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Minimodal: Dimensional Domain of Miniature Shipping Containers for Intermodal Freight Transportation

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MINIMODAL: DIMENSIONAL DOMAIN OF MINIATURE SHIPPING CONTAINERS FOR INTERMODAL FREIGHT TRANSPORTATION

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Abstract

This study explores the feasibility of miniature shipping container usage within existing intermodal transportation (IT) supply chains. Smaller intermodal container shipments may help realign freight shipments with the most efficient transportation mode, rail. These containers embolden the dimensional domain (DD) of shipping. The shipping container dimensional domain (container size variation and modal fluidity) is widespread and results in shipments that are often larger or more infrequent than needed. The DD impacts: transport mode, shipping frequency, shipment velocity, intermodal supply chain accessibility, and regional shipping networks. This study suggests that container size impacts the DD and, therefore, mode choice.

As miniature shipping containers may be used to delineate between large and one-off specialized shipments, inventories are leaned out and warehousing functions shift towards the supply chain. Several organizations may be affected such as ports, railroads, over-the-road and less-than-truckload trucking companies, shippers, buyers, and trans-loading facilities. Therefore, this paper will explore Minimodal's (MM) integrational feasibility with an evaluation of rail efficiency over trucking efficiency, standard operating procedures, and the emboldening of the dimensional domain. Additionally, future research efforts may further examine the dimensional domain of shipping, and to what extent container size impacts mode choice.

Keywords: Intermodal, intermodal transportation, miniature shipping container(s), Minimodal, dimensional domain of shipping, twenty-foot equivalent (TEU), velocity, container size optimization, trans-load(ing), feasibility, OTR and LTL trucking, lumpy shipments, transportation sharing.

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Introduction

The purpose of this study is to understand the integrational feasibility of miniature shipping container usage within existing intermodal transportation supply chains. At this stage, miniature shipping containers will be generally defined as Minimodal (MM). The referenced containers will be 1/16 the size of a twenty-foot equivalent unit (TEU). Shipping containers are widely used throughout intermodal transportation (IT) as a means of standardizing shipment sizes, accelerating embarkment and disembarkation, and consolidating load destinations.

Intermodal transportation, moving goods by more than one mode of transportation, is a shipping marvel that has reshaped, resized, and globalized the world economy. This process combines truck, rail, ocean carriers, and shipper resources to move freight. According to the Association of American Railroads (AAR) the United States (US), rail intermodal volumes increased from 3.1 million containers and trailers shipped in 1980 to 13.7 million containers and trailers shipped in 2015 (AAR, 2016). It is expected that rail IT will continue to grow as the US economy continues to compete in a continually changing global environment, especially since the Panama Canal Authority widened the Panama Canal.

A wider canal is needed to facilitate Pacific-Atlantic oceanic navigation for post-panamax ships. Post-panamax ships carry 10,000 TEU shipping containers (World Shipping Council, 2006). They are roughly twice the size of ships that could previously pass through the ante-magnus canal. Such a canal significantly lowers the cost of transporting shipping containers to the US East Coast. This will result in container traffic shifting away from the duopolistic east-west intermodal rail corridors that Class 1 railroads, Union Pacific (UP) and BNSF Railway (BNSF), have. Conversely, eastern railroads should experience an influx of business as more traffic is directed to eastern ports.

Eastern railway infrastructure may need updating, and western railroads should look at continuously adding value to their west-east overland transport corridors. The tradeoffs for truck-rail conversion must be great enough to persuade shippers to abandon over-the-road (OTR) and national less-than-truck-load (LTL) trucking companies to make the switch to rail intermodal. Much of the IT literature is focused on operational efficiencies where shippers need to ship large quantities within economies of scale, which have nonlinear costs (Bierwirth, Kirschstein, & Meisel, 2012). While operational efficiencies are important, railroad companies must remember that their services are subject to the service life cycle and they will, over time, mature. As new technology and procedures are implemented, railroads may find limited opportunities to compete. Elon Musk and Richard Branson’s Hyperloop projects may be future contenders, especially if they are convertible to freight transportation.

Review of Related Literature

Since MM is a relatively new concept and related literature is lacking, overcapacity, container size development, external and internal costs, shipping domains, and developing megaregions are examined. Developments in the global shipping industry created excess capacity that depressed freight tariffs, resulting in overcapacity.

Overcapacity will force prices down if railroads only focus on operational efficiency; railroads are already faced with cyclical and seasonal capacitive constraints. Ocean liners learned about the woes of overcapacity as ocean transport fares fell while capacity continued to increase (Lim, 1998). Recent traffic rerouting because of the Panama Canal expansion will impact inland IT firms, which are greatly affected by containerization. Class 1 railroads and trucking companies must focus on differentiation and adding value to existing IT services to counter these effects. Continual innovation and service development strengthens logistical information flows creating hyper-connected supply chain networks.

Regarding the hyper-connectivity of the global economy, it is necessary to consider that more shipping options must be made available. Traffic reroutes, infrastructure improvements, cyclical capacity woes, and expensive overland trucking fares have created an opportunity for shippers to nudge in a niche IT service that can siphon traffic from OTR/LTL carriers. Using smaller shipping containers in rail and trucking IT supply chains may do this. Smaller containers are already made, yet they are rarely used in IT. Economies of scope and integration can assist in MM adoption.

The integrational feasibility of MM shipping containers may allow for greater flexibility amongst shippers. Shippers could choose to either ship via OTR/LTL or rail with regional drayage companies delivering freight to its destination. Container size is not usually questioned as most ocean liners opt for 20 and 40 ft. shipping containers (Zhang, Yun, & Kopfer, 2015). There is already, however, development in container size variety, and CTX-Containex offers shipping containers that are as small as 6.5’ L x 6.4’ W x 6.25’ H, or 260 ft^3 (CTX-Containex, 2017). These containers provide more size variety and differing functionality.

Intermodal transportation is a function of the economy that is ever changing and adapting to business needs, and it is diverse in application. Since businesses are universally connected to transportation, productivity gains must continue to incrementally enhance the operating conditions that support IT. Using MM shipping containers within existing infrastructure to embolden the dimensional domain (DD) of shipping may improve IT productivity. Additionally, trucking inefficiencies disproportionately distort rail IT functionality.

