Smart Freight: Applications of Information and Communications Technologies to Freight System Efficiency

Therese Langer and Shruti Vaidyanathan

July 2014

An ACEEE White Paper

529 14th Street NW, Suite 600, Washington, DC 20045

Phone: (202) 507-4000 • Twitter: @ACEEEDC

Facebook.com/myACEEE • www.aceee.org

Contents

Acknowledgments

The authors appreciate the support of our colleagues and ACEEE in preparing this paper. Neal Elliott, Susan Mazur-Stommen, Steve Nadel, and Ethan Rogers provided helpful comments and advice. The authors alone are responsible for the content of the paper.

We thank Fred Grossberg for his assistance in the publication process, Kate Hayes for copy editing, Roxanna Usher for proofreading, and Patrick Kiker for his help in launching the paper.

Abstract

Information and communications technology (ICT) can permit large energy savings in the freight transportation sector while improving speed, reliability, and security. Transportation and logistics professionals have been using ICT tools for decades, but the rapidly increasing sophistication of these technologies in the last few years has opened up energy savings opportunities far greater than those realized to date.

This paper discusses applications of ICT to save energy by improving the efficiency of freight vehicle operation, making better use of the freight network, and reducing ton-miles traveled without compromising business objectives. ICT brings the potential for effectively unlimited data collection, greatly enhanced predictive capabilities, and real-time, dynamic decision making and implementation. Together, these new capabilities could lead to a dramatically more efficient freight system based on completely visible and accessible physical and digital networks.

The paper describes the potential of ICT and provides examples of companies who are applying various ICT-based approaches to reduce fuel use and carbon emissions without sacrificing freight performance. It concludes by identifying barriers to more widespread adoption of ICT tools and offering recommendations to overcome those barriers.

Introduction

Energy efficiency is just one of many considerations influencing the freight-movement decisions of shippers and carriers. However it is an important consideration because fuel consumption has a major impact not only on the bottom line but also on environmental performance, a factor that is tied to corporate goals and image for an increasing number of companies. Yet the delivery of goods must also be reliable, fast, and secure, attributes that do not always line up with energy efficiency. For example, with the widespread practice of just-in-time delivery, goods are moved in smaller batches, and that tends to increase total fuel use. The demand for speedy and reliable delivery will not decline, even though cost may become a greater factor in times of high fuel prices or a poor economy. Consequently, to maximize energy efficiency, the freight sector must find ways to reduce fuel use while improving—or at least maintaining—speed, reliability, and security.

Enter intelligent efficiency. Earlier ACEEE reports (Elliott, Molina, and Trombley 2012, Rogers et al. 2013) have defined intelligent efficiency as the cost-effective application of information and communications technology (ICT) to save energy at the level of energy-consuming systems.[1] In the realm of freight movement and, more broadly, logistics, a wide range of ICT applications is already available, and these applications are often precisely what are needed to help align logistics priorities such as timeliness and reliability with energy efficiency. Many existing applications answer fundamental industry needs in the areas of data collection and analytics, real-time information, and both automated and human-mediated feedback and response. Now, a new generation of tools is emerging that could greatly increase the efficiency of the U.S. goods-movement system and greatly reduce energy consumption in the process.

This paper provides a quick tour of three types of ICT applications to freight movement:

- Applications that make the trucks themselves operate more efficiently
- Applications that advance efficient use of the transportation network
- Applications that reduce the need for miles traveled without compromising business needs

We give examples of these types of application in text boxes below. The bulk of the paper is devoted to the second type, though the first and third address important considerations as well.

Foster and Langer (2013) compare several estimates from the literature of potential energy savings and greenhouse gas reductions from freight-system efficiency measures. The authors argue that a supply-chain perspective enlarges the universe of potential savings within the transportation sector. They also go beyond the usual boundaries of freight

[1] Elliott et al. (2012) defined intelligent efficiency more specifically as "a systems-based, holistic approach to energy savings, enabled by information and communication technology and user access to real-time information. Intelligent efficiency differs from component energy efficiency in that it is adaptive, anticipatory, and networked."

transportation to include distribution issues and even, on occasion, manufacturing. This is consistent with the paper's clear implication that substituting an integrated supply-chain approach for a siloed transport/warehousing/manufacturing approach allows more efficiencies to emerge. Furthermore, ICT tools help eliminate these silos.

Discussions of supply-chain management and intelligence are often oriented toward global commerce. Global supply chains are typically extended and highly complex, and they may face data and communications challenges far greater than those experienced by domestic enterprises. Global trade also presents good opportunities for localized system-efficiency investments because of the enormous concentration of freight activity at international airport and seaport facilities. However, even the highly dispersed origins and destinations that domestic freight networks serve present opportunities for energy savings through intelligent efficiency.

One way to begin thinking systematically about the potential for freight energy efficiency is to express the energy used in a particular freight mode in terms of three factors:

- Average vehicle fuel efficiency
- Tons of freight per vehicle
- The distance the freight travels

Total freight energy use is then obtained by summing over all freight modes:

$$Freight\ energy\ use = \sum_{Freight\ modes} Energy\ use\ per\ vehicle\text{-}mile \cdot \frac{ton\text{-}miles}{ton\text{-}miles\ per\ vehicle\text{-}mile}$$

The ICT applications discussed below save fuel by taking on one or more factors on the right-hand side of this equation. That is, they:

- Improve vehicle fuel efficiency (reduce energy use per vehicle-mile)
- Improve load factor (increase ton-miles per vehicle-mile)
- Reduce ton-miles required to achieve a given business end
- Shift goods to a more efficient mode

This paper does not estimate the potential contributions of each of these factors to reducing freight-transport fuel use. We walk through emerging practices, trends, and ideas relating to the use of ICT to promote freight energy savings, and then we consider barriers to progress and make recommendations to address those barriers. In doing so, we invite further work in this area.

Improving the Efficiency of Vehicle Operation

Freight movement involves a complex system of infrastructure, goods, people, and locations. The use of ICT to improve freight efficiency begins at the vehicle level.

FREIGHT TRUCK MILES PER GALLON

Today's freight truck is a complex system that includes multiple computerized control subsystems governing the engine's fuel-injection timing, emissions control, turbocharger operation, and transmission shift schedule, among other functions. On-board diagnostics systems monitor and report the operation of all these subsystems, helping to improve truck efficiency while maintaining or lowering emissions.

Standards adopted in 2011 by the U.S. Department of Transportation (DOT) and Environmental Protection Agency (EPA) regulate the fuel efficiency of new freight trucks in the United States (EPA and NHTSA 2011). The agencies set standards that will reduce fuel consumption by up to 24% for new tractor trucks by model year 2017. The standards will deliver a 16% reduction in fuel consumption, on average, across all heavy-duty vehicles by model year 2018. A second phase of the standards is now under development, and the agencies will propose a new rule by March 2015. A synthesis of recent assessments of heavy-duty vehicle efficiency technologies concludes that the first and second phases of the standards together could achieve a 40% reduction in heavy-duty fuel use of new vehicles by 2025 (NRDC et al. 2014).

These standards reflect the potential for major reductions in fuel consumption made possible by vehicle engineering improvements including control systems with sophisticated sensors and software. However the program does not include other strategies to make vehicles operate more efficiently. The vehicle's interactions with the driver, the infrastructure, and other vehicles offer additional opportunities for intelligent efficiency.

