Incorporating Energy-Based Metrics in the Analysis of Intermodal Transport Systems in North America

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As both regulators and operators strive toward energy, security, sustainability, and carbon accounting goals, establishing a consistent approach in monitoring and comparing intermodal freight transportation becomes essential. Current freight performance tools focus on capacity, speed, throughput, productivity, or emissions and tend to be segregated within individual transportation modes. These tools are neither holistic enough for supply chains striving to eliminate waste, nor for transportation planners trying to prioritize public funding. This paper argues that evaluating intermodal quantitatively within an energy-based freight sustainability framework ensures that funding results in lower cost per ton of reduction of carbon, oxides of nitrogen or particulate matter emissions than from the practice of focusing on new engines, retrofits, or electrification.

INTRODUCTION

Supply chain managers face many competitive choices when deciding how best to minimize costs in the processing, staging, and transportation of goods. In recent years, the introduction of better practices have helped logistics costs decline significantly from 17.9% of U.S. GDP in 1980 to 8.3% by 2010 (CSCMP 2011), allowing U.S. businesses to more effectively compete in the global economy. Yet since transportation costs annually account for $768 billion of the $1.2 trillion total cost of logistics (CSCMP 20111), and energy is a major component of those transportation costs, the prospects for future gains are limited. Future challenges include the high likelihood of rising energy costs, longer supply chains that require more fuel, and more stringent safety and security requirements (delays consuming more fuel as well as negatively impacting labor productivity). Nevertheless, there is great potential to reduce freight energy consumption in North America with higher utilization levels of intermodal rail, as well as niche applications for barges and short sea shipping. Improving rail intermodal on-dock and near-dock efficiency are particularly critical. In 2005, congestion resulting from port landside access was estimated to cost up to $200 billion annually, which includes 2.3 billion gallons of fuel and 3.7 billion man-hours wasted (USDOT MARAD 2005). Moreover, wasted fuel and man-hours are only likely to worsen as a growing number of larger ships—off-loading and loading many more containers per port call—are put into service.

Historically, U.S. rail infrastructure has been private and not publicly funded like port, highway, and airport infrastructure. This outlook changed in recent years with the funding of projects such as the Alameda, Heartland, Crescent, and National Gateway Corridor projects through public/private partnerships (Chase 2009). Public funding of intermodal rail is now looked at favorably as a means to increase freight capacity as well as reduce highway congestion, diesel truck emissions, and highway maintenance costs. But in light of capital scarcity, the question is how to evaluate the merits of public investment in intermodal versus other freight projects. While comprehensive methodologies have been developed for energy-based sustainability analysis of freight moved by a single mode (e.g., IFEU Heidelberg et al. 2010), these methodologies do not take into account the full complexity of North American intermodal transits. Thus, there is a critical need for energy-based sustainability methodologies, particularly at the terminals where the modal transfers take place. Studies comparing intermodal to truck freight (ICF Consulting 2009) have been using estimates of

limited value because energy use per container throughput significantly varies by terminal design, operational practices, and volumes in relation to capacity.

This paper contends that energy-based analysis per individual intermodal transit can be determined, and that objective energy measures can be compared and tied to improvements in costs, reliability, and congestion. Therefore, this paper evaluates the applicability of current intermodal measures for freight efficiency, introduces new terminal efficiency metrics, and presents methodologies for terminals so that intermodal movements can be compared to truck-only movements. Before analyzing current measures, the dimensions of intermodal fuel consumption need to be identified, along with other freight efficiency factors (economic and social) that affect modal decisions.

FREIGHT EFFICIENCY

For freight moving through the supply chain—whether taking place on a single mode or through an intermodal sequence—a measure of economic efficiency and sustainability relates to the minimization of energy use, which is best measured in British Thermal Units (BTUs) to better account for terminal and storage operations becoming electrified, and the different energy contents of fuels. Energy-based analysis of intermodal freight has three aspects: line haul, modal transfer, and storage components.

- **Line Haul Energy** is the fuel needed to transport goods (ton-miles/BTU) so that comparisons can be made across different modes. Additional energy for equipment repositioning and temperature control need to be accounted for as well. Finally, drayage miles per intermodal transit are needed to calculate complete trip energy usage. Naturally, the higher the ratio of drayage to rail mileage, the less the energy advantage of intermodal.
- **Modal Transfer Energy** pertains to all freight transfer points. Whereas truck freight usually involves only origin and destination facilities, intermodal entails multi-transfer points, encompassing the fuel used in the terminal for modal transfer by cranes, drayage trucks, yard tractors, service vehicles, as well as energy use for switching.
- **Storage Energy** relates to warehousing operations, including loading, unloading, storing and cross-docking (moving cargo from one transport vehicle directly into another). Temperature-sensitive products require additional energy to operate the mechanical equipment to insure the integrity of the goods being carried, and therefore, their commercial value.

Although supply chains naturally tend to strive toward minimizing energy use since it is a major operating cost for all modes, there are other important overriding economic efficiency factors impacting intermodal decisions. For transportation providers, these include labor productivity and equipment life cycles, and for shippers and receivers, major concerns include inventory carrying costs and cash flow (e.g., shortening the in-transit times shortens the period between when goods are paid for and sold).