Per mile trucking fares are one such inefficiency, and they do not completely reflect underlying costs associated with freight movement. The literature by Sahin, Yilmaz, Ust, Guneri, Gulsun, & Turan (2014) appropriates these highway infrastructure depletion charges by vehicle unit. These are recognized as unpriced negative externalities, and they include: infrastructure damage, accident risk, traffic congestion, pollution, and noise emission. External and internal costs both produce unintended consequences on society. Because of the DD, Minimodal container use may help realign these unpriced negative externalities with the proper transport mode.

There are four domains that affect the IT supply chain: logistical, transport, infrastructural, and locational (Notteboom, & Rodrigue, 2009). Each of these domains must be emboldened for rail IT services to remain competitive and profitable. The DD of shipping—regarding different container sizes to maximize shipment source diversity—will directly affect the velocity and frequency of shipping. Velocity is a primary metric that transportation companies use to gauge fleet performance. Velocity measures the speed that equipment travels over a rail network (BNSF, 2013). To increase velocity, trans-loading times (the length of time it takes to stage, sort, load and unload freight) must decrease. Principle shippers and buyers must be responsible for this time charge, and not logistical and transportation organizations. By using Minimodal containers, the

IT productivity curve will shift outward as velocity and supply chain accessibility are realized. As supply chains are made more accessible, megaregion development will further increase demand for regionally-centered transportation hubs.

US megaregion growth will determine the development of future regional shipping networks. Therefore, Megaregions provide the catalyst for new productivity advances within the shipping industry. Any productivity enhancements must be closely integrated with these networks. Increases in regional shipments are sure to augment stress to related highway infrastructure. Reducing the number of package handling instances can segue international and domestic shipments from Megaregion service areas to the smallest inland customer while reducing shipping costs.

Megaregions have a higher share of road transport, which adds to traffic congestion (Dablanc & Ross, 2012). Traffic congestion will increase as more freight is moved by truck and infrastructure spending remains stagnant. Increasingly, just-in-time delivery requires efficient warehousing that increases the number of handling instances for a shipment. These movements add to congestion and encourage logistical sprawl.

Traditionally, warehouses were located near rail stations and city centers; however, with the enormity of modern-day fulfillment centers, cheap countryside land, and highway, airport, and waterway access, warehouses are increasingly located in suburban and exurban areas (Dablanc et. al.). This creates a transportation system that is increasingly in flux, and, while using static locations for warehousing, needs more variety in shipment size for bulk movements.

Areas of interest

Academic literature on IT is extensive, and literature concerning efficiency maximization is especially common. It seems, however, that literature on miniature container usage is lacking. This is not surprising since miniature shipping containers are a somewhat recent notion. As MM adoption increases more freight will be moved by one-off orders, thereby further leaning out inventories and increasing delivery frequency. This feasibility study will include:

- **Cost Efficiency**
    - External and internal costs
- **Operating Procedures**
    - Government, railroad, trucking company, and trans-loading
- **Dimensional Domain**
    - Velocity, proposed dimensional domain

Feasibility Study

The study is designed so that a conclusion will be drawn regarding the feasibility of integrating MM containers into existing IT supply chains; additionally, cost efficiency will be examined for justification. This will include the interoperability of such containers between government regulators, standards authorities, transportation firms, and logistical providers.

Cost Efficiency

Intermodal rail transport saves money while maintaining acceptable lead times to market. Even though the truck-rail cost differential is significant, businesses continue to transport freight by truck instead of rail. This occurs partly because the external costs of infrastructure repair and replacement are not properly factored into diesel fuel prices resulting in a significant subsidy for the trucking industry.

Unpriced External Costs
(2014 cents per ton-mile)

Type of Cost	Truck Costs*	Rail Costs*
Pavement Damage	0.74–0.96	0.05–0.06
Traffic Congestion	0.42–0.90	0–0.03
Accident Risk	0.85–2.28	0.11–0.25
Emissions: PM and NO_x	0.59–0.80	0.13–0.24
Emissions: $CO_2^{\dagger}$	0.02–0.22–0.92	0.007–0.05–0.24
Total	**2.62–5.86**	**0.30–0.82**

Note. Figure 1 from: "Pricing freight transport to account for external costs; U.S. Congress. Congressional Budget Office (CBO)" by D. Austin, 2016, *Congressional Publications.*

These external costs can be around eight times higher for trucks versus rail (Austin, 2016). Additionally, there are external rail infrastructure costs, but railroad companies usually pay for them. Railroad companies maintain and build their own infrastructure. The Congressional Budget Office (Austin, 2016) notes that trucking cost per ton-mile varies from $2.62—5.86, while rail external cost per ton-mile varies from

$0.30—0.82. Figure 1 highlights these differentials.

External Costs. A mathematical model, formulated by Sahin et al. (2014), shows how unpriced negative externality variables c_{ac}, c_p, c_n (respectively, costs from accidents, pollution by emission, and noise pollution) are unaccounted for by freight costs. The equation lacks a variable that models unaccounted external costs associated per unit ton-mile for infrastructure depreciation. In this feasibility study, unassociated infrastructure depletion charges are represented as variable c_i. However, Sahin et al. (2014) factors investment costs on a per vehicle basis for road transportation even though vehicles vary in size and load limits. Heavier loads deplete infrastructure at faster rates; therefore, load limits justify cost apportionment by weight. Thus, it is better to equate infrastructure depreciation costs as a function of unit ton-miles and not vehicle units. While actual estimates are beyond the scope of this paper, the following adapted equation estimates the present value of external costs.

$$U_{ex} = \frac{\left(c_{ac} + c_p + c_n + c_i\right)\ L\sum_{t=1}^{n}\ \left((1+e_x)/(1+r)\right)^t}{(1+e_x)\sum_{t=1}^{n}[(1+r)^{-t}]}\left(\frac{Y_d^*}{Y_d}\right)$$

Figure 2. Note, adapted from: Sahin et. al. (2014). Equation now includes variable c_i to account for unpriced infrastructure depletion.