ICT is increasingly used to optimize the way the truck is operated, whether through automatic adjustments or by providing feedback to the driver. Adaptive and predictive cruise control adjusts vehicle speed to maximize the use of kinetic energy gained on the downhill. Aided by such control, which is informed by full knowledge of current and upcoming conditions, less-efficient drivers can approach the performance of the best ones. Additional information- and feedback-based tools are available to assist drivers in saving fuel.

VNOMICS

Vnomics Corporation offers a fleet-management tool to improve safety, driver performance, and efficiency. The Vnomics tool calculates fuel-efficiency potential in real time and informs the driver of ways to optimize operation based on equipment, road, load, and environmental conditions. The In-Cab Advisor® alerts drivers to improper shifting, hard acceleration, excessive speed, and extended idling, displaying information on a scorecard in the vehicle and on Vnomics' web portal. The tool rates drivers' fuel economy performance by normalizing achieved miles per gallon to potential miles per gallon under the actual driving conditions. The company reports that both new and experienced drivers have seen a more than 20% sustained increase in miles per gallon, as well as safety and productivity improvements (Vnomics 2014b). Con-way Freight, the third largest less-than-truckload (LTL) carrier in the United States, uses the Vnomics tool across its entire fleet of more than 8,600 trucks (Vnomics 2014a). (LTL freight comprises shipments having multiple destinations combined in a single vehicle.)

Other approaches to improving fuel efficiency include treating a group of vehicles as a system, for example, an electronically coupled vehicle convoy. Communication among the vehicles, infrastructure, and a central server reduces aerodynamic drag and fuel-consumption-associated acceleration/deceleration events by governing relative speed and distance among the participating trucks.[2] Successful tests of such systems have been conducted in Europe and Japan, where distances between vehicles were reduced to approximately 33 feet (Jeschke 2013). U.S. DOT has also undertaken multiple connected vehicle projects involving both passenger and freight vehicles (U.S. DOT 2014). In addition to saving fuel, such systems are intended to improve safety and increase effective roadway capacity.

INTELLIGENT TRANSPORTATION SYSTEMS

Launched in the 1990s, intelligent transportation systems (ITS) were precursors to today's ICT-based approaches to transportation-system efficiency. Entire catalogues exist of ITS measures that have been implemented to improve the flow of traffic, such as electronic tolling, electronic signboards, and ramp metering (Pol 2010). U.S. DOT has developed multiple freight ITS projects including Smart Roadside, the Commercial Vehicle Information Systems and Networks, and the International Border Program.

The objective of many ITS projects has been traffic-congestion mitigation rather than fuel savings. While the idling and stop-and-go traffic associated with congestion waste both time and fuel, any net fuel savings resulting from congestion mitigation are quite context specific. The phenomenon of induced demand, i.e., new trips generated by an increase in roadway capacity, is well documented (Noland and Lem 2002), and reducing congestion effectively increases capacity. In any case, conventional ITS approaches have been used for many years, and we do not discuss them further here. Extensive information on ITS projects is available

[2] While the savings potential for these convoys may be considerable, it is worth investigating whether the freight corridors in which they would be practical might also present opportunities for rail transport, which would be still more energy efficient.

at U.S. DOT (2014). As these websites show, longstanding efforts to develop ITS have also expanded its scope to include measures discussed in this paper.

Making the Most of the Freight Network

While efficient vehicle operation can save substantial amounts of fuel, freight efficiency must ultimately be measured relative to the useful work done, i.e., in terms of energy consumed per revenue ton-mile. From this perspective, the unit of interest is the item to be moved rather than the vehicle moving it. This approach places the challenge of freight efficiency in the domain of logistics.

ICT AND LOGISTICS

ICT is a cornerstone of today's freight logistics industry. The contribution of ICT to logistics efficiency is evolving rapidly and qualitatively as technological capabilities grow. Continuous improvement in the efficiency of operations depends on the gathering and analysis of ever more operational data. Transportation energy efficiency is no exception to this rule, and it is an area in which ICT advances have allowed enormous gains (Simchi-Levi 2013). One supply-chain researcher describes ICT as an enabler of descriptive, diagnostic, predictive, and, ultimately, prescriptive analytics for logistics (Cooke 2014).

The ability to track shipments, monitor performance at any level of detail, and respond accordingly in real time is the foundation for many logistics functions and a prerequisite for the end-to-end optimization of freight trips. Reliability and speed are top criteria in this optimization. At the same time, cost and environmental impact are also typically key criteria, and these will tend to favor solutions that minimize energy consumption.

Just as the shipping container revolutionized international goods movement, automated tracking of goods at the container, crate, and individual levels has enabled major advances in logistics. This tracking is the basis of supply-chain visibility, that is, knowledge of the location and status of all components of the supply chain at all times. Radio frequency identification (RFID) of goods and equipment and, more generally, automatic identification and data capture are particularly important technologies supporting this practice. The ability to capture, transfer, and use electronically stored information allows major gains in efficiency, as well as in security and customer service.

UPS

United Parcel Service (UPS) cites the constant collection and analysis of operations data as key to improving its performance and minimizing its carbon footprint. The company's Package Flow Technology reduces fuel consumption and emissions by optimizing the allocation of pickups and deliveries each day at each facility, and by designing a delivery route that minimizes total distance covered, driving time, and idling time (UPS 2009). The system uses historical data to forecast conditions and create driver dispatch plans that eliminate left turns and minimize waiting at lights and miles driven. UPS has also used data-based truck strategies to reduce fuel use for some time. UPS sensors and telematics collect data from fleet vehicles on over 200 engine-operating parameters and on vehicle component operation. In 2009, the company reported saving almost $200 per vehicle per day in fuel costs through the combination of these strategies (Barnes 2009).

Data on the location and trajectory of shipments allow companies to combine goods of different types from different sources to maximize the loading of transport vehicles. This is the basis of many of the fuel savings opportunities discussed throughout this paper. Fleetmatics, a company providing web-based fleet management systems, calculates that if the 12.6% of commercial vehicles in the United States and Canada currently under fleet management systems adopted Fleetmatics' optimization system, fuel savings would reach 573 million gallons per year, approximately 1% of U.S. commercial vehicle fuel use (Fleetmatics 2014).

THE CROSS-TOWN IMPROVEMENT PROJECT

The movement of intermodal freight in the United States requires the coordination of multiple truck hauls in addition to the primary mode of freight movement (rail, ship, or air). Freight is loaded onto trucks for short trips through or around metropolitan areas in order to transfer freight shipments from one rail or truck carrier to another. Such shipments may also include the local delivery of goods from an intermodal location to a warehouse, distribution center, or another delivery company.

Because economic development in cities often necessitates more freight movement, it is a challenge to ensure that roads and highways are not overburdened (IFTWG 2007). As a key U.S. intermodal hub, Kansas City experiences heavy truck traffic and the associated congestion, pollution, and road wear and tear. Approximately 4,000 rail containers pass through Kansas City intermodal facilities weekly. Of these, 1,600 are diverted in Kansas City to be delivered locally or transferred between intermodal facilities (IFTWG 2007). These local and cross-town moves add to Kansas City truck trips and traffic congestion, which in turn jeopardizes the on-time performance of the trucks making those moves.