APPLICABILITY OF CURRENT PERFORMANCE MEASURES

Energy usage in intermodal freight transportation can be evaluated in four areas: line-haul, equipment utilization/repositioning, temperature control, and terminal transfer operations.

Line-Haul

Approximately 71% of U.S. petroleum consumption is used by the transportation sector. Rail uses only 2.13% of this total while accounting for 40% of all domestic freight movements (U.S. Senate 2010). This rail energy advantage is reflected in Table 1, which shows rail to be around 10 times more energy efficient than truck (Davis et. al. 2009). This advantage continues to improve with advances in locomotive technology, tribology (friction, wear, lubrication), and material science

making possible lighter and more durable rolling stock. For example, a five-unit articulated double stack well car sharing axles and wheels with other car units results in the highest ratio of freight weight to total train weight than any other rail rolling stock.

Table 1: Comparative Freight Mode Energy Efficiency

Transportation Mode	BTU per short ton mile	kJ per ton kilometer
Class I Railroads	341	246
Heavy Trucks	3,357	2,426

Source: Davis et al., 2009.

Despite double stack well cars being the most energy efficient means to move freight over land, intermodal includes other factors that have a profound impact on overall fuel usage. Additional line haul mileage from less direct rail routes (e.g., built alongside winding rivers), drayage mileage at the origin and destination, terminal energy consumption, and gradients for the rail route all contribute to diminish the estimated energy efficiency advantage of intermodal rail down to a multiple of 2.75 to 5.5 times greater than trucking (ICF Consulting 2009).

Though barges have been advocated as an efficient means of moving intermodal containers, any barge energy efficiency advantage is primarily attributable to very slow speeds. Thus, from an energy sustainability and economic efficiency perspective, using barges to transport containers is only appropriate for low value and non-time sensitive freight, or for inland ports that are relatively close to the port terminal.

Energy measures for intermodal services also must account for the reality of equipment weight relative to freight weight. In particular, trailer loads have a significant tare weight advantage over the heavier container and chassis combination. This means that drayage fuel economy will be slightly lower for any given weight of freight, and the freight weight that can be carried will be less. However, this drayage operation disadvantage is often partially offset by the weight of the over-the-road sleeper berth.

Another freight network inefficiency is that overweight roadway limits for the drayage leg puts a cap on the ton-miles per gallon advantage that can be achieved on rails. This has been mitigated in some states by systems allowing overweight drayage trucks to haul freight to and from intermodal terminals and combination trucks of two or more trailers. Raising weight limits for all trucks improves trucking efficiency, but would negatively affect freight efficiency because it will cause a modal shift away from rail. On the other hand, permits that allow overweight trucks only on routes to and from intermodal terminals positively affect both rail efficiency in terms of increasing returns to density and freight efficiency.

As supply chain management continues to make strides in reducing the size and weight of packaging, an increasing percentage of loads are "cubing out," implying that a load exhausts a container's volume well before exceeding its weight limit. It is likely that more ship lines will offer greater quantities of 53-foot containers to match the standard truck length in the United States. This is a more efficient strategy than the practice of transloading near the port (e.g., the contents of three ISO 40s transferred into two domestic 53-foot containers). In 2007, the ship line APL began offering 53-foot container service in Los Angeles for high-value and time-dependent loads to be quickly trucked from the ports to their final local destinations. Despite demand from the supply chain (Journal of Commerce 2011), the usage of 53-foot containers remains very limited since container ship holding cells are designed to accommodate 20- or 40-foot containers.

Equipment Utilization and Repositioning

Better equipment utilization permits smaller and more productive fleets, which lowers capital costs and the energy required to manufacture the materials used in chassis and containers. Chassis

utilization is a perplexing problem for the industry (Zumerchik et. al. 2009). While a small number of chassis results in an inability to support modal transfers, too many result in increasing marginal costs (storage, rehandling, and damage costs). Industry sources estimate the North American fleet to be around 820,000 (Mitchell 2007, Prince 2008), indicating a very low utilization rate. For 38 to 39 million chassis moves per year the mean chassis utilization rate would be less than four trips per month (Intermodal Association of America 2011).

Aside from utilization, containers face an empty repositioning problem. Containers are either not available, or when they are, the cost of repositioning and drayage costs are prohibitive. Moreover, because of the considerably higher container rates imposed on inbound trips, which are trade imbalance driven, ship lines often reposition their empty containers back to Asian export markets immediately instead of waiting for the availability of an export load. The performance measure of average container dwell at the terminals gives some indirect insight into container and chassis utilization. Extended free container time before demurrage charges, up to 10 days at some marine terminals, obviously works against better container and chassis utilization. Both the container and chassis are effectively unproductive transportation units when serving as a warehouse on wheels at terminals and receiver facilities.

Improving motor carrier efficiency is critical since motor carriers must interface with both shippers and receivers, and represent the critical first and last mile of every intermodal trip. Even though the percentage and mean distance of empty backhauls are considerably greater for over-the-road freight than for intermodal (ICF Consulting 2009), intermodal has a greater potential to reduce empty mile energy consumption with better container repositioning strategies, strategically positioned empty container depots, more intermodal terminals, more chassis and container pick up locations, and more efficient drayage operations (e.g., reducing chassis-related delays and costs).

