Modeling Intermodal Transportation Systems: Establishing a Common Language

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I. Introduction

"It is the policy of the United States Government to encourage and promote development of a national intermodal transportation system in the United States to move people and goods in an energy efficient manner, provide the foundation for improved productivity, growth, strengthen the Nation's ability to compete in the global economy, and obtain the optimum yield from the Nation's transportation."

—Intermodal Surface Transportation Efficiency Act of 1991

The conduct of technical research requires terminological common ground – widely accepted, clearly defined terms. This paper takes the critical first steps toward developing this common ground in studying intermodal transportation, especially for mathematical modeling of intermodal systems. The terms lay the foundation for mathematically modeling intermodal transportation, making their definition and delineation crucial to the efficient development of useful models for policy analysis and decision-making.

The lack of common terminology arose from the lack of coordination that characterized the development and persists in the operation of the current transportation system. Each of the principal transportation modes uses an independent terminology, which militates against integrated computer models. While the independent terminologies are based in history, they confuse model developers and users in the context of an intermodal future.

According to Barnhart et al. [4], a common terminology base will ease the communication among the different entities involved in intermodal transportation and its study. This terminology base should contain all terminology necessary for describing an intermodal transportation system. This paper briefly reviews the literature on mathematical modeling and assessment of intermodal transportation systems, especially as it helps to define the terminology for constructing mathematical models of intermodal transportation systems. The paper also offers common terms and definitions that cross modal and other disciplinary lines. The paper gives a brief history of the intermodal problem, a short literature review of mathematical modeling of intermodal systems, and describes and defines the terminology necessary to support effective modeling of intermodal systems.

II. A Brief History of the Problem

Four modes of transportation, each with advantages and disadvantages, carry freight and passengers in the U.S.: water, air, rail and road. Water transport inexpensively moves bulk cargo and large numbers of passengers at limited speeds to limited destinations. Air transport rapidly moves cargo and passengers in limited quantities and numbers to limited destinations. Rail transport moves large quantities of cargo over long land routes to limited destinations. Road transport moves cargo and passengers to virtually any destination in limited quantities. This is basic to any understanding of the U.S. transportation system.

Each mode developed independently and even now a separate government agency administers each mode. This independent evolution meant a lack of coordination among the modes that still limits the efficiency of the national transportation system. The independence and lack of coordination underlie USDOT's recent emphasis on intermodal transportation and intermodalism. USDOT hopes that increased modal coordination and study will increase the efficiency and effectiveness of a transportation system [1].

Intermodalism "refers to a transportation system in which the individual modes work together or within their own niches to provide the user with the best choices of service, and in which the consequences on all modes of policies for a single mode are considered" [2]. The potential benefits of an intermodal transportation system include reduced fuel consumption, air pollution, and traffic; increased access to infrastructure through better coordination of bus, rail, and air schedules; and reduced pressure on infrastructure. To help achieve these ends, mathematical modelers will attack systems analysis and design problems like vehicle scheduling, material handling, passenger movement and queuing, resource allocation, inventory control, and maintenance planning. These types of problems exist in other industries and have been successfully addressed using computer simulation, queuing analysis, mathematical programming, probabilistic analysis, graphical analysis, and other approaches.

III. Mathematical Modeling of Intermodal Transportation: A Short Literature Review

The literature on modeling intermodal transportation emphasizes facilities over networks, and although it includes both freight and passenger intermodal facilities, the language, input requirements, and outputs of the models differ greatly even within these categories.

Ship terminal models dominate the intermodal freight literature, with work by Kondratowicz [5], Holguin-Veras and Jara-Diaz [9], Kraman et al. [10], and Park and Noh [12]. Kondratowicz [5] simulated a ship-to-rail intermodal freight terminal using a knowledge base and a set of algorithms. The knowledge base consisted of the physical elements of the terminal and the terminal operations processes–specifics about the loading and unloading of equipment, the type of vessels arriving to the terminal, the storage facilities, the type of cargo being handled, and the interactions among these elements. Kondratowicz defined the vehicle, its arrival frequency and time of first arrival, its economic cost, and its required operations. He described processes by the type of cargo transfer (storage to vehicle, vehicle to vehicle, etc), the type of cargo, a process efficiency measure, and the terminal elements required to carry out the process.