U_{ex} = External costs per unit
c_{ac} = Accident costs
c_p = Pollution costs
c_n = Noise pollution costs
c_i = Infrast. depletion costs

Y_d^* = Reference fullness ratio
Y_d =Average fullness ratio
e_x = External cost escalation rate
L = Route length
r = Discount rate

Internal costs. The internal costs of constructing one mile of rail versus one mile of interstate highway also results in cost differentials. The cost to build an additional lane of highway to an interstate can cost $15 million dollars but only $2 million to $4 million to add a mile of railroad (AAR, 2016). Therefore, there should be more emphasis on building railroad infrastructure than trucking infrastructure based solely on cost. Even so, adding extra rail capacity in an unstructured method would result in costs too high for single companies to maintain; it would be economically unfeasible (Pazour, Meller, & Pohl, 2010). Infrastructure investment must be implemented in high-traffic rail corridors that add the most velocity to the rail network. These high-speed corridors can connect emerging megaregions one by one until the network is complete. Minimodal shipping containers may augment domestic demand for intermodal rail by offering more container size options, thus increasing modality while maintaining current rail miles.

Negative Externality Cost Differential. Below are sample computations that estimate cost differentials between a 1000-mile delivery by truck with a 1000-mile delivery by using both truck and rail transportation. Transloading costs are not factored into the outcomes. Rather, it is a simple calculation using CBO unpriced negative externality data. The total differentials highlight significant rail over trucking efficiency.

1000-mile delivery: Truck only

Miles	Pavement	Traffic	Accident	Emission PM, NO_x	Emission CO_2	Total
*Truck Cost	.74-.96	.42-.90	.85-2.28	.59-.80	.02-.22-.92	2.62-5.86
Truck x 1000	**740-960**	**420-900**	**850-2280**	**590-800**	**20-220-920**	**$2620-5860**

*Table 1. Adapted from Figure 1. CBO (2016)

1000-mile delivery: Truck (100-miles) and rail (900-miles)

Miles	Pavement	Traffic	Accident	Emission PM, NO_x	Emission CO_2	Total
*Rail Cost	.05-.06	0-.03	.11-.25	.13-.24	.007-.05-.24	.30-.82
Rail x 900	**45-54**	**0-27**	**99-225**	**117-216**	**6.3-45-216**	**$270-738**
*Truck Cost	.74-.96	.42-.90	.85-2.28	.59-.80	.02-.22-.92	2.62-5.86
Truck x 100	**74-96**	**42-90**	**85-228**	**59-80**	**2-22-92**	**$262-586**
Total Cost	**119-150**	**42-117**	**184-453**	**176-296**	**8.3-67-308**	**$532-1324**

* Table 2. Adapted from Figure 1. CBO (2016)

Rail is clearly more externally efficient than trucking. The trouble is that rail creates an additional layer of logistical complexity to shipments. However, rail cost efficiency can be transferred through these additional logistical layers by following generally accepted government, third party, and private enterprise operating procedures.

Operating Procedures

Government Procedures. Many governing bodies participate in intermodal transportation regulation. These regulations define IT operations, and any adjunct transportation processes or schema must adhere to them. Operating agreements, challenges and opportunities, transportation planning, federal registration, and actual government litigation are factors that affect intermodal transportation. The most influential and relevant sources of legislation, enactments, and regulation are analyzed below.

USDA standard operating agreement. This document is important because it defines who is considered as an IMC, and how they will interact with the USDA when providing IT service. The Standard Operating Agreement Governing Intermodal Transportation "establish[es] the trailer on flatcar/container on flatcar (TOFC/COFC)…service needs of the [USDA] for the movement of…freight, and to ensure that the Intermodal Marketing Company (IMC) arranging for the transportation service has both the willingness and the capability to meet these needs" (USDA, 1999, p. 1). Since MM transportation could potentially carry agricultural commodities it is necessary to analyze this document.

The document defines an IMC both in continental US and non-contiguous US operating contexts. These companies shuttle empty and loaded trailers and/or shipping containers between destinations, are liable for loading procedures, and must safely and accurately transport the shipment while maintaining sufficient insurance coverage. Additionally, IMCs are required to maintain business relationships with at least one railroad.

These conditions are hereby sufficient to allow for IMCs to carry MM shipping containers between destinations and interact with both the USDA, shippers, and consignees. As outlined in **Item 150:c** there is support for intermodal transportation between an IMC and railyards, which is physically imperative for intermodal operations to occur (USDA, 1999).

Quick response freight manual II. The Federal Highway Administration (FHWA) authored the Quick Response Freight Manual II (ORFM) with the intention of providing a source document that contains valuable, transportation-related information for development of transportation networks and other activities centered around freight planning. The ORFM addresses relational concerns between transportation modes, infrastructure planning, resource allocation, and mathematical modeling. Within the manual, different characteristics of IT are defined as generally accepted practices and procedures, which aides in freight planning and policy making (USDOT, 2017a). Minimodal must also be defined and accepted as a viable type of container to be used in shipping and, although a pedantic MM definition need not be unnecessarily contained therein, the Manual should at the least reference the benefits or drawbacks of container size variation.

Intermodal Market Area. Section 13.3.1 specifically references drayage procedures where, “distances exceeding the intermodal market area, the drayage costs relative to the total intermodal transportation cost become too prohibitive for the entire truck-rail intermodal move to be cost-effective" (USDOT, 2107a, p. 13-4). Cost prohibition for full-sized truck transport is a definite setback for intermodal transportation where an intermodal market area may only expand a few hundred miles. Running hot shot (using non-traditional trucks for delivery) MM deliveries may outperform conventional full-sized truck delivery thereby increasing the intermodal market area.

Intermediary facilities function within trucking networks where a variety of techniques are used to reapportion freight to its proper destination. Cross-docking is frequently used for LTL trucking with minimal warehousing occurring. Trans-loading is more warehouse intensive where shipments may be handled by an intermediate warehouse before it is transloaded onto a truck, train, plane, barge, or ship. Since these networks already exist there is strong support for any type of MM activity. With these supporting networks, shippers could choose to utilize whichever option best fulfilled the shipment's needs. Additionally, as shipments flow from one mode to another via intermodal networks information may be gleaned as to the timing, location, and inventory of the shipment, thus supporting independent container transference.