The Intermodal Freight Technology Working Group at the Federal Highway Administration (FHWA) uses technology to improve freight productivity and public benefits. This group developed the Cross-Town Improvement Project (C-TIP) in Kansas City. As part of a pilot project in 2010, C-TIP worked with railroads, trucking companies, and state and regional transportation agencies to improve the local movement of freight.

C-TIP was conceptualized as a database that would track intermodal trips and coordinate cross-town drayage moves between rail terminals to reduce empty trips. (Drayage is a short-distance truck portion of a freight trip whose main portion uses another mode.) The program used information sharing to coordinate moves between parties in order to minimize partially loaded moves (Butler 2010). It also encouraged competitors to share warehouse space to reduce empty backhauls. C-TIP deployed several technologies to improve the efficiency of cross-town moves:

- *Intermodal move exchange*. A collaborative management system that allowed rail, truck, and facility operators to coordinate freight dispatches
- *Wireless drayage updating*. The use of wireless technology to connect drivers, dispatchers, and other C-TIP users
- *Real-time traffic monitoring*. Up-to-date information on traffic conditions for drivers and dispatchers
- *Dynamic route guidance*. Use of traffic monitoring and geographic information systems (GIS) to provide drivers with alternative routes around congestion-prone areas
- *Chassis utilization tracking*. A collaborative application for the management of intermodal chassis among railroads and trucking companies (Schiller, Butler, and Jensen 2012)

These technologies increased the percentage of fully loaded trips within the metro area and reduced unproductive moves. On average, C-TIP reduced fuel consumption by freight carriers in the area by 8% and reduced travel time by 19% (Butler 2012).

More generally, DOT has developed the Freight Advanced Traveler Information Systems (FRATIS) program as an umbrella for multiple public–private partnerships that use ICT to address local freight challenges, including those associated with ports and other major intermodal facilities. Providing real-time information on accidents, terminal wait times, and traffic incidents, these projects will save fuel by reducing empty trips, optimizing routing, and reducing idling. FRATIS has established several "10-year transformative impact targets," including reducing freight vehicle fuel consumption by 10% in program locations (Butler 2014).

COLLABORATIVE LOGISTICS

With the advent of just-in-time delivery, a fundamental tradeoff in logistics became explicit, and customized solutions trumped generic solutions. The customized solution involves delivering goods precisely when and in the quantities the client desires. This approach reduces warehousing needs, reduces parts shortages or surpluses, and can yield faster customer response times. However transport costs for just-in-time operations are generally high because of near-exclusive reliance on air and highway transport, deliveries of partial loads, and peak-hour deliveries. Energy-intensive modes and the increase in vehicle miles traveled due to partial loadings result in greater energy use and greenhouse gas production.

Unfortunately, shippers and carriers are unlikely to abandon solutions tailored to their clients' needs in order to reduce energy consumption. Indeed, recent glimpses of the near future as provided, for example, by Amazon's ads for package delivery drones suggest there is a long way to go before this trend plays out.

On the other hand, approaches are emerging that preserve the advantages of modern freight delivery while improving energy efficiency. Businesses are increasingly sharing transportation resources to minimize the costs and impacts of their supply chains. ICT plays a central role in this collaboration, both for businesses and for individuals. Real-time access to data can facilitate the use of low-cost shared transport resources to meet just-in-time demands. If all parties have access to real-time data on shipping needs, loads can be bundled without delaying shipments. Moreover, carriers can boost a parameter that shippers value even more highly than speed: reliability. The wealth of information on system conditions provided by electronic monitoring increasingly allows carriers and logistics providers to predict delays and to act accordingly. The result is a simultaneous optimization of multiple parameters, including energy use, greenhouse gas emissions, time, and cost. In particular, load factor increases for freight vehicles, as does the potential share for intermodal and non-truck modes.

DAL-TILE

In 2011, stone and tile producer Dal-Tile initiated a project to combine shipments from Mexico of its high-density product with shipments of low-density appliances from Whirlpool to optimize the use of space in freight vehicles (SupplyChainBrain 2012). Since few goods are of the necessary density to reach freight vehicle weight and volume limits simultaneously (10-12 pounds per cubic foot), homogeneous shipments typically cannot make full use of both the weight and volume capacities of a container, trailer, or boxcar. Combining goods of differing types that travel along the same routes can achieve the optimal average density, saving fuel by reducing the number of trips required and saving money for shippers.

Dal-Tile previously had experienced 20% volume utilization in its intermodal and over-the-road shipments to the United States, while Whirlpool used 20% of allowed boxcar weight. By 2012, Dal-Tile was transporting 10 to 12 co-shipments per day with Whirlpool and additional partners Covermex (plastic tableware) and Werner Ladder Company. The companies were able to increase their use of rail intermodal services. Estimated annual diesel fuel reduction for 2012 was over 180,000 gallons. Participants reported cost reductions of 20–30%. (SupplyChainBrain 2012).

The Dal-Tile project saves fuel not only through increased load factor and thus fewer miles traveled but also through greater intermodal share. Shipping goods across the U.S.–Mexico border is a notoriously cumbersome process, and the coordination required between otherwise unconnected partners would not be practical without ICT tools.

When companies in a supply chain collaborate, they are better able to foresee circumstances across the distribution system and adjust actions accordingly. One way, according to Michael Levans of *Logistics Management*, is by altering the timing or mode of shipping:

> The key feature you'll see is that all partners in the supply chain are able to look at and provide input to the same data at any given point in time. Consequently, imbalances are resolved much more quickly than what you would find in a less collaborative model where everyone has to e-mail or call back and forth multiple times and with many partners any time a change is required. What you also see in the long term as a result of this technology-enabled collaboration is that shippers and service providers are much more likely to view each other as true partners who all play a role in ensuring successful supply-chain execution. (Levans 2014)

INTERMODAL TRANSPORT

All modes of freight transport—air, road, rail, water, and pipeline—have strengths and weaknesses, and overlapping yet distinct tasks at which they excel. While air and road typically are the fastest modes, rail and water are less expensive and more energy efficient. However, the domains in which each mode is relevant shift over time as fuel prices, infrastructure conditions, trade patterns, goods characteristics, and technologies change. Optimizing the freight transport system means making the best use of all modes, subject to these dynamic conditions. The feasibility of complex operational modes grows as tracking and control of shipments and infrastructure use become more sophisticated. One example is a two-track supply chain involving parallel freight corridors, one of which carries a certain quantity of a given product to maximize speed and reliability and the other of which carries the bulk of the product to minimize cost. Such solutions are unlikely to be practical without ICT tools.

Intermodal freight transport is defined as the use of more than one transport mode for a single trip without reconfiguring the shipping unit. In the United States, intermodal transport developed primarily to move freight arriving at the nation's seaports. Containerized goods typically travel by rail to major population centers far from the port of entry and are transferred to their final destination by truck. While domestic freight can use intermodal transport as well, this market has been limited to date.

Using rail requires a high concentration of activity to yield enough goods to transport without extensive delays. The cost of the transfer and drayage required at one or both ends of an intermodal trip offsets to some extent the cost advantage of rail over truck on the line haul. Those costs are fixed and therefore impose a lower bound on the distance at which intermodal transport is cost effective. Intermodal is also generally slower than trucking, and the transfers involved may increase the likelihood of loss or damage to cargo. Hence goods that are perishable, fragile, or high value travel point to point by truck or plane.

