. The global trend in waste management is also discussed.

Thermal sludge drying\textsuperscript{12} is a process where the dewatered sludge from a waste water treatment plant is dried by heating. This produces a type of biomass which has greater than 90 percent solids content that can be reused as an organic fertilizer or soil conditioner. Thermal drying is a simple process. The high drying temperatures sterilise, deodorise, and change the nature of the sludge, making it acceptable for a wider range of end users. The benefit includes reduced bulk mass and odour.

In summary this method of waste treatment\textsuperscript{13}:

\begin{itemize}
\item Produces a sterile and pathogen free product that will comply with a Class ‘A’ biosolids regulation
\item Produces no offensive odour
\item Dries dewatered sludge to 90-95 percent solids content
\item Produces biosolids that are granular in nature and have been subjected to temperatures of 500-600\textdegree C
\item Provides options for a variety of beneficial disposal options such as fertiliser
\end{itemize}

\textsuperscript{10} QUEST software used in shipping line.

\textsuperscript{11} Source: PATH (http://www.path.org)
\textsuperscript{12} This technology is produced by Flo Dry Engineering, NZ.
\textsuperscript{13} Source: Flo-Dry Sludge Drying System (http://flo-dry.co.nz).
\textsuperscript{14} Source: HotRot Technology (http://www.hotrot.co.nz).
scale. This shift requires appropriate engineering and process control to ensure that composting is consistent. A new technology\textsuperscript{15} is an enclosed U-shaped vessel with a central axial shaft. The shaft is controlled by a central computer. Other considerations when mixing the compost, including the feed-rate of waste, retention time of material in the composter, and shaft rotation, are fully computerised. The unit contains temperature and other sensors that monitor the process. The unit is connected to the internet to enable remote control and maintenance.

Another composting alternative is digestion (anaerobic). It is a process carried out by bacteria in the absence of oxygen. The treatment process produces energy-rich biogas which can be used as a fuel. The process can be applied to a wide variety of solid and liquid organic wastes, including waste from food and beverage production (sugar, soft-drink, potato, vegetable, distillery and brewery wastes), from meat, dairy and wool processing, and waste from pharmaceutical and chemical industries. The advantages of digestion processes are: reduced sludge production and the ability to extract valuable fertilisers from the digested residue.

The conventional method of waste management is directing the waste to a sewage system. In recent developments, tools such as pumps, and extractors for drawing waste, have been made energy efficient and effective. Solar, wind, and other renewable sources are utilised in the operations of these tools.

\textit{Global trend in Waste management} Technology is moving fast in the waste-to-energy area with a number of new approaches or renewed technologies. Waste has a diversity of physical and chemical properties requiring matching energy conversion technologies. Moisture content and contamination levels are particularly important. Drier forms of waste are usually converted through the thermal energy conversion paths, while wet waste may be processed through biochemical pathways. Figure 6 illustrates the variety of pathways through which waste sources can be converted to energy or energy related products.

\textsuperscript{15} HotRot systems are manufactured and sold in Australia and NZ by RS Solutions Ltd.

Copper and cow dung are two of the materials that can be used to produce electricity. A US company\textsuperscript{16} is seeking to establish a production scheme in Bangladesh to generate electricity using an engine powered by methane biogas. The methane is produced from a bio-digester that converts cow manure and plant materials into both methane and fertilisers. In another plus for the environment, energy from biomass is a sustainable form of energy that does not have a greenhouse effect. Unlike fossil fuels, biogas from cow dung is considered carbon neutral, providing a green alternative to the billion tonnes of carbon dioxide that are emitted to the atmosphere each year. Through anaerobic digestion, in a process similar to the creation of compost, manure can be turned into energy-rich biogas, and standard micro-turbines can be used to produce electricity.