Transportation planning process. Coordination efforts between transportation regions are addressed by this paper from the USDOT. Therefore, existing infrastructure must be optimized by implementing multimodal and intermodal transportation systems (USDOT, 2017b). Transportation planning efforts consider trip generation and distribution, mode split, and network assignment (USDOT, 2017b). Minimodal directly affects each of these four modeling steps, although it will assimilate similar IT practices that are already used.

Four-step modeling process. Modeling transportation demand assists in understanding the operational solvency of a potential market. There are four steps used for this modeling: trip generation, trip distribution, mode split, and network assignment. Transportation performance for a specific market should be thoroughly modeled while allowing for potential changes to be fairly represented as they develop. Robust transportation models allow for fair representations of how changes in a market may affect freight tariffs, traffic congestion, land use, and emissions output. These models will be needed for a thorough analysis of any impacts MM may have in any given intermodal market.

Data from readily available intelligent transportation systems (ITS) can close gaps caused by model distortion. Although heuristics may seem too forward for implementing new systems, data gathered from similar IT shipping container usage should be incorporated into transportation models. Models, ITS, and data are all readily available for use in MM.

Intermodal surface transportation efficiency act of 1991 (ISTEA). This legislation authorized and appropriated funds for completing an IT system in the US. It states, "that it is U.S. policy to develop a national intermodal transportation…system that is economically efficient, is environmentally sound, provides the foundation for the nation to compete in the global economy, and will move people and goods in an energy efficient manner" (United States. Congress, 1991, para. 1). A national transportation system is essential for IT to allow US access to world markets. One could argue that, because of its infrastructure, the US is globally connected. ISTEA is probably the most comprehensive since the interstate system was developed by President Eisenhower.

ISTEA explicitly allocates resources for preparing feasibility studies, mobility and innovative projects, and "priority intermodal projects throughout the [US]" (US Congress 102^{nd} 1^{st} session, 1991). Foundational, federal support is crucial to any innovative IT developments. States are given grants for developing IT systems, and non-Federal entities may engage in cost-sharing R&D with the Federal Government covering 50 percent or more if projects are of considerable public interest. Emerging trade corridors (megaregions) are of special interest especially if they facilitate trade between Canada and Mexico.

This legislative precedent embraces intermodal transportation R&D while fostering innovation from within transportation sectors. Unaccommodating legislation would consciously limit any sense of entrepreneurship and R&D efforts. Efforts aimed at introducing new transportation processes, technology, or containers will be affected by this Act.

Railroad Procedures: BNSF Intermodal Rules and Policies Guide. Many governmental rules and policy guidelines govern railroad surface transportation. The BNSF Intermodal Rules and Policies Guide specifies rules governing IT, or transportation services rendered by the BNSF Railway (BNSF, 2016). Many of BNSF's rules are modelled after AAR rules and regulations; additional restrictions are placed solely by BNSF. These restrictions affect logistical instructions, equipment, and shipment contents.

Logistical instructions. Before any shipment is to be moved by the BNSF a shipper must "establish credit, arrange for EFT [electronic funds transfer], and sign" (p. 6) a BNSF Intermodal Contract (BNSF, 2016). After these cardinal preconditions, a shipper must then submit shipping instruction to the BNSF. Shipping instructions must include contents, weight, and destination manifests along with any other pertinent information for the safe movement of the cargo. Shippers are subject to these requirements regardless of whether they chose to ship by full sized containers or MM. Therefore, shippers that already have established protocol for engaging with BNSF intermodal facilities are most suitable for the MM concept.

Equipment. Shippers are responsible for loading, bracing, and properly sealing shipping containers. Failure to comply may result in delays and surcharges. Containers must have design elements as outlined by AAR specifications. Container design and construction must be suitable for lifting by appropriate container handling devices. To ensure that equipment fits onto intermodal rail cars BNSF requires that containers have the dimensions shown in Table 3 below. Equipment must be catalogued in the BNSF

Outside length	Minimum 19 feet (or 228 inches) Maximum 53 feet (or 636 inches)
Outside width	Maximum 8 feet, 6 inches (or 102 inches)
Overall height	Maximum 13 feet, 6 inches (or 162 inches), with a maximum suitable lifting height of 9 feet, 6 inches (or 114 inches). Maximum suitable lifting height is measured from the top of the equipment to the bottom of the equipment (excluding tires)
Maximum weight	59,000 pounds

Table 3 from: BNSF Railway, (2016). BNSF intermodal rules and policies guide.

Equipment Register or in the AAR Universal Machine Language Equipment Register. BNSF requires that 20’ containers be tendered in pairs otherwise they may be held until another 20’ container is ready for shipment. This is especially relevant because delays may be incurred if there is not a minimum of two 20’ bulkhead flats with MM containers ready to ship.

Restricted shipments. There are a variety of prohibited and restricted shipments that BNSF allows for intermodal service, and these restrictions do not affect container type. However, "LTL (less than truckload) shipments" (p. 83) are a restricted item (BNSF Railway, 2016). Therefore, it is assumed that LTL refers to trailered shipments or TOFC that are not full loads. There is no mention of less than full container shipments, so the same restrictions may apply for COFC shipments.

Trucking Procedures. Trucks are one of the most important aspect of modern transportation systems. This is because they are the physical connection between principle parties and rail networks. It is not the intent of this paper to minimize the importance of trucks but to reallocate their services to a regionally centralized drayage system. Therefore, it is requisite that trucking, rail, and principle party operations sync. For understanding trucking company perception of MM, a professional opinion was solicited from Tony Spadafora, V.P. of Operations at Denver Intermodal Express (DIX).

There was one concern, and Spadafora stated that the containers must fit onto a "regular 53' intermodal chassis" (personal communication, January 24, 2018). This was the only condition mentioned that could potentially interrupt truck service. In fact, Spadafora ensured that if MM containers could fit on a 53' chassis that DIX "could handle it immediately" (personal communication, January 24, 2018). Additionally, Spadafora explained that DIX writes its procedural manuals from trucking standards manuals such as the **FMCSA: Driver's Handbook on Cargo Securement** and the **AAR Intermodal Loading Guide** (personal communication, January 24, 2018). Accordingly, an evaluation for each manual is made below.