Temperature Protection in Transit

Typically, 0.4 to 1.7 gallons per hour of diesel fuel are burned to control product temperature in transit (Shurepower LLC 2005), which must be added to the energy for transport. For a standard refrigerated container, energy efficiency is impacted by the added weight of the equipment and fuel, or the reduced internal volume because of the insulation in the floor, ceiling, and sidewalls. Although over 12% of tractor and trailer load originations use refrigerated containers (ACT Research 2007), the number of products requiring some form of temperature protection, depending on seasonal conditions and length of transit, is considerably greater. Protection classes include frozen, chilled, conditioned, protected, and ambient, with either large or small recommended or required temperature variance. For shorter transits or for products with less stringent required temperature variances, passively protecting temperature-sensitive products in dry containers saves significant energy compared with climate controlled containers. Unfortunately, dark painted containers, favored for the cleaner more presentable look, makes providing passive heat protection more difficult. During a static field test, when the daytime high temperature reached 25°C, the internal air temperature of a high albedo (reflective) white painted container rose to 38°C (52% greater than daytime high), while that of a low albedo (absorptive) brown-painted container rose much more to 50°C (100% greater than daytime high) (DWD 1989). Without the additional weight of climate control equipment and fuel, shipping passively in high albedo containers also can allow for more cases per container. Further, passively shipping temperature-sensitive products addresses the reality of a shortage of refrigerated containers, and allows for consolidation of loads to achieve more cases per load by mixing classes of freight.

Climate controlled trailers and containers parked dockside for use as additional warehousing are often a part of the supply chain warehousing decision. This affords greater flexibility, but it is the most energy intensive option and reduces intermodal equipment utilization. At the other extreme is underground storage such as Subtropolis outside of Kansas City. Subtropolis, a former limestone

mine that spans 4.5 square kilometers, retains an ambient temperature in the range of 18 to 21 degrees Celsius year round. For the warehousing of temperature controlled products, energy costs at the Subtropolis are about 50%-70% less than they are for conventional warehousing (Hunt Midwest 2008). Although supply chains have effective tools to account for advanced carbon reductions strategies, there exists no widely accepted methodologies for temperature-controlled product transportation and storage, which are considerably more energy intensive than shelf stable product shipments.

Modal Transfers

Despite many states claiming intermodal connections as an important criterion of their freight transportation system, McMullen and Monsere (2010) found that few evaluate the performance of their intermodal rail or port facilities. Barber and Grobar (2001) looked at performance measures at the San Pedro Ports, but the measures were to determine capacity, throughput, and productivity. Productivity is the only measure that can have energy implications. For example, crane productivity can be increased by operating cranes more hours each day (utilization), or achieving more lifts per operating hour (efficiency), fewer moves per container transfer, or the distance moved per container for transfer. However, only the latter two, involving terminal operation and design, have energy implications.

Determining transfer energy consumption is, in its simplest form, about determining the amount of handling during the transfer process: the number of times a container is handled, the number of operations involved in interchange, the distance over which a container is handled within a terminal, and the handling of chassis and hostler usage to bring containers trackside or to storage areas. Better terminal designs result in energy conservation benefits, which provide far greater savings than energy efficiency gains by eliminating handling processes altogether, as opposed to continuing the same processes, but with more energy efficient equipment. The European EcoTransit methodology for intermodal, which assigns a universal value of 4.4 kWh per intermodal transfer (IFEU Heidelberg et al. 2010), is of limited utility because of the wide variations in container handling operations. For example, a hoist height of 30 feet (atop containers stacked three-high) requires significantly more energy than for 10 feet. The same is true for a container requiring several rehandling lifts compared to a transfer requiring none. Beyond lifts, there is tremendous potential to conserve energy by eliminating or reducing the need for yard tractors, concentrating all rail transfer activities under widespan gantry cranes instead of at remote storage areas, and terminal designs that eliminate switching, and railroad grade conflicts, minimize within terminal drayage mileage, and direct all roadway traffic moves in one direction (idling and safety benefit).

Intermodal terminals consist of three interactive operations: gate, transferring (ramp/berth), and storage. The storage function can be "stacked," which uses remote and the center row (rail) to store containers, or "wheeled" with containers stored on chassis. Generally, small volume rail terminals use primarily wheeled operations, and higher volume terminals use wheeled and stack storage. The minimally mechanized wheeled operation transfers containers with one lift, not requiring multiple lifts like a stack terminal, but requires much more land to store chassis and park containers on chassis.

None of the current terminal metrics gives a direct insight into energy conservation and efficiency. However, these can be calculated. For yard tractors and vehicles that move and stack containers, the energy profile for a terminal can be determined by the distance traveled per transfer, along with idling time per transfer waiting on a crane (yard tractor), or the time needed for a container crane (crane spreader) to engage a container's four corner castings. Likewise for cranes, an energy profile can be determined by the mean lifts per modal transfer, mean distance per lift, and whether the operation involves single cycling or double cycling.