Figure 6. Pathways in which waste can be converted to energy products (Source: Australian Business Council for Sustainable Energy)

\textbf{FUTURE SUPPLY CHAIN TRENDS}

\textbf{Scenario 1 – Micro-Managed Macro Supply Chain}

A recent study on the proliferation of the use of RFID for supply chain management (RFID/SC) has suggested a series of changes in three stages (Soon & Gutierrez, 2008). The first stage is the immediate impact as companies hurried the adoption of RFID/SC to comply with mandates. The action creates challenges as it develops. The second stage ensues when the first tier suppliers have implemented the technology and begun to contemplate on the operational and tactical issues of sustaining the technology. At this level, managers are

\textsuperscript{16} Emergence BioEnergy Inc. is an award winning company exploring energy solutions for developing countries.
faced with integration issues. The third stage is the post RFID/SC challenge. The aftermath in the long run may have impact on the way the supply chain operates. Thus there is a need to address the changes. In NZ, most organisations are already looking at RFID and exploring various applications with other AIDC technologies. There is also no pressure from customers or major retailers to implement RFID/SC. Therefore, there is less impact from the first and second stages on NZ organisations. The third stage would have some effect on our future supply chains.

Since the announcement of the RFID/SC mandate by Wal-Mart and Metro, the supply chain industry has seen the largely unfamiliar RFID technology proliferate. This is the start of the first stage of the effects of the mandates. Suppliers rushed to comply with the mandates while learning about the technology. As the technology is developing, the sudden rush to comply with the mandate has increased the demand for its hardware, both the tags and the middleware. The industry is simply not prepared for the mandate and to meet the demand for hardware and software.

Moving on to the second stage, suppliers who have now implemented RFID/SC will start working at integrating the technology into their existing enterprise systems. In complying with the mandate’s deadline, suppliers might not have sufficient resources and knowledge to design a full integration of the technology and might only be ready to integrate at the WMS level. Vijayaraman and Osyk (2006) comment that most suppliers did not envisage a higher level of integration with their overall IT strategy and Kommareddi (2005) estimates that 90 per cent of retailers implementing RFID are not incorporating business intelligence infrastructure or analytical systems to analyse and synthesise the data captured by RFID. This means that the initial implementation will need to be reworked within the organisation to fully integrate all relevant information systems. Companies without a scalable network infrastructure will likely have to incur additional costs in redesigning the network to cater for additional hardware and data traffic capacity. On top of the impact on existing systems and infrastructure, business processes and values are also affected.

The Third Stage

New ways of supply chain operation start to emerge when RFID/SC is integrated into the enterprise systems. This is the beginning of the third stage of the mandate effect. Overtime, warehouse operations will define new approaches and configurations. As inventory turnover moves faster and products spend shorter time in storage, cross dock activity becomes more important (Twist, 2005). This has implications for the design of a warehouse. The proportion of storage and working areas may change. The design of storage racks may need new configurations to suit cross-dock activity. This in turn may affect the way material handling equipment is used. Newly won businesses are likely to take a longer implementation time given the added complexity of systems integration. Retailer and supplier relationship at this stage moves to a higher level of collaboration and there are likely to be more interactions between them. The interactions form a closer, long-term relationship that ties both parties to strive to make the relationship work. New players may find it difficult to enter the market. In the supplier-owned warehouse, cross-dock activity will become a major part of the warehouse operations. Thus, there is a need to redesign the warehouse layout taking into consideration material planning, production, and order configuration profiles. With micro-level information, organisations can identify inefficiency along their workflows. Workflow management will become a common application.