FMCSA: Driver's handbook on cargo securement. The handbook is based on the North American Cargo Securement Standard, and because of federal, state, and provincial statues it is not all inclusive. However, the handbook provides guidance on intermodal container securement and transportation. The requirements cover container transport by both chassis and non-chassis trucks. For securing intermodal containers on a container chassis, integral locking devices must be used, and if a lock is missing, that corner should be secured by alternative means, wire rope or chain (FMCSA, 2003). When containers are moved via non-chassis vehicles, each corner must rest on the vehicle while secured by wire rope, chain, or integral locking devices. There are instances when all four corners do not have to rest on the vehicle. According to the FMCSA (2003), each of the following requirements should be met in such an instance:

- The container is balanced before securement.
- The container does not overhang by more than 1.5 m.
- The container does not interfere with the vehicle's maneuverability.
- The container is secured for movement in all directions.

Association of American Railroads. Certain loading and interchange rules are established by two documents from the AAR. They are the: **AAR: Intermodal Loading Guide (2011)** and **AAR: Intermodal Interchange Rules (2014)**. Where the FMCSA handbook covered trucking container movements, these sets of guidelines and rules respectively govern proper shipping container commodity loading and railroad/trucking interchange. Any shipment made in a MM container would be subject to the rules and guidelines laid out therein.

Hazmat placarding, load limits, weights, loading practices, load disbursement, and other related topics are addressed by the documents. These guidelines mainly focus on the commodity or load being shipped and not the container type. Notwithstanding, this source material offers support for differing container sizes given that many different types of containers with multiple functionalities, specifications, and applications are mentioned within. However, the use of standardized containers made with either AAR or International Organization for Standardization (ISO) standards is mentioned throughout. This is highly relevant because without standardization different government regulations and container sizes would interfere with loading and interchange celerity.

ISO Standardization. International regulation does not fall within the ambit of a singular federal regulatory power, so third parties frequently help with policy making. Therefore, understanding ISO standards for shipping container sizes is paramount. These international standards transpose as a nationally uniform regulation that governs the size, quality, specification, safety, and are quite often fundamental in facilitating trade (ISO, 2017). ISO compliancy will allow MM to interoperate between international carriers without conflict during physical transloading.

Hapag-Lloyd (2018), a container fleet operator, uses a wide variety of containers to satisfy customer requirements. The **Hapag-Lloyd Container Specification** guide lays out quantitative and qualitative container specifications. Forty-foot high cube flatracks and twenty-foot regular flatracks are of interest because they are the bulkhead flats that could carry MM containers. The Hapag-Lloyd specification guide and ISO standards firmly support container size variety. Standardization strengthens innovation by translating raw technology, products, and processes into transferable action into which many players participate. Since the container industry is completely subordinate to standardization, there is a strong case for new container size development which in return strengthens standardization.

Trans-load Procedures. Trans-loading occurs when freight is moved from one transportation mode to another. There are scenarios when trans-loading will apply to MM shipments. Traditionally, hub-and-spoke and cross-docking are very frequented trans-loading methods. Although the nature of these two methods is accommodating for traditional freight, velocity is reduced each time a shipment is handled. Minimodal will require further velocity gains where freight is momentarily, if at all, handled. Cross-docking lacks geographical fluidity because facilities are fixed; however, another method, 'cross-yarding,' can provide similar trans-loading functionality while maximizing velocity.

Hub-and-spoke. Shipments transit from principle parties to intermodal terminals via a hub-and-spoke network. This network allows for freight to be consolidated from many points of origin to a singular destination, which then travel to the intermodal terminal. Even though this allows greater access to the cost savings of rail networks, there are delays, less reliability, and it results in performing additional operations at trans-load facilities (Bektas & Crainic, 2007). Minimodal is designed to reduce unnecessary costs from hub-and-spoke networks as shipment frequency increases, and freight embarkment rates decline.

Transitional embarkation reduces shipment velocity, and warehousing at hub-and-spoke terminals is not ideal for the MM concept although, the transportation networks themselves are. Decreased handling frequency requirements supports cross-docking where shipments are momentarily handled and reapportioned to a geographical area. Hub-and-spoke warehousing for urgent, time-sensitive, and ultra-fluid shipments is entirely unnecessary.

Cross-docking. Trucking companies cross-dock to distribute loads to different geographical areas. Inbound loads are placed on a dock; once there is enough freight destined to a certain area the truck is loaded and shipped. This allows trucking companies to vertically integrate and access a larger portion of the supply chain (Heins, 2013). Cross-docking supports the MM philosophy by using fixed location freight redistribution to external areas, which increases intermodal marketing areas.

Creating a seamless flow between all functions will increase customer retention and differentiate a business by offering one-stop-shipping. Ultimately, cross-docking is also untimely and creates an environment of jumbled shipments that must wait for either trucking resources or pending shipments to fill a geographically destined truck. Therefore, hub-and-spoke network use for shipment delivery to destination by 'cross-yarding' may further increase velocity.

Cross-yarding. Cross-yarding occurs when any available and open common/private area is used to transfer MM containers to another mode. Facility availability is irrelevant as trans-loading is shifted to any available open yard. The MM concept is ideally suited for this type of trans-loading facilitation because of the nature of the containers and size of trucks used. Facilities are no longer needed as trans-loading takes place in the open.