Significant potential exists for crane productivity and energy conservation gains with double cycling to reduce the number of cycles required to turn a vessel or train. Rail terminal modeling by

Goodchild et al. (2011) showed that cycles could be reduced by almost 50% and crane gantry travel by 75% to turn a train. The faster and more reliable trains are turned around, the fewer locomotives and well cars are needed to service a particular corridor, and the fewer loading tracks are needed in the terminal. For shipping lines, port turnaround times tend to be more significant to maintain schedule integrity than the number of vessels allocated to a maritime route. Turnaround times are a function of the cranes available, utilization (container lifts per crane), and cycle times. Cycle times in lifts per container gantry crane-hour are usually 25-40 moves per hour for quay cranes, and 40-60 for rail cranes (Tioga 2010).

Another important factor is the concept of immediate selectivity, which is the unloading and loading of containers in a manner so that cranes, trucks, and yard tractors do not have to wait on each other. The cranes unloading and loading vessels and trains require significant synchronization with yard tractors to minimize waiting, and the same holds for cranes servicing drayage trucks for container yards. The enormous amount of time in the terminal that trucks consume fuel while the engines idle, estimated to be about 0.82 gallon/hour (US EPA 2002), can be dramatically curtailed by terminals that provide immediate selection. Since terminals are optimized for crane productivity, the lack of immediate selectivity resulting in diesel engine idling is predominantly a problem for drayage trucks.

Lack of immediate selectivity is not reflected in current terminal freight efficiency metrics that primarily focus on land use productivity and capacity. The most common is throughput density expressed in TEU per acre per year. It is the annual throughput divided by the size of the terminal, which is not a meaningful measure to compare wheeled operations, stacking operations, and terminals that do both. For example, the port of Singapore handles over 24,000 TEU per acre per year compared with only around 4,500 at the San Pedro ports (Tioga Group 2010). Stacking reduces land costs while increasing handling costs. This metric also cannot account for the unique operations of each port. Again, while Singapore is a transshipment hub with about 95% of its traffic ship-to-ship, the San Pedro ports are gateways with the bulk of the traffic bound to their hinterland, and include acreage devoted to on-dock rail. Singapore can thus contend with much higher stacking densities since the containers are transferred between ships. On the other hand, lower TEU per acre for wheeled terminals is often justified because of lower handling costs. Though a wheeled terminal requires fewer lifts and cranes, the downside is that sprawling wheeled terminals are more labor, time, and energy intensive, especially when compared with stack operations that move all chassis storage outside of the gates, eliminating maintenance, repair, racking, inspections, and chassis flips (transfer a container from a bad chassis to a good chassis).

Throughput density is a function of average container dwell time, which has significant freight efficiency implications. The shorter the average container dwell time, the higher the throughput density of a given terminal. Reducing the average container dwell time from seven to four days can increase terminal capacity from 4,500 to 7,900 TEUs per acre (Sisson 2003). More importantly, this reduces the number of rehandling lifts required for stack terminals, and the size of the chassis fleet for wheeled terminals. However, reducing free dwell time before demurrage charges can put pressure on terminal gates and local access roads since customers have fewer options to pick up their cargo.

The standard practice of not charging for container storage at terminals is inefficient and the more extended free time before demurrage charges begin could add to freight inefficiency. The problem is similar to employer-provided free parking for passenger vehicles. Studies have found that employer-provided free parking subsidies are one of the greatest impediments to commuting and carpooling (Shoup and Breinholt 1997). Use of the container yard as a supply chain buffer is effectively giving something away free that has a significant cost to the provider, not only the opportunity cost of using the land for some other productive use, but also the cost of constructing, gating, monitoring, and maintaining the container yard. Nevertheless, this practice is likely to continue as ports with excess capacity offer longer free dwell times as a competitive advantage.

Terminals without excess capacity must find solutions. A general assumption is that the freight inefficiencies associated with stacking and the multitude of chassis costs and utilization problems of wheeled operations (Zumerchik et al. 2009) are unavoidable. One technology that will positively address these major equipment and labor productivity weaknesses of both wheeled and stack operations is the Automated Transfer Management Systems (ATMS) in Figure 1 (Zumerchik et al. 2009). As an interim step, ATMS in combination with appointments would be effective for a wheeled terminal or a mixed wheeled and stack terminal. Wheeled containers would be loaded into the stack side ATMS by the yard tractor drivers before the dray appointment time (Huyhn and Zumerchik 2010). In essence, the appointment would initiate the chassis flip by completing half the chassis flip operation before the driver arrives. The objective would be for dray firms to make appointments so that the container is transferred into an ATMS for immediate selection before the driver's arrival. Terminals with ATMS also would reduce the fuel wasted idling while waiting for a chassis to flip a few minutes instead of up to two hours at some terminals (Harrison et al. 2009). Further, if ATMS systems are vessel or track side, terminals achieve much lower operating costs as well as decreasing marginal costs. Although the authors know of no average and marginal cost curves for intermodal terminals to date, every current terminal experiences increasing marginal costs well before reaching their design capacity.

Except for drayage mileage per intermodal transit, metrics for comparing energy implications of terminal location alternatives, in conjunction with terminal efficiency, have yet to be developed. There is also the drayage driving distance picking up and dropping off equipment within the terminal to consider, which will vary by terminal design and chassis requirements. For example, the drayage driver who arrives at the Port Elizabeth terminal (New Jersey) dropping off and picking up a chassis can travel up to 1.7 more miles in the terminal than drivers coming and going with their own chassis. Thus, replacing a conventional terminal with a well-designed modern terminal can eliminate millions of truck and yard tractor in-terminal miles annually.