Yet intermodal freight movement is enjoying rapid growth in the United States, achieving 9.1% year-over-year growth in May 2014 (Szakonyi 2014). Fueling this growth are truck driver shortages, high fuel prices, and continuing increases in roadway congestion. The recurring threat of the depletion of federal funds in the Highway Trust Fund is also a factor; rail investment, largely privately funded, is less exposed to this concern. At the same time, ICT tools are helping to make intermodal viable for more domestic moves. A recent analysis of the intermodal industry (Hatch 2014) forecast strong growth in rail intermodal in the coming years, led by domestic intermodal. The analysis cited investment in information technology along with capital investment as essential to the realization of the forecast.

Shippers can now monitor their shipments from origin to destination, and they can take steps in real time to improve the speed, reliability, and security of intermodal transport despite the multiple handoffs between modes. According to the Center for Neighborhood Technology:

> [W]hat makes such coordinated [intermodal] transportation efficient and even possible is the increasing sophistication of the information technology

> used by the third-party logistics firms and other intermediaries, as well as the truck and rail carriers. The new technology enables effective matching of shipments to carriers and arranges door-to-door service, as well as the kind of real-time tracking of containers that reassures shippers. (CNT 2014).

When the FHWA Intermodal Freight Technology Working Group analyzed the movement of a container entering the United States at a maritime port and traveling by intermodal transport to a distribution center and beyond, they found that 40% of the total transportation time was taken up waiting for information exchanges between supply-chain partners (FHWA 2010). Technology advances can dramatically reduce such time penalties.

The ability to make decisions in real time increases opportunities to use energy-efficient modes. If rail intermodal is appropriate for a certain shipper on some but not all occasions, dynamic mode choice keeps the shipper from having to make a fixed, suboptimal mode choice simply because it works on all occasions. The predictive capabilities enabled by ICT can also improve the reliability of intermodal transport, which is key to its capturing a greater share of goods, especially high-value goods. In short, easy access to information on operations and the ability to respond dynamically to that information can give intermodal transport some of the flexibility that has given trucking a big advantage over other modes. Perhaps most importantly, shippers and carriers have come to see the various modes as complementary rather than strictly competitive.

RAILEX

Railex LLC provides transportation and logistics services for perishable cargo. The special requirements of perishables have led to their being transported almost exclusively by truck; less than 2% of fresh produce shipped within the United States uses intermodal transport (Kulisch 2014). While Railex provides some short-haul truck services and transports goods from origin to final destination, it is fundamentally a rail transporter. The company advertises its service as "the best of both worlds: the velvet touch of private long-haul trucking with the bigger efficiencies and much larger capacity of express rail service" (Railex).

Railex also operates refrigerated warehouses with climate control specific to each produce type. It offers five days of free storage at a warehouse close to the final destination, allowing clients to "pulse" deliveries to final destinations based on individual store needs. It also guarantees five-day coast-to-coast transit times at cost savings of 10–20% relative to long-haul trucking (Kulisch 2014). With the aid of advanced technology, the operation is able to outperform trucking on precisely the criteria that have typically been used to marginalize rail as a viable modal option: speed, reliability, flexibility, and cargo-specific handling. At the same time, the operation keeps the advantages of rail shipping, including its relatively low cost due in part to low fuel consumption per ton-mile.

Operations began in 2006, with weekly transport of 55 refrigerated boxcars of fresh produce from Washington State to Albany, New York. This is an origin–destination pair that previously had negligible rail share, despite connecting a major produce state with several of the largest population centers in the nation (Kuntz 2006). The establishment of Railex involved investments on the parts of Union Pacific Railroad and other private parties, the Port of Walla Walla, and the county, state, and federal governments.

Railex exemplifies the new intermodal opportunities that come with end-to-end supply-chain visibility and optimization. ICT makes this possible through such services as RFID using bar codes for real-time inventory and tracking at the pallet level, Global Positioning System (GPS) tracking and automated control of the internal temperature and humidity of each railcar, sensors to detect door-opening events, accelerometers to evaluate in-transit impacts that could damage cargo, virtual inventory management with 24/7 web access, and integrated order processing (Kulisch 2014; Railex).

The company has expanded the range of perishable products it transports to include dairy, flowers, frozen foods, pharmaceuticals, and seafood. The number of facilities and markets served and frequency of service have also increased. Two weekly trains run between Delano, California and Rotterdam, New York; trains to Jacksonville, Florida will soon be added. Both large- and small-volume producers have access to the service since truckload and less-than-truckload shipments, and all package sizes and weights, can be accommodated.

Other providers of refrigerated intermodal services are developing rapidly in response to new technology-based capabilities and to stresses on the trucking industry. These include McKay Transcold, Green Express, Cold Train, and Tiger Cool Express (Kulisch 2014). However the growing importance of intermodal freight transport and the role of ICT in that growth go far beyond the transport of perishables, as illustrated by trends at major U.S. carriers.

J.B. HUNT

J.B. Hunt is one of the largest transportation logistics companies in the United States. Founded in 1962 and headquartered in Arkansas, the company provides freight shipping services throughout the United States, Mexico, and Canada. Despite originating as a truck-based freight company, Hunt has greatly expanded its multimodal freight business. The company has identified intermodal transport as the single biggest way to save on fuel costs and reduce carbon emissions. According to Hunt, converting over-the-road shipments to transport by rail in intermodal containers saves 200 gallons of fuel on average per container, reducing carbon emissions by more than 50% (J.B. Hunt). As a result, the company has invested heavily in building its intermodal services in the United States and accumulating a large fleet of intermodal containers. In collaboration with BNSF on the West Coast, Norfolk Southern on the East Coast, and a number of smaller rail providers in between, the company has helped create a network to enable fast, efficient shipment of goods.

In addition to expanding its intermodal rolling stock, Hunt has sought to help customers identify shipments that can be converted most efficiently from truck to rail. As part of its "carbon diet" plan, the company designed the Clean Transport™ calculator to evaluate intermodal conversion opportunities, improve efficiency, and reduce emissions for a given shipment or customer. The main goals of the calculator include:

- Identifying ways to reduce or eliminate vehicle miles travelled
- Maximizing payload on each shipment
- Optimizing the transportation mode for each shipment
- Maximizing the energy efficiency of the transportation services (J.B. Hunt)

Hunt has made intermodal freight the centerpiece of its corporate sustainability strategy. In combination with a number of other initiatives, the company has taken strides toward achieving an efficient freight transportation network. One industry expert notes: "It is no coincidence that the best returns in the TL [truckload] sector come from Hunt, whose intermodal business is now larger than its traditional trucking" (Hatch 2014).

Hunt's client PETCO illustrates the role of ICT in Hunt's growing use of intermodal (BNSF). Seeking to lower its transportation costs while reducing carbon emissions, PETCO began an intermodal transport pilot with J.B. Hunt and BNSF in 2007. Inbound shipments to distribution centers achieved good on-schedule performance. PETCO has found that intermodal can be used even for time-sensitive shipments and is increasingly using it for outbound shipments. With its growing use of intermodal, PETCO is considering streamlining distribution by relocating its operations.

MIGRATION TO THE CLOUD

Businesses frequently outsource logistics services, which may include transportation, warehousing, packaging, and inventory management, to logistics providers. Sophisticated and rapidly evolving ICT tools are essential to their work. In fact, non-asset-based provider services rely entirely on information and analysis.