Scenario 2 – Renewable Energy Driven Supply Chain

With the surge in fuel prices and the concurrent shrinkage in oil resources, environmental issues related to effective energy utilization have gained importance in supply chain management. A 1993 study of Landliebe Yogurt revealed that the ingredients in a single container — including milk, strawberries, wheat, cultures, glass for the jar, paper for the label, and aluminium for the lid — had travelled a total of more than 9,100 kilometres (about 5,600 miles) before reaching the consumer’s hands. Some of the innovations of the next five years will focus on reducing this type of inefficiency. Marks and Spencer, for example, has a specific initiative under way to reduce “food miles,” sourcing its wares from nearby locales and working with local farmers to increase the growing season. Other initiatives will
increase transportation efficiencies: A truck that once carried 150 items will now carry 300, or carry the same volume of goods with less fuel. Other projects will reduce and simplify packaging, closely track the joules consumed, or switch to less carbon-intensive materials and energy sources (such as renewable energy and more efficient lighting sources)\(^\text{17}\). Discussions with one of the respondents indicated that there is a gradual shift toward logistics technologies that consume less power. Passive RFID tags (transponders) in this respect offer some advantage as a passive tag is powered by the radio frequency field generated by the reader. As far as energy is concerned, this has the obvious advantage that no battery is needed. This has an impact on lifetime and cost. The lifetime of a passive tag can be said to always be longer than the usage time (Nilsson, et al. 2007). Research reveals that there is a strong possibility of a breakthrough in large format lithium ion batteries, in terms of safety and cost. The introduction of lithium ion batteries, assuming sufficient sources of lithium, would lead to a monumental transformation of the energy economy. General Motors for example has seemingly made a definitive commitment to develop and commercialize the Chevrolet Volt with an on-board, rechargeable lithium ion battery, and driving range of over 600 miles.

There is a mass movement towards the use of alternative fuel such as biomass, particularly from the waste or animal matters source. The future supply chain will be energy efficient and self sufficient in terms of energy usage. Solar and wind power are potential renewable sources that can be introduced to supply chain management in the next five years. In the effort to reduce waste, the output or waste from a supply chain will be recycled as energy back to the supply chain. While there will be increased transportation, the density of the mass will reduce greatly as a result of better and innovative waste treatment.

**Scenario 3 – Monitored Warehouse Operations**

The development in robotic and telematic technologies is advancing towards a fully automated and monitored warehouse operation. Already, robots are used in manufacturing and to a certain extent for packaging products. The use of ASRS not only improves the utilisation of warehouse space, it saves on energy by switching the lights off. The future in robotic warehouse operations will be in the loose order picking and de-cartonising areas. AGV will see more deployment in the warehouse operations such as for moving pallets or cartons. Organisations are already keen to explore these areas to further improve their operations and order fulfilment.

GPS would likely continue to be wide spread in location-based applications. Within the warehouse, the use of indoor positioning systems will be popular with organisations wanting visibility of their operations in real-time. At the moment, the positioning is achieved with nodes or sensors strategically installed in grids. Ad-hoc indoor networks will leverage the development of wireless technologies to create a mesh of internet users, and provide cost effective and time saving positioning systems.

There will also be increasing use of sensor technology for monitoring events and data collection from environmental changes, such as temperature and humidity. It is likely that Input technology such as voice and touch technology will add efficiency to warehouse operations by enabling more interactive and accurate input. Warehouse operators will no longer be required to input information into the WMS using a keyboard. Instead, voice commands will be used to assist in order picking, and touch technology for confirmation of products and locations.

To a larger extent, the future supply chain will be more virtualised. Robotic and telematic information help create virtual inventory management where processes can be simulated and optimised before they happen. In the display technology, 3D graphical display of the operations will provide a different perspective to the organisation. 3D display facilitates the visualisation of the utilisation of the warehouse, making it easier to manage, particularly in a high density, non-symmetrical storage area.

This concludes the research that the research team undertook to investigate the future trends in supply

\(^\text{17}\) Source: http://www.strategy-business.com/resiliencereport/resilience/rr00049?pg=1
chain management. A pictorial of the scenarios are presented in Appendix A.

The research team would like to thank all participating organisations for their contributions. The research team would also like to thank the members of the Centre for Supply Chain Management that provided the opportunity to embark on such an interesting research project. Those members are Fonterra and NZ Trade and Enterprise.

RESEARCH TEAM
Project Manager: Gay Florence, Costain
Research Lead: Chin Boo, Soon
Research Member:
Andy Huat Bin, Ang  Christoph, Breidbach
Amira, Khattak  Laleh Ardekani, Haerian
Hendrik, Reefke  Aman Ullah, Muhammed
Henry Xiang, Shi  Ranjan, Vaidya
Lincoln, Wood

BIBLIOGRAPHY


Senge, P., Carstedt, G., & Porter, P. (2001). Innovating our way to the next industrial


Appendix A

Future Supply Chain Scenarios