Dimensional Domain

Velocity. Velocity is often the most important metric that railroad companies use to gauge the flows of traffic between terminals. When velocity is low, costs escalate because of congestion, and when it is high, too little traffic

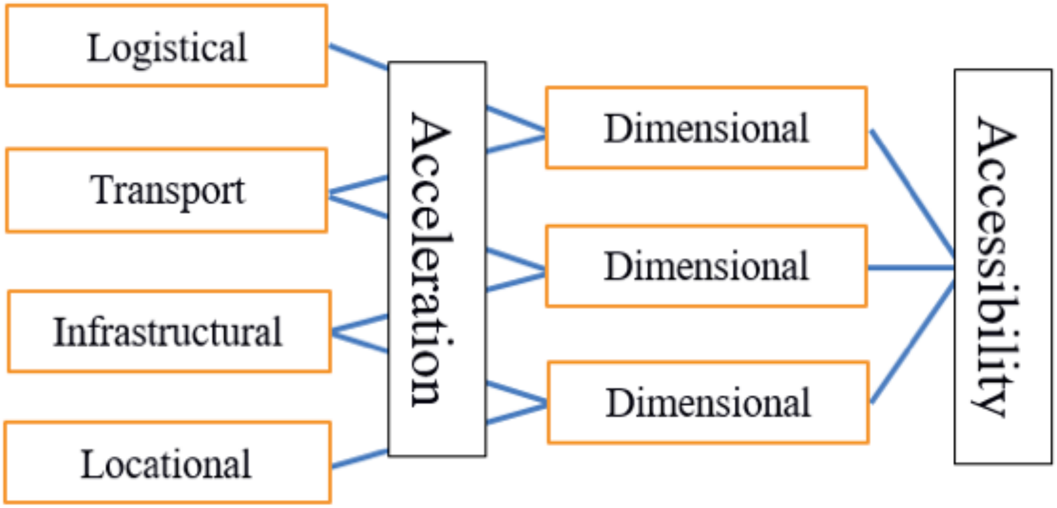
$$Velocity = \frac{\Delta \boldsymbol{d}}{\Delta \boldsymbol{t}}$$

$\Delta \boldsymbol{d}$ = change in distance
$\Delta \boldsymbol{t}$ = change in time

Figure 3. Measure of velocity.

results in trains running smoothly without congestion. Velocity increases capacity when more trains are scheduled into current infrastructure; not only over the road traffic flows but also intermodal operations for train loading and unloading (Notteboom, et al. 2009). The same concept applies to container size. Placing MM containers in a cell block pack that is loaded and unloaded as a single unit will not negatively impact velocity but add to rail capacity. Without drastically increasing investment, rail velocity has possibly reached maximum efficiency with current rail miles. Increasing velocity at trans-loading terminals is an unrealized productivity gain.

Proposed Dimensional Domain. Notteboom et al. (2009), as previously noted, suggests that there are four domains that will affect future containerization efforts: logistical, transport, infrastructural, and locational. Another effect worth noting—a discovery of this study—is the dimensional domain. Dimensional domain involves container size makeup for shipping mix and frequency. Domestic and international shipping can benefit by increasing TEUs shipped. Acceleration and frequency of intermodal usage among small business further opens domestic markets that once were isolated because of economies of scale. Shipping container value density must increase as related packing triggers become more frequent and delivery frequency is increased, thereby contributing to time-based distribution and low inventory levels (Nottenboom, et al., 2009). Figure 4 shows how the DD is interconnected with all other shipping functions while providing access to IT.



Note. Figure 4 “Dimensional Domain” adapted from: Nottenboom, (2009). The future of containerization: Perspectives from maritime and inland freight distribution. *Geojournal, 74(1), 7-22*

Principle parties. Container packing and unpacking functions are the responsibility of shippers and buyers rather than a transportation or logistical firms liability. Transferring loading functions to the source and destination of shipment cuts out wasted time and extricates the supply chain of this accountability. Principle parties must be able to integrate their operation into the IT supply chain. This will require information systems compatibility, which may require extensive use of 3PL logistical services. This study assumes that packing functions are primary party obligations.

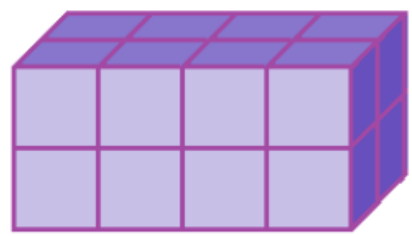
Minimodal Concept

Conceptually, Minimodal delineates freight by geographical area, or customer preference. Shippers can order a single MM container and pack it with other MM containers to form a MM 2-pack, 3-pack, 4-pack, or 5-pack cell block. Any configuration is possible if the containers are the interlocking type; one could configure 16 MM containers with rough dimensions of 4’ 9”L x 4’ 3”W x 6’ 9”H (see dimensions from Table 3; three dimensional drawings provided in Appendix B) into a 16-Pack that has 20 ft. TEU dimensions.

Two 3-pack MM cells on a flat-bed rail car:

Note. Figure 5 adapted from: www.honeycombcargo.com,

Conceptual 16-pack cell block:



Note. Figure 6 adapted from: www.mathspace.com, (2016)

Container Consolidation

When a standard 20ft. or 40 ft. shipping container is not full a logistics provider must fill the excess capacity. This increases the containers profitability per cubic ft.; however, it is time consuming, and excessive material handling, warehousing, drayage, and administrative costs are incurred. Traditional containers, within a respective region of shipping influence (megaregion or country), should be consolidated at a consolidation port; emissions are lowered, and the capacity fill of each container increases (Laik, & Way, 2016). The problem then becomes how to consolidate the freight into one 40 ft. container. The merchandise must be unpacked from the source transportation mode and packed into a destination container. This creates an environment of disarray that unnecessarily adds a time charge to the supply chain. Traditional container consolidation reduces emissions output, while increasing variable trans-loading service charges, and contributes to lost time. Minimodal containers bridge a gap resulting from the unintended consequences of freight consolidation.

Container Size Optimization. Companies that ship nationwide can benefit from container size optimization (CSO) and consolidated shipment within region (CSR) where freight volumes dictate the type of container to be used and consolidation efforts (Laik, & Way, 2016). When a shipment is singular, emissions efficiency is maximized by CSO. When shipments are regular, and occur from multiple points within a megaregion, CSC offers additional emissions savings (Laik, & Way, 2016). Minimodal deleverages economies of scale generating a non-capital-intensive threshold where small businesses can share in IT cost savings.

Businesses rely on hard data for making decisions. Therefore, this paper suggests a theoretical integral to possibly estimate productivity gains from MM usage. The models may be used to measure hypothetical velocity increases between principle parties, trans-loading facilities, and intermodal rail terminals. A theoretical mathematical model representing velocity measurements between integrals is represented in Appendix A.