A basic tool of logistics services, whether in-house or outsourced, is the transportation management system (TMS). Based on the collection, analysis, and application of operations data related to transportation, a TMS performs such functions as maximizing container use, optimizing mode choice, and improving routings. While the TMS is considered essential and continues to evolve, its use is being superseded by of supply-chain management practices that integrate manufacturing, transportation, and warehousing into a single system (Levans 2014). Supply-chain management is already steeped in "intelligence," and, as with logistics management, practitioners are seeking to extend that intelligence from decision-making support to predictive capabilities (Carroll 2010).

The logistics industry has the potential to level the playing field for large and small shippers by optimizing transportation and warehousing services. In particular, companies of all sizes are able to save energy by sending goods on fully loaded vehicles. The chief information officer of UPS noted that moving the company's logistics services to the cloud has allowed all clients to "gain the power to collaborate with suppliers, make more accurate delivery forecasts, minimize excess inventory, and avoid last minute surprises" (Barnes 2011).

As data on the distribution of individual companies' freight becomes available in the cloud in real time, opportunities for collaboration proliferate and can reduce costs dramatically. The collaborative functions of Web 2.0 introduced by social networks are directly applicable to the logistics world. Logistics services can be a major expense, and the cloud allows operators large and small to negotiate and manage their own logistics operations while sharing infrastructure and equipment with others. International transportation managers are already seeing declining growth as a result of container lines' directly seeking goods to transport (Armstrong 2014). This disintermediation process will also enlarge the universe of businesses with which a given company can collaborate on goods distribution, because collaboration can arise spontaneously as opportunities come up rather than being dependent on business relationships established over time by a logistics provider. As the universe of potential distribution partners expands, companies have greater choice and flexibility, as well as more opportunities to optimize shipments over all parameters including energy efficiency and greenhouse gas emissions.

Cloud-based services offer many advantages in the logistics space, including reducing costs by transferring purchase, installation, and hosting away from individual companies and toward shared capabilities. In addition to facilitating freight fuel savings through the ICT strategies discussed throughout this paper, companies can reduce equipment energy use by replacing their own or their logistics provider's data management and analytics with cloud-based services.

Cloud-based services also promote standardization of data formats, allowing immediate communication and transparency (GT Nexus 2010). Moreover, once all shippers or carriers with common origins and destinations can communicate directly through the cloud, visibility becomes virtually unlimited. This in turn promotes reliability and flexibility of goods movement, more load consolidation, and other cooperative activities.

Reducing Ton-Miles Traveled

A third category of freight-system efficiency improvements involves reducing the number of ton-miles traveled without detracting from business objectives. Strategies in this category range from well-established practices to ideas that rely on technologies only now emerging. ICT has a role throughout this spectrum.

OPTIMIZING ROUTING AND FACILITY LOCATION

Carriers have used increasingly sophisticated analytical methods and technologies over the years to minimize the duration and length of vehicle trips. Today's technology allows for continuous updates throughout the course of a trip to reflect roadway conditions as well as dynamic vehicle loading in multi-segment trips. UPS reports that it has eliminated 100 million miles from its delivery routes using information systems (UPS 2009).

Facility location is another complex optimization problem. Companies must consider economies of scale and transportation costs when deciding where their facilities should be. A company with a large number of facilities typically incurs greater inventory management and building operations costs. On the other hand, having facilities closer to customers reduces transportation costs. The final leg of the trip to the retail outlet or customer uses a less efficient form of transportation (rail or tractor-trailer) than does the move from point of manufacture to the distribution facility via small truck. An analysis of the effects of oil prices on the optimum number of manufacturing and distribution facilities of a hypothetical national retailer found that, as oil prices increased from $75 to $200 per barrel, the optimal number of distribution facilities increased from five to seven, and the optimal number of manufacturing facilities increased from two to three (Simchi-Levi 2013).

Walmart has 19 "centerpoint facilities" that intercept and consolidate shipments that are then shipped by full truckloads to distribution centers (PPIAF 2011). Smaller companies share space with other parties to maximize the use of freight vehicles and gain the efficiency and flexibility of a network of warehousing and distribution facilities. Whether facilitated by a logistics provider or directly through a cloud-based platform, the feasibility of such approaches is based on the availability of real-time data and analytics.

SHIFTING POINTS OF PRODUCTION

Production of goods close to the point of use is becoming more attractive and feasible, largely because of the substitution of information for the movement of goods (Jeschke 2013). Technology innovations such as 3-D printing (also known as additive manufacturing) and, more broadly, practices of production on demand will increasingly lead to distributed manufacturing, which is driven by the preference to customize products and avoid inventory and transportation costs.

Coupled with relatively low natural gas prices, the appeal of proximity to demand is expected to accelerate the return of some manufacturing operations to the United States or elsewhere in North America (George 2014). It will also change goods-movement patterns and could shift the assignment of goods to particular modes. The net transportation efficiency effects of such shifts are complex, and their energy impacts are not readily predictable. The World Economic Forum concluded that the transportation energy benefits of nearshoring would likely be small. This is because the container-ship-to-rail trajectory taken by a large fraction of imported manufactured goods would be replaced by the less efficient transportation modes used to transport goods from distributed manufacturing facilities in the United States (WEF 2009).

THE PHYSICAL INTERNET

Professor Benoit Montreuil has written extensively about the Physical Internet, a comprehensive strategy to eliminate the large inefficiencies in today's freight system. He defines the Physical Internet as "an open global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols" (Montreuil 2012). The information highway that became the Internet thus provides in turn the model for an advanced freight transportation system that achieves vastly improved efficiencies by connecting all participants in the industry with shared infrastructure and protocols.

Montreuil points to the large percentage of empty space in freight vehicles, use of inefficient modes, and excess production due to failures in timing or communication to illustrate the enormous potential for efficiency gains from creating such a system. He envisions an open market for freight transportation, universal usage of modular containers, and shared transportation and distribution networks. Simulating distribution flows between two top retailers in France and their 100 top suppliers, Montreuil estimated a threefold reduction in greenhouse gas emissions as a result of applying the Physical Internet construct to increase the efficiency of road transport and expand intermodal freight usage (Montreuil 2012).

This reworking of the freight system would also reduce ton-miles traveled by optimizing routing and facilities location, in part by creating open distribution systems available to all shippers. It would also create an "open global realization web" in which product specifications would be digitally transmitted and products would be manufactured, assembled, and finished as close as possible to the point of use. This strategy reduces cost and energy use not only by reducing ton-miles but also by cutting down on the production of goods that will never be sold.

Barriers to Smart Freight

While the use of ICT to advance freight efficiency is by no means a new development, the breadth and depth of its implementation have been limited. Even basic technology-enabled functions are not yet standard practice. Several barriers to greater implementation are in evidence.

Lack of standardization. One of the greatest advantages of ICT tools is that they allow greater visibility, not only of a company's own supply chain but of the distribution network as a whole, including the movements of other companies. Visibility depends on standardization of data formats, software, and protocols. Such standardization is clearly a tall order, given the number of companies and products providing services of this type, as well as participating companies' likely concerns about confidential business information. In addition, equipment must be standardized to realize the efficiencies of load consolidation, collaborative distribution, and intermodality that ICT makes available.