Ward [8] simulated a dockside container intermodal terminal using three sub-models - two container throughput models and a gate complex traffic demand model. The models assume a terminal throughput of 500,000 containers per year. One throughput model predicts capacity requirements, the other optimal operating procedures and equipment for handling the container traffic. The gate complex model determines the lanes, queuing space, and workers required to avoid overloading truck lanes. The simulation produces net productivity of all dock cranes (containers/hour), total net productivity of all rail yard cranes (containers/hour), and the mean cycle time of trucks in the yard (minutes). These measures help determine the best equipment and the best procedures.

Holguin-Veras and Jara-Diaz [9] presented a linear programming model of an intermodal container terminal. The model estimates storage charges to maximize a "pricing" function subject to the storage capacity for containers. They classify containers according to marginal operating costs, space requirements, and price elasticity of dwell times. The objective function is evaluated according to the storage charges placed on each container classification. This price function may maximize profit, or profit subject to a breakeven constraint. The model is constrained by a function of the average stack height, dwell time, and input rate for each container classification.

Kraman et al [10] present a probabilistic model of a port intermodal terminal. An ideal port terminal has enough berths to prevent arriving vessels from having to wait to dock. The model balances the cost of the berths against ship waiting costs, with the optimal number of berths reached when the costs are equal. From this optimal number of berths, an estimate of container throughput can be calculated.

Park and Noh [12] simulated a bulk cargo port. The model evaluates the existing port's capability to support future predicted demand and to evaluate proposed changes in the port's operations. The simulation evaluates the port's performance according to projected future demands and performs the same evaluation for any modification that may be made within the port. An economic analysis determines whether or not the proposed change is economically feasible.

Models of intermodal passenger facilities included work by Lott [6], DiFabraro et al. [7], Boile et al. [11], and Jim and Chang [14]. Lott [6] simulated an intermodal train terminal with personal vehicle, taxi, regional and local bus, courtesy vehicle, rail rapid transit, commuter rail, and high speed rail. The simulation represented segments or passenger interaction areas: waiting lines and areas, corridors, entry/exit areas, open spaces, concessions, restrooms, baggage claim areas, ticketing areas, bus and train platforms, taxi stands, etc. The model delivered information on passenger activity on the bus and train platforms, such as boarding and de-boarding rates and percent occupancies, in up-to-the-minute form or in a complete history of the simulation. The model also gave the average segment time for a passenger, flow rate in/out of a segment, queue lengths and waiting times for service segments, and occupancies in restroom and concession areas, demand for services and total terminal occupancy.

DiFebbraro et al [7] simulated an intermodal passenger transportation system. The model provided passengers on-line, real-time information concerning the status of the system. The system modeled three modes of transportation: buses, underground rail, and above-ground rail. The model defined nodes, macronodes, links, inner links, and events.

Nodes represent a station that serves a mode of transportation. Macronodes represent a combination of nodes. Links represent the paths over which a mode of transportation can travel. Inner links refer to the path taken by a passenger to transfer between two nodes within a macronode. Events are defined as anything that may cause a change in the system. They can represent normal traffic conditions and/or stochastic occurrences within the system. Normal events are arrivals and departures of vehicles to a node. Stochastic events are breakdowns and congestion (for buses).

Boile et al [11] presented a nonlinear programming model of an intermodal commuter network. The model evaluated proposed modifications to an intermodal network based on user and operator costs. The intermodal network consists of auto, auto-to-rail, and pure (walk to rail) rail modes. It is based on a commuter system that consists of five origins and one destination. Paths from the five origins to the one destination include three major highways, several smaller roads, and one rail line with a connecting station at each origin. The model minimizes user costs. The constraints are rail and terminal capacity, demand conservation, and link flow conservation. Also, no passenger can unilaterally change routes or unilaterally change modes. The user costs and capital costs from the model help to determine if the proposed change to the network is acceptable.

Jim and Chang [13] presented a computer simulation model of an airport passenger terminal. The model evaluates the design of a passenger terminal based on passenger flow. The model begins with passenger flow diagrams and uses flight schedules, passenger characteristics, and facility information. The model outputs include statistics on the waiting times, queue lengths and occupancy counts at each service counter.

IV. Terminology

This section defines the terminology for modeling intermodal transportation systems. The terminology base includes transportation terminology as well as mathematical modeling terminology. The terms included in this base are underlined.