Figure 1: A 2-High ATMS Positioned Perpendicular to the Tracks, with WSG Crane and Loading Tracks in the Background

The design of the rail freight network itself holds enormous potential as the largely point-to-point network evolves toward more of a hub-and-spoke model. When freight requires interchange between an eastern and western railroad for transcontinental rail freight flows, high-value and/or time-dependent containers are trucked across town, which effectively doubles terminal processes. In the Chicago area alone there are about 20,000 cross-towns a day (Butler 2010). Thus, better coordination between rail systems would result in enormous energy savings (Rodrigue 2008, Lanigan et. al. 2007).

New Terminal Metrics

For comparative analysis of terminal efficiency, Mi-Jack has developed two new metrics—container capacity per acre (CCPA) and container handling efficiency factor (CHEF)—to measure a terminal's capacity in relation to handling efficiency. CCPA is the annual transfer capacity for inbound and outbound transfers divided by the total acres of land required for the transfer operation. For a one million annual transfer terminal on 450 acres, the CCPA is 2,222 (1 million/450). Higher CCPAs indicate more efficient use of terminal land. For example, sprawling primarily wheeled operations with large areas dedicated to chassis storage will have a much lower CCPA than primarily stacking operations requiring a smaller chassis fleet, or a fleet located outside the terminal gates. Whereas CCPA is a land productivity measure, CHEF measures the number of lifts and internal handlings to perform one million modal transfers. It captures all handling for inbound or outbound completion of the modal transfer, all activities to and from storage from the well cars or sea vessel, and rehandling lifts required for the delivery of outbound and loading of inbound containers to the truck carrier.

Historically, the initial criterion for designing rail or port terminals is the number of transfers per year for inbound and outbound shipments. The number of internal lifts and handling was not a major consideration because technology limited terminal design choices. However, new technology like ATMS can result in major efficiency gains through reductions in handling. For terminals, the maximum efficiency is one lift per modal transfer. In other words, each container transferred is handled once with no internal handling and lifts.

Assuming no live lifts directly onto a truck carrier's chassis, conventional wheeled terminals require a minimum of two internal handlings per container to complete the modal transfer (e.g., a yard tractor to bring the chassis to trackside followed by moving the chassis and/or container to a storage area). This results in three million total handlings annually for one million modal transfers:

      1 million transfers/450 acres = 2,222 CCPA
      2 million internal handlings
      3 million transfers and handlings/450 acres = 6,667 CHEF

Because each transfer also includes a minimum of two internal handlings, the maximum efficiency for this wheeled terminal operation is a CHEF of 6,667. This also indicates that the maximum efficiency ATMS terminal is three times more efficient than conventional wheeled terminals.

CHEF can track handling efficiency for whatever are the actual total internal handlings and lifts needed for modal transfers. When a terminal runs out of chassis and must start grounding or stacking containers, this adds a minimum of two additional lifts per transfer (yard tractor-stack, and stack-truck carrier), making a minimum of five. This would raise the CHEF to 11,111 as shown below.

      1 million transfers/450 acres = 2,222 CCPA
      4 million internal handlings and lifts
      5 million/450 acres = 11,111 CHEF

The lift total also must include rehandling lifts to reach containers at the bottom of stacks. If the terminal needed 800,000 rehandling lifts annually, the following calculations show the total would be 5.8 million lifts for one million modal transfers, resulting in a CHEF of 12,889:

     1 million transfers/450 acres = 2,222 CCPA

     4.8 million internal handlings and lifts

     5.8 million/450 acres = 12,889 CHEF

To confirm the usefulness of CCPA and CHEF for energy-based sustainability analysis, Table 2 compares the lifts and internal handling for an emerging inline ATMS rail terminal design on 71 acres to a primarily wheeled (650 acres) and 60% stacked (350 acres) terminals for one million modal transfers annually. For the 60% stacked terminal, replacing rubber tire gantry cranes with widespan cranes to reduce the need for yard tractor shuttling would significantly improve CHEF.

By keeping all terminal activities concentrated under the widespan cranes, the inline ATMS terminal significantly reduces energy consumption from 510,417 to 168,750 gallons (67% less) for stacked terminals, and from 837,000 to 168,750 gallons (80% less) for wheeled terminals, and can be located on only 71 acres of land for a very high CCPA and CHEF of 14,085:

     1 million transfers/71 acres = 14,085 CCPA

     0 internal handlings and lifts

     1 million/71 acres = 14,085 CHEF

Whereas it is well-known that wheeled operations are the most energy intensive (i.e., the higher the volume of drayage and yard tractor trips the greater the distance per trip), few realize they also entail the highest operating costs. Wheeled operations are often presented more favorably than in reality (e.g., Tioga Group 2010) when the analysis ignores land costs and chassis storage that may take up to 35% of a terminal's land (Kelly 2010). Similarly, a favorable presentation may occur if the analysis ignores the increasing marginal costs of maintenance and repair of chassis fleets (e.g., racking and stacking damage), the large chassis fleet required, and the costs assumed by other parties. From a staging of container cost perspective, shuttling containers between storage and trackside is considerably more costly than stack-well car lifts of widespan cranes. By allowing the truck carrier self-service staging, a major benefit of the inline ATMS terminal is container staging for train loading at no cost to the railroad. This efficiency benefit, and the sequencing delay time savings benefit associated with fewer phases/events/movements for the inline ATMS terminal, are additional operational cost benefits not captured by CHEF and CCPA.