Human factors. Organizational structure and human behavior can also be barriers to ICT implementation. Logistics experts note that companies cannot take advantage of software tools' capabilities if they select and apply them within functional silos. In particular, management systems cannot deliver end-to-end optimization of processes so long as supply-chain execution is fragmented. These experts advise against any investment in logistics-oriented ICT tools until processes and personnel have been adequately integrated (Levans 2014).

Split incentives. Costs of even the most fundamental ICT applications can be significant and may fall on a market actor who is not the primary beneficiary (Simchi-Levi 2013). The cost of electronic tracking of freight units, for example, falls to the freight originator, while the benefits accrue to the carrier and the recipient. As a result, such tracking is neither entirely functional nor ubiquitous.

Inadequate infrastructure and equipment. Technology can help relieve pressure on transportation infrastructure; for example, many intelligent transportation system strategies reduce congestion, at least in the short term, without roadway expansion. On the other hand, the potential for ICT strategies to increase alternative freight-mode shares will be limited absent accompanying increases in investment in rail and waterway infrastructure and equipment. At this time, public funding for transportation infrastructure in the United States is in danger of running out, with no near-term prospect of an agreement to increase investment or even to match the already constrained allocations of recent years. In addition, the ongoing container shortage, as well as the non-fungibility of marine containers (40 feet) with those suitable for over-the-road trucks (53 feet) presents an obstacle to further intermodal growth.

Path dependence. Solutions to freight-movement challenges are path dependent in the sense that practicable options at a given point in time depend on choices made up to that point. Once the freight industry and governments have already invested in one type of logistics infrastructure, whether physical or digital, they may be unwilling or unable to adopt entirely new systems, even when these represent major advances. Path dependence often leads to incremental, suboptimal solutions (Rodrigue).

Reluctance to share information. The benefits of ICT to the freight system depend on the sharing of information, some of which companies may regard as confidential. In addition, large companies may seek to maintain an advantage over smaller clients and competitors by using their superior real-time information about the freight system as a whole. This leads to asymmetries among the players in the system, preserving inefficiencies that benefit only a subset of companies (Rodrigue).

Missing technologies. Cooke (2014) argues that, with the arrival of big data, technology is now the limiting factor in achieving the final benefit of ICT for logistics, namely prescriptive analytics. He claims that further developments in artificial intelligence will be required to generate the forward-looking solutions that such analytics are expected to provide.

The Role of Public Policy

Freight transport is a function of the private sector and will remain so. The railroads have largely built and maintained their own lines, and intermodal facilities are typically privately funded. Nevertheless, all levels of government play important roles in the freight transportation network through their funding of roads and dredging projects and oversight of navigable waterways and, in some cases, seaports and airports. Additional targeted governmental support for that network and for freight system efficiency is warranted because of the public benefits that a robust, multimodal freight network provides. Government involvement in the freight system also may be appropriate because of the following:

- Environmental impacts and other externalities of freight movement (including impacts of truck traffic)
- The need for standardization of equipment and protocols
- The need for innovative technologies and strategies, which may involve considerable risk and so have difficulty attracting private-sector investment
- The potential for sharing infrastructure among competitors and across state lines
- The importance of collaboration among nontraditional partners and competitors

The United States has a relatively extensive freight rail network and a high rail share for long-distance trips, and consequently a lower energy intensity of freight movement than many other nations (Young et al. 2014). Over the past decade, the EPA SmartWay Transport Partnership has raised the freight industry's awareness of energy use and emissions reduction strategies and helped many companies improve their performance in these areas.[3]

U.S. transportation policy nominally emphasizes the deployment of technology and innovation in the freight sector: the 2012 transportation authorization law, Moving Ahead for Progress in the 21st Century (MAP-21) establishes a National Freight Strategy to achieve goals including the use of advanced technology and innovation (MAP-21 2012). However, the freight provisions of MAP-21 focus almost exclusively on highway freight transport. The law also does little to promote regional cooperation on freight projects, instead focusing on state planning requirements. The potential for government to help bring together disparate freight partners is in evidence in major infrastructure projects such as the Alameda Corridor in the ports of Los Angeles and Long Beach, and Chicago's CREATE (Chicago Region Environmental and Transportation Efficiency) Program. The FHWA FRATIS project, described above, shows the important role of government agencies in smaller, non-infrastructure-based projects.

The need for public-sector involvement in the freight system has long been acknowledged in other parts of the world. U.S. freight efficiency policy lags behind that of the European Union (EU) in particular. One reason is that the EU Emissions Trading Scheme, which began operation in 2006, focuses on reducing freight system greenhouse gas emissions. The EU Seventh Framework Programme funded the development of a Roadmap on ICT for Sustainable Freight Transport and Logistics that treats in detail many of the themes raised in this paper (Logistics for Life 2011). More generally, government policies in Western Europe and the Asia-Pacific region have influenced business practices with respect to choices of transportation, distribution, and supply-chain partners to a far greater extent than in North America (Carroll 2010).

---

[3] See http://www.epa.gov/smartway/.

Conclusions

This paper considers three types of strategies to make freight transportation more efficient: vehicle-level improvements, better use of the freight network, and changes in the distance freight travels. Each category has benefitted already from ICT-based efficiency measures: ITS at the vehicle or multivehicle level, load consolidation to improve network efficiency, and route optimization to reduce ton-miles traveled. More recent technology developments are helping to open up further opportunities in each of these areas, including vehicle-to-vehicle communications, new markets for intermodal transport, and distributed manufacturing.

The ongoing pursuit of quicker, more reliable, and more flexible freight-movement services often has been at odds with improving fuel efficiency. Technologies can help to harmonize these priorities. A multitude of applications of ICT, both existing and emerging, can save energy and cut costs and emissions while promoting the overall efficiency of freight transport. Many already have been effectively employed, and are continuously being improved, by shippers, carriers, logistics providers, and other participants in goods movement, including governmental entities.

ICT can maintain the trend toward logistics services tailored to the requirements of individual products and users while preserving the advantages of large volume. In particular, while just-in-time delivery has contributed in recent decades to trucks' growing share of tonnage and to the partial loading of trucks, companies can maximize just-in-time services while reducing costs by using ICT to better coordinate logistics. ICT also helps companies measure and track energy consumption and emissions and use these measurements when making transport decisions and marketing their services.

These benefits follow from the effectively unlimited data collection, enhanced predictive capabilities, and real-time, dynamic decision making and implementation enabled by ICT. Such capabilities in turn lead to improvements in multiple key freight transport objectives, including the following:

- *Complete tracking and performance monitoring*, whether at the package, shipment, vehicle, company, or corridor level. This equates to complete visibility of the logistics chain and supports continuous improvement.
- *Potential for collaborative usage of infrastructure, equipment, and data*. This can allow small enterprises to be almost as efficient as large ones.
- *The ability to anticipate and prepare for future needs*. Increased confidence in the projection of future needs supports the adoption of more innovative approaches that represent major departures from past practices.
- *Optimal end-to-end transportation solutions*. This is accomplished through flexibility, load matching, and trip consolidation. It can also entail the replacement of a given transportation objective (move X from point A to point B) by a higher business objective (satisfy need Z).

More fundamentally, full integration of freight transport into the larger universe of supply-chain management could change how goods are moved, with major implications for freight energy use. Approaches that encompass sourcing and manufacturing are superseding strategies to optimize transportation and distribution systems alone.