Intermodal Transportation Systems

The lack of a consistent definition of intermodal transportation has inhibited the development of a national intermodal transportation system. If the constituencies involved in the development of the system differ on what intermodal transportation means, then the successful implementation of the system will be complicated. Bragdon [15] defines intermodal transportation to be "the safe and efficient integrated movement of people, goods, and information involving air, land, and sea in a four dimensional virtual environment." DiFebbraro et al [8] define it to be "the serial use of different modes of transport to move passengers and/or freight from one place to another." The United States Department of Transportation [16] defines it as "the convenient, rapid, efficient, and safe transfer of people or goods from one mode to another (including end-point pick-up and delivery) during a single journey to provide the highest quality and most comprehensive transportation service for its cost." These definitions cover the broad spectrum of transportation, but some definitions are limited to specific issues in transportation. Jennings and Holcomb [17] argued that these definitions apply "to containers designed and used to move goods via different modes of transportation."

In this research, intermodal transportation is defined in an attempt to incorporate all modes of transportation. *Intermodal transportation* is the shipment of cargo and the movement of people involving more than one mode of transportation during a single, seamless journey. An *intermodal transportation system* is a collection of passengers and cargo moving via multiple modes of transportation, the vehicles that move them, the routes along which they are moved, the terminals at which they are stored, transferred, etc., and the processes which they experience while being moved. These terms are essential to the framework for constructing mathematical models of intermodal transportation systems.

Mathematical Modeling

Constructing mathematical models of intermodal transportation systems falls under the domain of operations research. Operations research can be defined as the "professional discipline that deals with the application of scientific methods of decision making, especially the allocation of resources" [3]. The primary activity in an operations research study is the formulation of a mathematical model of a system.

A *system* is a collection of items that act together toward the accomplishment of some end. The system is the study of the subject of interest, and the focus of this study helps to determine the system boundaries. For example, if the system in question is the operation of an airport terminal, the boundaries will be the walls of the terminal. If the system in question is the operation of a service area within the terminal (ticketing, security, baggage, etc.), the boundaries will be drawn around the area that includes the service activities (the queue area, the service center, and the servers). A *model* is a simplified representation of a system. There are three basic types of models: iconic, analog, and symbolic. Iconic models are scale models, and analog models use different systems with similar behavior to model the system of interest. Symbolic models are based on the logical relationships that drive system behavior. Symbolic models are often referred to as mathematical models.

A *mathematical model* of a system describes system behavior using only equations and logical relationships. Types of mathematical models include probabilistic models, mathematical programming models, and simulation models. In addition to the functional and logical relationships that describe system behavior, mathematical models include several other components. *Decision variables* are the quantities over which the decision-maker (or system manager) has control. *Parameters* are values over which the decision-maker has no control. Examples of decision variables are the number of cranes to be installed at a container berth, or the number parking spaces at an airport terminal. Examples of parameters are the service rate of an agent at a ticket counter, or the arrival rate of trucks to a container terminal. Identifying the decision-maker for a system is an important step in the modeling activity. If the president of a distribution company is the decision-maker, the location of a warehouse might be a decision variable. If the decision-maker is the warehouse manager, then the location of the facility is a parameter.

Constraints are any limitations that may be placed on the decision variables. Examples of constraints are area limitations for dockside cranes at a container terminal, budget limitations for operating an airport terminal, and towing capacity limitations of the trucks used in an intermodal system. A constraint may limit a single decision variable or it may involve two or more decision variables.

Performance measures are quantities that capture the level to which the system is operating. Examples of performance measures are throughput, waiting times, equipment utilization, operating costs, and inventory levels. An *objective function* identifies an important performance measure and the optimization goal (maximize or minimize) for the measure. For example, an objective function may maximize utilization of yard tractors, minimize operating costs of an airport terminal, or maximize the profit generated from a container terminal. In a mathematical model, decision variables, parameters, constraints, performance measures, and objective functions are all captured using equations and/or logical relationships.

Transportation Terminology

The following transportation terms are needed to complete the terminology base for modeling intermodal transportation systems. The terms in this section are essential for modeling intermodal transportation systems.

Cargo

Cargo is any commodity being transported [2]. Cargo may be handled loosely and unpacked, or it may be consolidated and loaded into containers or handled with pallets. A *container* is a structure into which cargo is packed. The container, therefore, may serve as the transfer unit rather than the cargo contained therein [2]. A *pallet* is a platform, with or without sides, on which a number of packages or pieces may be loaded to facilitate handling by a lift vehicle [2].