With the collection and tracking of lift and handling activity, the CHEF and CCPA effectively can capture efficiency gains from new operations, designs, and technology, including information technology designed to limit rehandling lifts. A secondary benefit of this measure is that by focusing efforts on reducing the number of times a container is handled, the terminal is improving safety and reducing the risk of damaging the container and freight inside it.

OPERATION AND SUPPLY CHAIN MITIGATING FACTORS

Although reducing energy costs is of paramount importance, often economic efficiency factors, such as equipment and labor costs, inventory carrying costs, and cash flow considerations, are a higher priority than capturing energy-based advantages. For example, rail and water shipments require cost analysis to determine whether line-haul economies, which include fuel savings, warrant the resulting operational and energy-related diseconomies. The introduction of double stack trains generated tremendous economies of density benefits without any additional tracks, which more than offset the diseconomies associated with the effective doubling of container volume at the terminals. However, mega containerships may be another matter. Railways and highways are not an open ocean. This raises the question if the benefits of transit fuel efficiency and economies of scale more than offset the energy cost and the cost of landside diseconomies mega ships require. These ships also require longer periods to load and unload, greater container handling, longer container dwell times, greater road and rail congestion, and major new investments that are required for new berths, larger cranes, higher clearance bridges, and channel dredging. Unless container handling is efficient, and most of the containers arrive and depart quickly and efficiently by on-dock or near-dock railway, servicing mega containerships will increase energy consumption per container throughput on the

Table 2: One Million Annual Transfers (500,000 Truck-Rail Inbound; 500,000 Rail-Truck Outbound)

	Wheeled*	60% Stacked	Inline ATMS
Acres	650	350	77
Yard Tractors (YT)			
Trips to/from Storage (no "live" or "direct" lifts)[1]	2,000,000	2,000,000	WSG; not applicable
Mean Distance/Trip (miles)[2]	1.5	0.75	WSG; not applicable
Mileage	3,000,000	1,500,000	WSG; not applicable
Fuel Consumption (6 mpg)[3]	500,000	250,000	-
Crane Lifts/Transfers[4]			
Unloading Wellcars	500,000	500,000	500,000
Inbound (Import) Storage (YT-Stack, Stack-Truck)[5]		600,000	not applicable
Outbound (Export) Storage (Truck-Stack, Stack-YT)[6]	-	600,000	not applicable
Rehandling Lifts and Flips[7]	50,000	300,000	
Loading Wellcars	500,000	500,000	500,000
Total Lifts	1,050,000	2,500,000	1,000,000
Fuel Consumption (40 lifts/hr; 6 g/hr)[8]	4,375	10,417	4,167
Double Cycling Fuel Savings 50%[9]	-	-	2,083
Total Fuel Consumption of Cranes	4,375	10,417	2,083
Total Lifts and Handling	3,050,000	4,500,000	1,000,000
CCPA	1,538.46	2,857.14	14,062.72
CHEF	4,846.15	12,857.14	14,062.72
Drayage Trucks			
Trips	1,000,000	1,000,000	1,000,000
Mean Miles In-Terminal[10]	2.0	1.5	1
Fuel Consumption[11]	333,333	250,000	166,667
Total (gallons)	837,708	510,417	168,750
Carbon Emissions lbs. (22.384 lbs./gallon)	18,751,263	11,425,167	3,777,300
Carbon Emissions (Metric Tons)	8,505	5,182	1,713
Fuel Cost ($3.25 gallon)	$ 2,722,552	$ 1,658,854	$ 548,438

*Assumption of no chassis shortages requiring containers to be grounded/stacked.

[1] 1M empty chassis/bobtail + 1M chassis/container = 2M trips; when chassis dropped trackside for next inbound train, it requires bobtail move.

[2] Mean mileage to and from trackside and the storage area; more real estate requires more miles: Wheeled > Stacked.

[3] Idling fuel consumption to connect/disconnect chassis not included.

[4] Assumes no chassis lifts; if chassis storage is limited, it would require adding stacking/racking lifts.

[5] 10% stacked for Wheeled (run out of chassis) and 10% wheeled for Stacked Terminal (e.g., reefers left wheeled).

[6] For Wheeled terminals, all outbound containers are left on chassis.

[7] Flips and rehandling lifts vary significantly by terminal; here 10% for Wheeled and 40% for Stacked.

[8] Lifts/hour and gallons/hour for diesel RTG; other container handling equipment performance/fuel consumption will vary.

[9] Not possible current terminals; double cycling: no empty moves, 50% fewer cycles, 50% less operating time (Goodchild,2010).

[10] Estimate of respectively 1 and 0.5 greater miles for chassis processes at Wheeled and Stacked (port of NYNJ it is 1.7 miles).

[11] ATMS automated communication, less idling, lugging, and delays (one way traffic, no grade crossings) ensures even less fuel use.