Table 1 list the companies mentioned in this paper that are using ICT to reduce freight energy use. While the cases we have described illustrate particular types of ICT deployment, most of these companies have applied a broader set of strategies.

Table 1. ICT applications to improve freight energy efficiency

ICT application category	Vnomics	UPS	C-TIP	Dal-Tile	Railex	J.B. Hunt	Physical Internet
In- and between-vehicle technologies	x					x	
Load and vehicle tracking		x			x	x	x
Load optimization and logistics		x	x	x	x	x	x
Collaborative distribution				x	x		x
Intermodal transportation		x	x	x	x	x	x
Route and distribution facility optimization		x	x				x
Distributed manufacturing and nearshoring							x

The freight industry has yet to fully benefit even from the technologies that are already familiar to industry leaders. Over time, competitive pressures will drive freight logistics to adopt more ICT-enabled fuel efficiency strategies. However, barriers to the further development of intelligent efficiency in the freight sector remain. Public policy will help determine how quickly these barriers are overcome and how successful the transition is to an advanced, highly efficient freight system.

Recommendations

Accelerating the deployment of ICT to save energy in the freight sector and maximize its other benefits will require actions beyond business as usual on the part of both freight-movement participants and governments. We offer the following recommendations for further efforts in this area.

Adopt energy and environmental goals and metrics. Federal and state transportation funding programs and state freight plans should adopt reduced freight-sector energy use and emissions as program objectives and project selection criteria. This should lead to increased deployment of ICT in freight projects. At the same time, ICT tools will improve the measurement and projection of fuel savings associated with projects and programs, making such metrics and goals more meaningful.

Promote standardization of protocols and equipment. Private-sector and government entities should participate in pilot projects and other efforts to demonstrate the feasibility, security, and cost savings of standard equipment and information-sharing protocols in the freight sector. They should also develop a roadmap showing how such standardization might be implemented over time.

Restructure business functions relating to the supply chain. Businesses should consider what changes to internal organization are required to ensure that the flows of information and goods within and beyond the corporate walls are unimpeded and integrated.

Prioritize innovation. In the current economy, continuing experimentation and investment in emerging technologies poses a challenge to many businesses, especially small businesses. Yet not only will ICT be increasingly important to remain competitive, but it also will likely become a way for smaller businesses to directly manage their own logistics and benefit from the economies of scale previously available only to larger players. The emphasis that federal freight policy places on innovation should be reflected in strategic investments in freight ICT projects and pilot programs.

Invest in infrastructure for future needs. Enormous shortfalls in public infrastructure funding make it more difficult to develop and fund projects aligned with future needs. However, a constrained funding environment makes it all the more important to prioritize investments in system efficiency ahead of system expansion, and to promote the rapid adoption of ICT tools that reduce ton-miles and vehicle miles while maintaining business function.

Promote collaboration. Given the difficulty of making a business case for such projects, government should help develop services and infrastructure that will be provided to or used by multiple unrelated companies. The DOT TIGER grant program is a good example of a funding model that is suitable for such projects; this funding should be renewed.

Conduct further analysis of costs and benefits. Together with the ICT and freight communities, federal and state agencies should quantify the energy savings, non-energy benefits, and costs of multiple scenarios for the deployment of ICT to reduce freight energy use. This is a prerequisite for making a strong case for major investment of public and private resources in this area.

References

Amazon. "Amazon Prime Air." Video clip. Accessed July 12, 2014. http://www.amazon.com/b?node=8037720011.

Armstrong, R. 2014. "3PLs Face Slowing Growth in 2014." *Journal of Commerce*, January 23. Accessed June 10, 2014. http://www.joc.com/international-logistics/logistics-providers/3pls-face-slowing-growth-2014_20140123.html.

Barnes, D. 2009. "Redefining ICT's Value to the Enterprise." Keynote address at Forrester ICT Forum, Las Vegas. Accessed May 8, 2014. http://www.pressroom.ups.com/About+UPS/UPS+Leadership/Speeches/David+Barnes/ci.Redefining+ICT's+Value+to+the+Enterprise.print .

——. 2011. "The Logistics Cloud." Speech at the ConnectShip Technology Conference, Tulsa. June 21.

Butler, R. 2010. "Cross-Town Improvement Project." FHWA Talking Freight Seminar, November 17. Accessed July 1, 2014. http://www.fhwa.dot.gov/Planning/freight_planning/talking_freight/10talking.cfm.

——. 2012. "Freight Advanced Traveler Information System (FRATIS)." Presentation to the Southeast Diesel Collaborative. August 6. Accessed July 1, 2014. http://www.southeastdiesel.org/Presentations%20for%207th%20Annual%20Meeting/Aug%206/5-%20The%20use%20of%20Technology%20in%20Freight%20Movememnt%20(R_Butler).pdf .

——. 2014. "Using Freight Advanced Traveler Information Systems to Promote Urban Freight Mobility." Presentation to Trucking Industry Mobility and Technology Coalition webinar, February 19. Accessed May 9, 2014. http://www.freightmobility.com/Pres/02_19_2014_TIMTC_Dynamic_Truck_Routing_Web.pdf.

BNSF (Burlington Northern Santa Fe Railroad). "PETCO Adopts Intermodal, Reducing Transportation Complexities and Costs." Accessed April 17, 2014. https://www.bnsf.com/customers/campaign/pdf/case-study-petco.pdf.

Carroll, T. 2010. "The Smarter Supply Chain of the Future: Insights from the Global Chief Supply Chain Officer Study." IBM Corporation. Accessed May 28, 2014. http://public.dhe.ibm.com/common/ssi/ecm/en/gbe03163usen/GBE03163USEN.PDF

CNT (Center for Neighborhood Technology). 2014. *America's Freight Future: Multiple Modes, Multiple Benefits, Multiple Opportunities.* Interim Report to the U.S. Department of Transportation from The Center for Neighborhood Technology.

Cooke, J. 2014. "Waiting on Big Data 'Prescriptions.'" DC Velocity. Accessed June 6, 2014. http://www.dcvelocity.com/articles/20140507-waiting-on-big-data-prescriptions/

Elliott, R. N., M. Molina, and D. Trombley. 2012. *A Defining Framework for Intelligent Efficiency*. Washington, DC: American Council for an Energy-Efficient Economy.

EPA and NHTSA (United States Environmental Protection Agency and National Highway Traffic Safety Administration). 2011. "Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles: Final Rule." *Federal Register* 76 (179), September 15.

FHWA (Federal Highway Administration). 2010. "The Cross-Town Improvement Project." Talking Freight webinar transcript, November 17. Accessed June 27, 2014. http://www.fhwa.dot.gov/planning/freight_planning/talking_freight/nov172010transcript.cfm.

Fleetmatics. 2014. "Introducing the Fleetbeat Report." Accessed June 27, 2014. http://www.fleetmatics.com/blog/introducing-fleetbeat-report-infographic/.

Foster, B. and T. Langer. 2013. *Energy Efficiency Potential of the U.S. Freight System: A Scoping Exercise*. Washington, DC: ACEEE.

George, K., S. Ramaswamy, and L. Rassey. 2014. "Next-Shoring: A CEO's Guide." *McKinsey Quarterly*, January. Accessed June 6, 2014. http://www.mckinsey.com/insights/manufacturing/next-shoring_a_ceos_guide .