Proposed Adoption

It is proposed that MM containers be integrated into supply chains. Theoretically, successful MM development depends heavily on realized velocity gains made during transloading. Without increased velocity, the concept is more vulnerable to continued trucking use. Certain businesses may be more attracted to MM than others. Some suitable conditions for MM use are:

- Distances greater than 500 miles
- Closed loop supply chain systems

- Frequent or regular shipments
- Initial penetration of an international market
- Need to reduce lumpy shipments
- US intraregional domestic trade development
- Supply chain sustainability initiatives and efforts
- Transportation sharing economy
- High value and non-urgent products

These situations are more likely to realize MM benefits because of the tradeoff between the cost gap and time differential of truck and combined truck-rail shipment. Maximizing value per product shipped is Minimodal's core benefit. Reducing intermodal transportation barriers to entry and deleveraging economies of scale for small business are additional MM advantages. It is suggested that the Minimodal shipping container be functionally integrated as a viable option when the conditions listed above are met. This will reallocate freight to efficient modes, lower costs, and benefit the economy.

Barriers and Other Inhibitors

As previously mentioned, trucking fares that improperly reflect negative external costs are a real barrier to MM adoption. Although they could be made to properly reflect external costs, it may take significate legislative lobbying to do so. Additionally, time delay coefficients resulting from rail interchange, transloading, general operations, return logistics, and container use maximization are also challenges. Information technology and logistical communication sharing can reduce these effects.

Other business-related questions about demand for the service, target marketing of the service to the right shippers, capital expenditure and cost of capital requirements, and other issues not included in this analysis may also impeded MM development. There may also be significant resistance to MM based on the amount of capital investment needed to make the concept work.

Qualitative resistance may take form as entrenchment mentality, psychological resistance to change, or skepticism. These are potentially serious impediments especially when considering that long-distance trucking fares in no way accurately reflect external costs, thereby fostering a culture of complacent dependence on transcontinental trucking. However, sustainability initiatives are more frequently a core requirement of many supply chain strategies. Innovation provides solutions that can further improve productivity while saving resources, thus improving supply chain sustainability.

Conclusion: Feasibility Evaluation

Free market competition is the moving force underlying transportation innovation, and firms can either adapt or lose competitive prowess. Once the Panama Canal Authority undertook initiatives to widen the canal, west-east transportation firms could no longer enjoy such a rigorous advantage. Shipping is more efficient than rail, and rail more than trucking; the competitive environment has changed.

Through an examination of efficiency justification from internal and external costs, evaluation of government, railroad, trucking, and trans-load facility operating procedures, along with the development of the dimensional domain, a conclusion can be made as to the interoperability of Minimodal shipping containers. The theoretical mathematical model in Appendix A shows potential productivity gains through increased velocity at principle parties, trans-loading facilities, and intermodal terminals, thereby supporting interregional adoption of the Minimodal concept.

Figure 1 from the CBO shows that it is more efficient to ship overland by rail. The internal and negative external costs are expensive and not appropriately reflected in trucking rates. To redirect these LTL/OTR shipments to intermodal shipments, freight railroads must either lobby for higher fuel taxes, or find other innovative ways to convince shippers to use rail more frequently. Realistically, a combination of both higher taxes and innovative solutions should be used. Nonetheless, the financial justification for MM adoption persists.

The government, railroad, trucking, and trans-loading operational procedures studied have, as shown, created an environment that strongly supports container size variety; however, most containers are of the larger type. Intermodal marketing companies, shippers, governments, railroads, and any other concerned parties are free to source whichever type of container for shipping if appropriate handling, loading, tonnage limits, and processes are in place for safe and secure movement over the shipping interval. The depth and breadth of intermodal guidelines, rules, and legislation significantly supports Minimodal use.

Future research efforts may further examine the dimensional domain of shipping, and to what extent container size impacts mode choice. The dimensional domain of shipping will continue to increase as 5G technology, robotics, neural networks, and integrated logistical communication are incorporated into supply chains. As shipment connectivity increases packing triggers will become more frequent and package tracking more precise. Package size will decrease as consumption increases thereby stabilizing demand.

Container size optimization will be further emboldened as many shipments are sourced from increasingly more points of origin. This will continue until there is a nearly constant flow of goods matched by perfect consumption of those goods. Initially, however, the suitable conditions mentioned in the ‘proposed adoption’ section can serve as favorable factors for Minimodal development.

This study on the integrational feasibility of using miniature shipping containers finds that there is strong financial, governmental, infrastructural, and private support for the further development of container size diversity, including Minimodal. However, this study does not take market demand or marketability into consideration. Therefore, further market research is needed to gauge perception and demand for the concept.

Appendix A

Theoretical Mathematical Representation: Minimodal Velocity Gains*

Definite integral:

$$\lim_{n \to 3} \sum_{i=1}^{n} V(t_i)\Delta x = \int_p^r V(t)dt$$

Theoretical Δ in velocity:

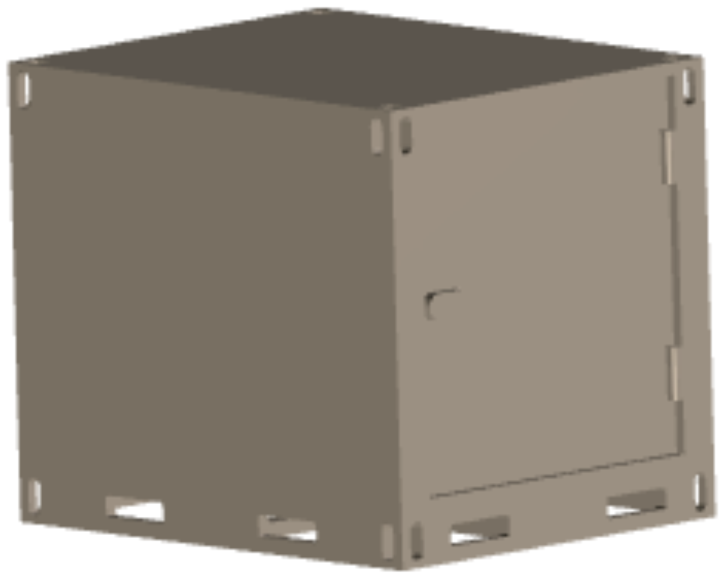
$$\left(\int_p^t V(t)\,dt + \int_t^r V(t)\,dt\right) - \left(\int_{p_m}^{t_m} V(t)\,dt + \int_{t_m}^{r_m} V(t)\,dt\right)$$

p = *principle party*
t = *trans-load facility*
r = *intermodal rail terminal*
m = *Minimodal use*
$V(t)$ = $d'(t)$ = *rate of Δ velocity*