Passengers

A *passenger* is defined as a person being transported. As passengers are transported across the transportation system, some are associated with passenger cargo. *Baggage* is defined as the trunks, bags, luggage, etc. of a traveler, especially when packed and being used on a trip. [18]

Movement

A *movement* is defined as the process of transporting passengers and/or cargo from one point to another. A movement may represent a train moving along a rail line, an airplane moving through an airway, a passenger walking through a concourse, a container being moved from a ship to a chassis, etc.

Vehicles

A *vehicle* is any equipment used for transporting passengers and/or cargo from one location to another. Each of the different modes of transportation involves a different type of vehicle. An *aircraft* is a vehicle used for traveling through the air. A *vessel* is a vehicle used for traveling via water. A *train* is a vehicle used for traveling over a rail line. An *automobile* is a vehicle used for traveling over a road. Some types of vehicles involve a separate power source from the passenger/cargo hold. *Power transports* are vehicles in which the power source and the passenger and/or cargo hold are comprised by one unit. *Unpowered transports* are vehicles that require an external power source. *Transport power sources* are vehicles used to push or pull unpowered transports. A *towboat* is a transport power source for water transportation. A *barge* is an unpowered transport for water transportation. A *locomotive* is a transport power source for rail transportation. A *railcar* is an unpowered transport for rail transportation. Some railcars are power transports. Examples of these types of railcars are subway cars propelled by an electrical current. A *tractor* is a transport power source used for road transportation. Both *chassis* and *trailers* are unpowered transports used for road transportation. Chassis are coupled with containers to accommodate transport.

Trailers have the cargo hold and wheel frame permanently attached. A *fleet* represents the collection of all the vehicles of a given type involved in a transportation system.

Routes

A *route* is the course or way that is, or is to be, traveled. An *airway* is a route along which aircraft travel. A *waterway* is a route along which vessels travel. A *rail line* is a route along which trains travel. A *road* is a route along which automobiles travel.

Terminals

A *terminal* is any location within an intermodal transportation system where cargo and/or passengers originate, terminate, or are handled in the transportation process [2]. Terminals include facilities that accommodate a wide range of terminal processes (ticketing, inspection, maintenance, vanning/devanning, etc.) or simple loading/unloading processes (bus stops). Within terminals, a *process* is any activity that passengers and/or cargo may encounter. There are many different types of processes. An *entrance* represents the process of passengers and/or cargo arriving to the system boundaries. An *exit* represents the process of passengers and/or cargo leaving the system. *Storage* represents the process of passengers and/or cargo being temporarily stored in some location. A storage process may represent queuing areas, waiting areas, warehouses, and parking areas. Both *service* and *wait until* represent the process of relying on a server to complete a process. The difference in the two processes is the activity of the passengers and/or cargo and the server. In a service, the server remains at a stationary location and the passengers and/or cargo move to the server. In a wait until, the passengers and/or cargo wait at a stationary location until the server arrives to the location. An example of a service is a ticketing counter where a ticketing agent remains stationary. Passengers proceed to the counter as ticketing agents become available. Once the passengers arrive to the counter, they are processed. An example of a wait until is the activity around intermodal loading tracks. This activity involves containers arriving to the loading track area via train or yard tractor. The containers are either parked on the track (resting on the flatcar) or alongside the track (resting on chassis). Once parked, the containers wait until a crane moves to the parking location to be moved from chassis to flat car or vice versa. *Load/unload* represents the process of passengers and/or cargo being loaded onto and/or unloaded from a vehicle. A *decision* represents the process of selecting from the different routes available at the intersection and/or split of modal routes.