GT Nexus, Inc. 2010. "The Cloud Supply Chain Data Network." http://mktforms.gtnexus.com/WPCloudSCDataNetwork_Reg.html

Hatch, A. 2014. *Ten Years After: The Second Intermodal Revolution*. Association of American Railroads and the Intermodal Association of North America. Accessed April 18. http://www.intermodal.org/information/research/assets/tenyrsafter.pdf .

IFTWG (Intermodal Freight Technology Working Group). 2007. "Cross-Town Improvement Project: Freight Travel Demand Management Case Study." Presentation. Accessed July 1, 2014. http://www.ctip-us.com/ctip_files/Final%20Report%20-%20C-TIP%20TDM%20Case%20Study%20v5%2010-12-07.pdf.

J.B. Hunt. "Innovations." Accessed June 6, 2014. http://www.http://www.jbhunt.com/responsibility/sustainability/innovations.jbhunt.com/responsibility/sustainability/innovations.

J.B. Hunt. "Carbon Calculator." Accessed June 22, 2014. https://www.jbhunt.com/responsibility/sustainability/carbon_calculator/.

Jeschke, S. 2013. "Vehicles, Loading Units and ICT: Smart Solutions for the Intermodal Transport Chain." Presentation to Truck & Bus World Forum, Lyon, France. November 21.

Kulisch, E. 2014. "Refrigerated Rail Heats Up." *American Shipper*. March.

Kuntz, J. 2006. "Railex Case Study." Presentation to the National Association of Regional Councils. December 5. Accessed May 10, 2014. http://narc.org/uploads/File/Transportation/Freight%20Summit/Kuntz_Railex.pdf.

Levans, M. 2014. "2014 Technology Roundtable: The Great Convergence." *Logistics Management.* May 1. Accessed May 15, 2014. http://www.logisticsmgmt.com/article/2014_technology_roundtable_the_great_convergence.

Logistics for Life. 2011. "Roadmap on ICT for Sustainable Freight Transport and Logistics." Version 1.0. November 30. Accessed July 2, 2014. http://www.logisticsforlife.eu/downloads/roadmap_v10.pdf.

MAP-21. An act to authorize funds for Federal-aid highways, highway safety programs, and transit programs, and for other purposes. 2012. Pub. L. No. 112-141. 126 Stat. 405.

Mathers, J. 2013. *Smart Moves: Creative Supply Chain Strategies Are Cutting Transport Costs and Emissions.* Environmental Defense Fund. http://business.edf.org/files/2014/03/smartmoves_07_screen1.pdf

Montreuil, B. 2012. "Physical Internet Manifesto." Version 1.11.1. Accessed July 13, 2014. http://physicalinternetinitiative.org/.

NRDC (Natural Resources Defense Council), ACEEE, Environmental Defense Fund, Sierra Club, and Union of Concerned Scientists. 2014. "Big Fuel Savings Available in New Trucks." Fact sheet. Accessed June 17, 2014. http://aceee.org/files/pdf/fact-sheet/truck-savings-0614.pdf.

Noland, R. and L. Lem. 2002. "A Review of the Evidence for Induced Travel and Changes in Transportation and Environmental Policy in the US and the UK." *Transportation Research Part D*, 7 (1): 1-26. http://www.sciencedirect.com/science/article/pii/S1361920901000098.

Pol, J. 2010. "ITS and Technology Adoption and Observed Market Trends from ITS Deployment Tracking." Final Report: October 8. Research and Innovation Technology Administration. Accessed July 14, 2014. http://ntl.bts.gov/lib/34000/34900/34991/ITS_Deployment_Tracking_FINAL_508C_101210.pdf.

PPIAF (Public-Private Infrastructure Advisory Facility). 2011. "Wal-Mart Stores, Inc.: Improving Components of the Supply Chain to Reduce Cost and Environmental Impact." In *Freight Transport for Development: A Policy Toolkit.* Accessed May 10, 2014. http://www.ppiaf.org/freighttoolkit/sites/default/files/casestudies/Walmart.pdf.

Railex. "Services." Accessed July 2, 2014. http://railex.com/services.

Rodrigue, J.P. "Forces Shaping the Diffusion of Information and Communication Technologies in Freight Transportation." The Geography of Transport Systems. Hofstra University. Accessed April 17, 2014. https://people.hofstra.edu/geotrans/eng/ch2en/conc2en/ict_freight.html.

Rogers, E. A., R. N. Elliott, S. Kwatra, D. Trombley, and V. Nadadur. 2013. *Intelligent Efficiency: Opportunities, Barriers, and Solutions*. Washington, DC: ACEEE.

Schiller, R., R. Butler, and M. Jensen. 2012. "Kansas City Cross-Town Improvement Project Evaluation: Results and Lessons Learned." Submitted for Transportation Research Board 2013 Annual Meeting. Accessed May 18, 2014. http://docs.trb.org/prp/13-0097.pdf.

Simchi-Levi, D. 2013. *Operations Rules: Delivering Customer Value through Flexible Operations.* Cambridge, MA: MIT Press.

Solomon, M. 2012. "Intermodal Struggles to Crack Short-Haul Market." DC Velocity. Accessed July 1, 2014. http://www.dcvelocity.com/articles/20121116-ntermodal-struggles-to-crack-short-haul-market/.

SupplyChainBrain. 2012. "Heavyweights, Featherweights Share Top Prize in 2012 Supply Chain Innovator of the Year Competition." Accessed May 11, 2014. http://www.supplychainbrain.com/content/nc/logisticstransportation/transportation-distribution/single-article-page/article/heavyweights-featherweights-share-top-prize-in-2012-supply-chain-innovator-of-the-year-competition/.

Szakonyi, M. 2014. "Faster Trains Point to Improving US Intermodal Service." *Journal of Commerce*, June 9. Accessed June 10, 2014. http://www.joc.com/faster-trains-point-improving-us-intermodal-service_20140609.html.

UPS (United Parcel Service). 2009. *2008 UPS Corporate Sustainability Report.* http://www.sustainability.ups.com/community/Static%20Files/sustainability/2008_CSR_PDF_Report.pdf.

U.S. DOT (United States Department of Transportation). 2013. Development of C-TIP Drayage Optimization Application. Final Report. DTFH61-12-C00013.

——. 2014. Intelligent Transportation Systems Joint Program Office. www.its.dot.gov.

Vnomics (Vnomics Corporation). 2014a. "Con-Way Freight Deploys Vnomics Real-Time Fleet Management System." Press Release. March 6. Accessed June 17, 2014. http://www.vnomicscorp.com/content/file/Company%20News/VnomicsConwayFreightPressRelease-FINAL%20CON-WAY%20APPROVED.pdf.

——. 2014b. "In-Cab Advisor® Driver Coaching." Accessed June 17, 2014. http://www.vnomicscorp.com/content/Vnomics_InCabAdvisor.pdf

WEF (World Economic Forum). 2009. *Supply Chain Decarbonization: The Role of Logistics and Transport in Reducing Supply Chain Carbon Emissions.* Geneva, Switzerland.

Young, R., S. Hayes, M. Kelly, S. Vaidyanathan, S. Kwatra, R. Cluett, and G. Herndon. 2014. *2014 International Energy Efficiency Scorecard*. Washington, DC: ACEEE.