Source: Calculated by the authors.

hinterland side. Yet, since the total line haul cost, including interest payments, depreciation, fuel, crewing, and maintenance per TEU, is 14% less on a 10,000 TEU vessel than a 5,000 TEU vessel (Smil 2010), many major ports are planning to accommodate the greater container surges expected as more mega containerships start calling at North American ports.

LABOR PRODUCTIVITY AND EQUIPMENT LIFE CYCLE CONCERNS

In the movement of freight from origin to destination, labor productivity can be measured in man-hours per trip. Aside from line haul time, all truckload, less than truckload, and intermodal freight involve time at the origin and destination, which varies depending on how quickly trucks are processed. While this time is comparable for trucking and intermodal, a container traveling in a 100 well car-double stack train requires far fewer line-haul man-hours than 200 tractor-trailers traveling by highway. But some of this intermodal line-haul labor advantage is offset at the terminals. For example, rail terminals require gate processors, crane operators, yard tractor drivers, ramp workers, searchers for misplaced containers, maintenance and repair personnel, and chassis and container inspectors. For intermodal rail, the fewest man-hours per intermodal transit can be achieved with longer unit trains over greater distances, faster train and truck turn times, and shorter drayage distances. Gross labor productivity at intermodal rail or marine terminals is measured by the number of moves per man-hour. Given the standard full-time work for one employee of 2000 man-hours per year, marine terminals generally achieve somewhere between 800-1500 TEUs per full-time employee per year, or 0.4 to 0.75 TEUs per man-hour (USDOT MARAD 1998).

In terms of miles driven per hour, it is far less for drayage drivers than for over-the-road drivers because of shorter trips, terminal congestion, and delays. For a wheeled terminal, it can take well over two hours to disconnect one chassis, connect another, hook up the lights and brakes, inspect the equipment, and fill out a Driver Vehicle Inspection Report (DVIR) for both the chassis being dropped off and the one picked up. Although experienced drivers with knowledge of a terminal's operation usually endure short turn times (Harrison et al. 2009), there is great potential to improve drayage productivity (Transportation Research Board 2011).

Because of the long expected life cycles of container handling equipment (often over 25 years), energy sustainability improvements, which also would be improving terminal labor productivity, will be incremental within current terminal designs and operations. Moreover, there are widely varying capital costs, productivity (lift cycles/hour), and operating costs that entail complex tradeoffs. For example, the capital cost of a double-engine vehicle used to move and stack containers (straddle carriers), is less than the cost of a rubber tired (RTG) and a rail-mounted (RMG) gantry crane, but requires significantly more maintenance. Because the combination of container handling equipment is often dictated by operational design, transitioning to an energy conserving terminal design is problematic since the change involves replacing existing equipment.

THE SUPPLY CHAIN AND SPEED EFFICIENCY

Freight shipping decisions are based on total logistics costs, which include the costs of inventory, warehousing, and transportation. The trend has been toward more just-in-time, and a shift from a demand-driven instead of a supply-driven supply chain. Characterizing a firm's decisions is difficult since shippers are not a homogeneous group. There are varying business models, and the market is dynamic with the introduction of new technologies, and continual changes in customer requirements and supply-chain strategies affecting inventory levels and distribution strategies such as transloading, point-of-sale distribution, direct shipments, and load consolidation. For example, while transloading is a less energy efficient strategy for intermodal containers headed to hinterland distribution centers than the norm, collaborative distribution involving multiple shippers consolidating and combining their shipments to create truckloads and direct ship strategies that bypass distribution centers, result in significant energy savings.

Because energy is a major cost of transporting freight, supply-chain managers will choose more energy efficient rail and water alternatives, but only when total logistics costs warrant those choices. For instance, intermodal transits sometimes take more days than trucked freight, so there is a "speed lag" cost to consider in determining the total logistics costs of a supply chain. Intermodal rail also carries the risk of missing train cut-off times, which can increase transit times. Based on the average value per volume or average value per ton, it is possible to calculate per-day inventory carrying costs to the receiver and the cash-flow costs to the supplier from delayed payment so that the "speed lag" costs can be determined. Terms of payment, whether shipping is controlled or arranged by the shipper or receiver, and whether freight is being transported for pre-sold orders versus replenishment of inventory, also have implications for desired speed.

Of related importance is greater accountability and transparency in meeting customer commitments for multi-modal transit moving through multiple terminals. The Canadian National Railway addressed this issue in 2010 by instituting a supply-chain scorecard that specifies performance targets and service measures, and calls for balanced accountability among supply-chain participants to provide better end-to-end transportation solutions that would help mutual customers compete more effectively in end markets (Morgeau 2010).

PUBLIC COST: MEASURING INFRASTRUCTURE EFFICIENCY

The social costs of truck emissions, congestion and safety, and highway and bridge repair are enormous and make it difficult to quantify the social benefits from public-private partnerships designed to divert more freight to more energy efficient rail than to greater highway capacity, dedicated truck lanes, and highways.

Emissions

Public funding of transportation projects are often judged by attaining environmental goals of reducing gaseous or particulate matter emissions by focusing on comparing the replacement technology to the current technology. Taking this approach often does not translate into freight efficiency improvements. For example, Table 2 shows that an intermodal terminal design that conserves energy by reducing handling will result in a better return on investment in terms of energy savings and emission reductions (e.g., lower cost per ton of particulate matter or reductions in nitrogen oxide emissions) than a technology replacement or retrofits that provide cleaner and more energy efficient equipment.