INFRASTRUCTURE

The *infrastructure* of a terminal is comprised of the components and areas that accommodate the processes and movements within the terminal. There are infrastructure components related to each mode. A *runway* is a straight path on land, used for the landing and takeoff of airplanes [2]. A *helipad* is a designated area for the landing, takeoff, or parking of helicopters [2]. A *taxiway* is a defined path established for the movement of aircraft from one part of an airport to another [2]. *Aircraft gates* are locations where an aircraft parks to accommodate the loading/unloading of cargo and/or passengers. *Arrival/departure tracks* are rail tracks used to accommodate the arrival and departure of trains into a terminal. *Lead/tail tracks* are rail tracks used to accommodate switching operations within a terminal. *Loading tracks* are rail tracks alongside which trailers and/or chassis/container combinations are parked to accommodate trailer-on-flatcar/container-on-flatcar operations. A *train berth* is a space designated for a train to occupy at a terminal platform to accommodate the loading and unloading of passengers. A *vessel berth* is a space where vessels tie up to a terminal pier to accommodate the loading and unloading of passengers and/or cargo. A *stevedoring area* is a landside area used to accommodate the movement of containers from a vessel to chassis via crane. *Automobile entrance/exit gates* accommodate the processes that automobiles must encounter upon arriving to or departing from a terminal. A *parking lot* is a location where automobiles may be temporarily placed into storage. A *warehouse* is a place for the reception, delivery, consolidation, distribution, and storage of cargo [2]. *Ground storage* areas are places where cargo and/or containers are placed in storage, without shelter.

MATERIAL HANDLING EQUIPMENT

Material handling equipment represents vehicles used for cargo movement within a terminal. A *conveyor* is a moving belt upon which material may be placed for movement. The movement of the belt may be continuous or may be controlled by an operator. A *crane* is machine for lifting or moving heavy weights by means of a movable projecting arm or horizontal beam traveling on an overhead support [18]. A *yard tractor* (doodle bug, yard mule, tug, hustler) is a small tractor used to move trailers, bombcarts, and chassis/container combinations around a terminal yard [2]. A *bombcart* is a wheeled cart pulled by a yard tractor on which cargo, baggage, etc., are placed for transport around a terminal. A *forklift* is a vehicle equipped with hydraulic driven, protruding metal blades that are used to raise and lower palletized cargo [2]. A *reach stacker* is a vehicle with a front-end lifting device used to load and unload containers from chassis and flatcar railcars. A *yard locomotive* (switch engine) is a locomotive that is operated only to perform switching functions within a single terminal area [2]. A *tug* is a vessel with towing knees for moving larger vessels.

Passenger Handling Equipment

Passenger handling equipment represents equipment used for the purpose of moving passengers within a terminal. An *elevator* is a cage or platform and its hoisting machinery for conveying people to different levels [18]. Elevators may also be used to move cargo to different levels. An *escalator* is a power-driven set of stairs arranged like an endless belt that ascend or descend continuously [18]. A *moving sidewalk* is a continuous moving, power-driven belt upon which passengers are moved. Moving sidewalks are located within walking corridors and provide an alternative to walking. *People movers* are power-driven vehicles that follow a defined path (usually rail) in moving passengers from one point within a terminal to another. *Carts* (golf carts, wheelchairs, etc.) are wheeled vehicles that provide transport for passengers unable to walk under their own power.

Personnel

An *operator* is a person who controls the use of any vehicle or material or passenger handling equipment. An *operating crew* is the group of operators required to operate a transportation vehicle. Examples of operators are airplane pilots, train engineers, truck drivers, and crane operators. A *server* is a person who provides the service required for a service or wait process. Examples of servers are ticketing agents, security officers, and baggage handlers.

Miscellaneous Equipment

Miscellaneous Equipment refers to all other resources beyond vehicles, material handling equipment, and passenger handling equipment that are necessary for passengers and/or cargo to complete some process. Examples of equipment are computers, maintenance tools, and fuel trucks.

Procedures and Policies

Procedures and policies are sets of rules or procedures that govern the behavior of an intermodal transportation system. Examples of procedures and/or policies are traffic regulations, hazardous materials legislation, flight schedules, and maintenance plans.

Disruptions

Disruptions are stochastic events that disrupt the normal operations of an intermodal transportation system. Examples of disruptions are weather events, equipment failures, and vehicle accidents.

V. Conclusions

While the ultimate goal of defining a language that is broadly accepted by analysts and the intermodal industry will be difficult to achieve, the terminology base presented in this paper covers a majority of the elements and activity involved in the operation of intermodal transportation systems and provides a foundation for building models of such systems. Undoubtedly, future research will reveal additional terminology and refinements to facilitate the modeling and analysis of intermodal systems. However, an efficient national intermodal transportation system will not be realized unless real problems are defined, models of these problems are constructed, and analysis of model outputs are used to identify and implement the most efficient solutions. The terminology base presented in this paper establishes a common language from which analysts can begin this important endeavor.

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