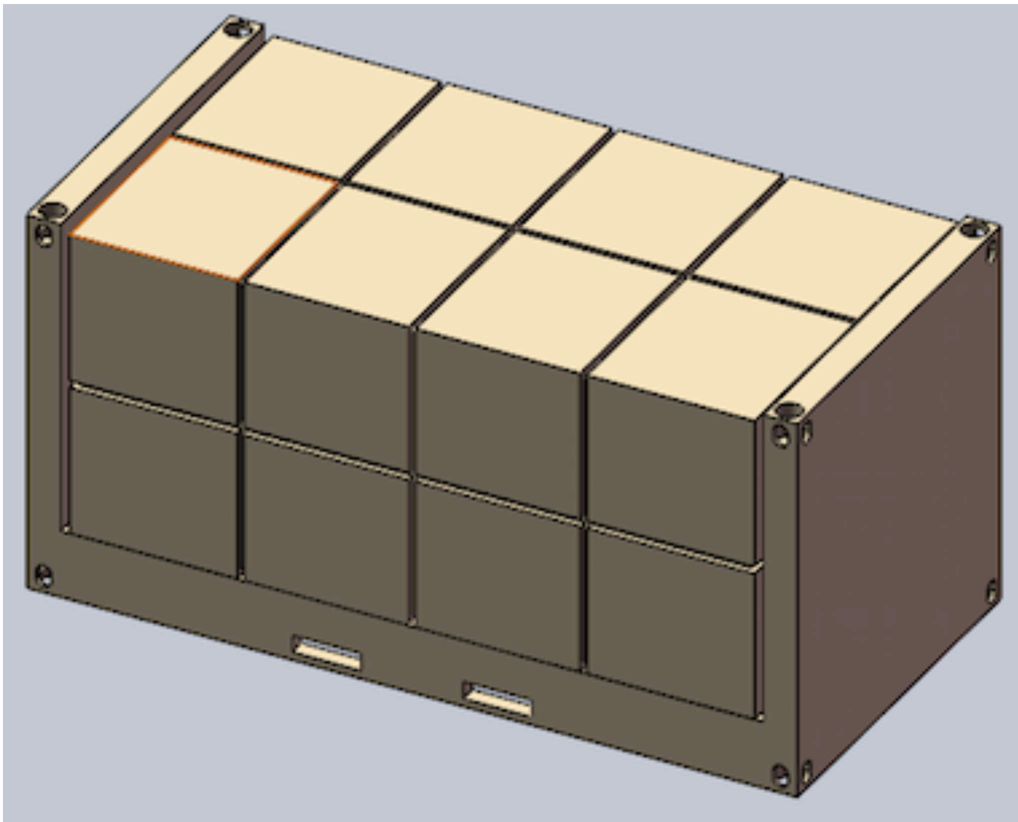
*Integral developed with help from professional mathematicians.

Appendix B

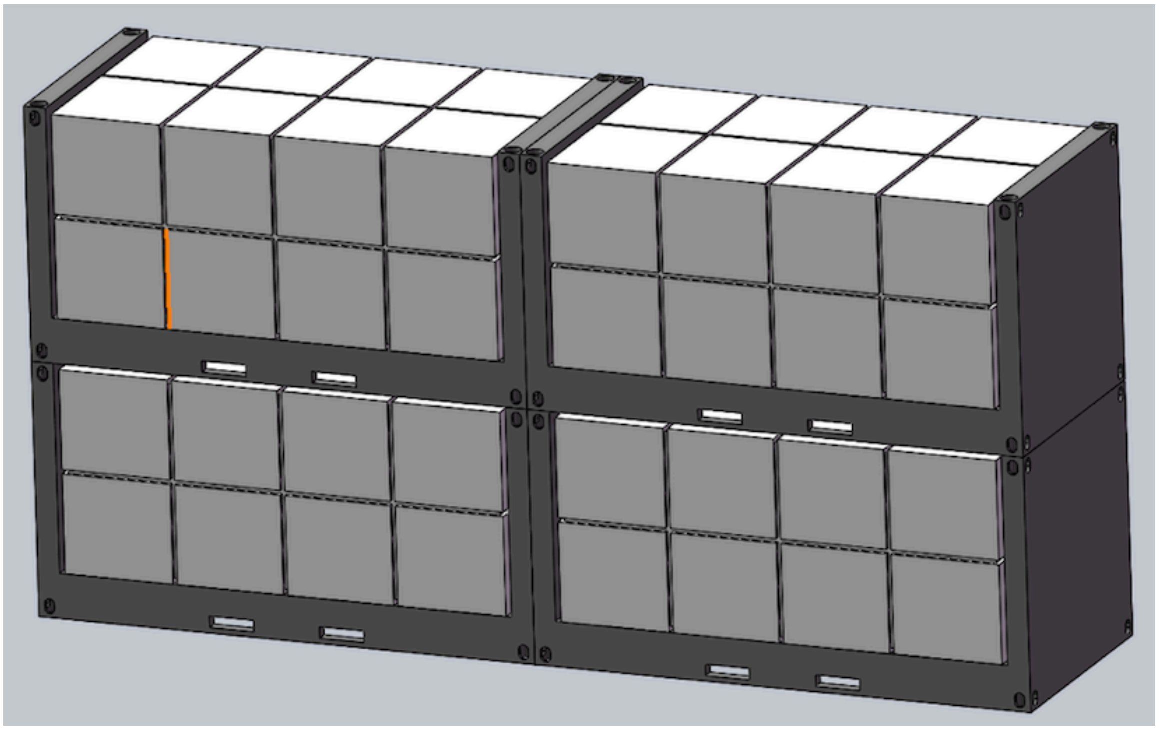
Minimodal: Single container



Minimodal: 16-pack and 20’ bulkhead flatrack



Minimodal: Four 16-packs (fully loaded intermodal rail car)



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