Congestion and Safety

Congestion, as an inefficiency factor, is not easily measured, but can be indirectly assessed with average speeds along highways or rail corridors, and the percentage of time that freight is not moving. Increasingly, this has been captured by the supply chain with equipment tracking technology more so for over-the-road trailers than for intermodal containers. Although North American railroads have invested heavily to upgrade their intermodal networks for higher speeds, sharing access with slower freight trains, Amtrak, and local passenger trains results in a considerable amount of idle time waiting along rail sidings or inside or outside terminals for traffic to clear. Not surprisingly, a tracked container moving from California to Atlanta was found to be in motion for less than 50% of the time (Elango et al. 2008). Because performance along corridors varies widely, information on idle time and average speed while in motion broken down by corridor would be helpful to better understand congestion-related delays along rail intermodal corridors.

Intermodal rail infrastructure investments are being considered to improve roadway safety and reduce highway fatalities because the fatality rate associated with the movement of intermodal containers by rail has been estimated to be nine times safer than moving similar containers by

truck (U.S. Department of Transportation 2010). Despite the safety benefit of greater volumes of freight moving intermodal, measures do not exist that quantify the benefits of a public investment in intermodal in terms of less energy wasted, reduced accidents, and fatalities.

Highway and Bridge Maintenance

Shifting 50 million of the 300 million long-distance truck originations of more than 300 miles (ACT Research 2007) to intermodal has the potential to dramatically reduce the wear and tear on bridges and highways. Since fuel taxes and fees cover only about 50% of the costs of highways and bridge maintenance and repair (Dutzik et al. 2011), any increase in intermodal market share will simultaneously increase freight energy efficiency while shrinking the difficult to quantify deficit between highway tax/fee revenue from trucks and the maintenance/repair costs caused by trucks.

CONCLUSIONS

Up until recently, the focus in assessing the performance of intermodal transportation was mostly on modal and terminal capacity and throughput. While these assessments remain entirely valid, economic and environmental considerations are primarily being used to assess investments such as raising bridge and tunnel clearances for double stack service, double tracking congested corridors, adding more and longer rail sidings, and new or retrofitted terminals. Largely by default, emissions have developed into one of the primary quantitative criteria used in analyzing public-private partnership funding of intermodal freight investments. This is an understandable development. Unlike other criteria such as safety, congestion, and highway maintenance, emission reductions can be quantified and objectively compared. Unfortunately, emission reductions are a poor indicator of freight efficiency. Thus, in an era of limited availability of public funding, maximizing returns on investment is even more salient.

Energy-based freight efficiency analysis ensures the best public and private return on investment in reaching the national goal of getting a much greater share of freight off the highways and on the railways. Whether freight efficiency is evaluated strictly in terms of energy-based sustainability, or includes economic efficiency and social factors as well, additional metrics like CCPA and CHEF, which can be applied to any rail or port terminal in North America to determine its efficiency, are clearly valuable. All aspects of intermodal freight transportation need to be analyzed so that robust carbon accounting methodologies and tools can be developed.

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Jack Lanigan, Sr., *Chairman of the Board, Mi-Jack Products Inc. Since founding Mi-Jack in 1954, Mr. Lanigan has been credited with collaborating with the railroads on many important intermodal innovations. Mr. Lanigan introduced the first Drott reliable overhead rubber tire gantry crane in 1963 for TOFC (trucks on flat cars), now called intermodal. Working with the Santa Fe in the mid-1960s, Lanigan helped convince the shipping industry to standardize container lengths and corner castings so that the railroads (Santa Fe, Union Pacific, and the Southern Pacific) could accommodate all the ship lines' containers, which made the landbridge feasible. In 1967, Mi-Jack delivered the first crane with the twist lock top pick for the new standardized container, but because Matsen, APL, and Sealand all had different corner castings and container sizes, Lanigan developed a corner side latch as a temporary top pick for the nonstandard containers during the transition. In the late 1970s, Lanigan worked with the Southern Pacific Railroad and APL on the top spreader that would accommodate the high side wall double stack car, and at the same time encouraged the development of the low side wall so that any type of side loader or overhead crane could load or unload double stack cars. Aside from equipment innovation, Mr. Lanigan is credited with developing the 2 for 1 terminal design (now the standard), and establishing one of the largest rail and port terminal operations in the nation, culminating in the 1997 Mi-Jack/Kansas City Railway Company joint venture to rebuild and operate the Panama Canal Railway to significantly reduce the volume of trucks transporting containers across the Isthmus highway. Lanigan was awarded the Intermodal Association of North America's Silver King Award (1989) and Intermodal Achievement Award (1992 on behalf of Mi-Jack) in acknowledgement of his contributions. David DeBoer in "Piggyback and Containers: A History of Rail Intermodal on America's Steel Highway" states that intermodal pioneers like Lanigan "cared so deeply about improving the business that they went substantially beyond the normal manufacturer-customer relationship. They often became missionaries for improvements that were only indirectly related to their primary products." www.mi-jack.com*

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