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CHAPTER 16

Simulation of Logistics and Transportation Systems

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16.1 INTRODUCTION

In highly industrialized nations, a sophisticated and widespread transportation system is an inherent need to provide both passenger and freight movements. Due to the unprecedented need for nationwide mobility, there is a requirement not only for various modes of transport but also increasingly sophisticated interfaces between customers, suppliers, and manufacturing and service industries (Wright and Ashford, 1989). Five modes account for all but a fractional percentage of all ton-mileage of freight and passenger mileage of person-travel: motor vehicles (Parsonson and Thomas, 1976; May 1990; Afshar and Azadivar, 1992; Schulze, 1993; Joshi et al., 1995), railroads (Hay, 1977; Atala et al., 1992), air transport (Ashford and Wright, 1984), water transport (Quinn, 1972; Bruun, 1981), and pipelines (Wolbert, 1979).

In this chapter we describe the application of discrete-event simulation techniques in the design, analysis, and management of logistics and transportation (L&T) systems. First, we outline the current approaches to solving various business problems and explain briefly why simulation methodology is appropriate for this industry. Next, various domains and fundamental issues that are important within L&T systems are identified. The entities, resources, and activities to be considered in the simulation model, and factors and responses (output reports) that are essential for strategic, tactical, and operational analysis of L&T systems are described in detail. Throughout the chapter we present readers with some of the common hurdles encountered during application of simulation methodology and implementation of results within the L&T domain.

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16.2 BACKGROUND

16.2.1 Direct and Indirect Resources in L&T Systems

Typically, an L&T system is built on a network composed of one or more terminals or hubs connected by a set of traffic lanes. Accordingly, the networks form hub-and-spoke arrangements and/or direct linkages between origin and destination (Lee and Fishwick, 1995). These networks and the associated topologies have evolved over long periods of time. Hence it is very expensive and often consumes enormous amounts of time and effort to make radical changes in a network. The L&T systems utilize many resources and we can classify them broadly as (1) *direct resources* used in physical transportation of freight (or physical goods) from one geographic location to another, and (2) *indirect resources* involved in sorting, storing, handling, retrieving, and consolidating at the various transit locations known as flowthrough centers, terminals, or hubs.

In a trucking system, trailers, tractors, and drivers are the *direct* (moving) resources, and the dock doors at terminals, refueling stations, fuelers, and maintenance crews are the *indirect* (stationery) resources. The terms *moving* versus *stationery* are used to distinguish the resources that move longer distances either on the road, air, or water versus the resources that tend to stay at one location (although the resource may have its mobility limited to one geographic location). Similarly, in a warehousing and distribution system, the trucks, aircrafts, and cargo ships are the moving resources; the docks, doors, forklifts, carts, storage bins, and racks inside the warehouse are the stationery resources. The moving (*direct*) resources are used to transport freight from plants to warehouses, distribution centers to customer sites, and so on. Again, in an air transportation system, the *direct* resources are aircraft, pilots, and air containers, and the scissor lifts, tug and dollies, forklifts, and hub personnel are the *indirect* resources (Horonjeff and McKelvey, 1983).

It is important that these two types of resources operate together in the most efficient manner for smooth and balanced operation of the entire L&T network. In addition, management and deployment of these resources must ensure the least amount of delay at terminals and hubs, maximum availability and utilization of resources, and on-time pickup and delivery of physical goods. A well-structured scientifically proven approach is required to accomplish these goals.

16.2.2 Challenges of L&T Systems Modeling

For the past several decades, the design, analysis, and control of transport systems were carried out mostly by field engineers (civil, structural, and traffic engineers) and operations research (OR) scientists (Ashford and Covault, 1978; Hamzawi, 1986; Ashford, 1987). A large number of L&T systems have evolved over time and become fairly huge and complex. The primary goals of an L&T business enterprise are to store, distribute and/or transport freight of varying size, form, and shape from its origin to its destination at the lowest cost in order to deliver the right quantities at the right time to its customers who are geographically dispersed; however, the underlying L&T systems that are built to guarantee on-time, damage-free, shortage-free delivery to customers have become extremely complex and often require expensive administrative, information, and decision support systems (Ashford and Clark, 1975).

Conventional L&T planning involves the development of analytical models for trip generation (Moore, 1957), trip distribution (Schneider, 1967), modal split (Wilson, 1969; Smith and Cleveland, 1976), and traffic assignment (Parsonson and Thomas, 1976). Numerous OR models were developed and applied during the past four decades in the design and configuration of L&T systems (Schiller and Marvin, 1956; Miller 1971; Agerschou et al., 1983; Gibson et al., 1992). In recent years, descriptive modeling of L&T systems has been gaining momentum in transportation companies (Frolow and Sinnott, 1989; Hsin and Wang, 1992; Atala and Carson, 1995; Blair et al., 1995). Computer simulation models are built to evaluate a set of operation policies prior to the implementation of large and complex L&T systems (Nilson and Nicolaou, 1967; Abdus-Samad, 1977; Soros and Zador; 1977).

Major challenges face the analysts in applying simulation technologies to the L&T domain. These can be broadly listed as follows:

- L&T networks are quite complex and involve a very large number of entities and resources.
- Existing simulation software do not support all the modeling/analysis features required.
- There is unfamiliarity of simulation technology in L&T industry.
- Optimization/heuristic methods are widely applied.
- Closed-form solutions are available for many design problems.

However, there are many problem domains within L&T systems, where the simulation approach is best suited if applied properly. For instance, simulation is highly desired for evaluating alternative strategies to operate a terminal (Koh et al., 1994; Manivannan, 1996) or a warehouse. Similarly, the impact of dynamic arrival and departure times of trucks and aircraft at a central hub on time windows and expected service performance can best be understood via computer simulation (Manivannan and Zeimer, 1996).

16.2.3 L&T Problems for Simulation Modeling and Analysis

In general, L&T problems appropriate for simulation studies are divided into three major categories:

1. New design
2. Evaluation of alternative designs
3. Refinement and redesign of existing operations

Accordingly, simulation models in L&T domains are built for the following purposes:

- Models for strategic planning
- Models for tactical planning
- Models for network/traffic control
  - Off-line control
  - Real-time satellite/telecommunication control
- Models for scheduling and dispatching
  - Off-line scheduling
  - Exception handling
  - Real-time monitoring

In this section we outline a list of problems and issues that fall under each of the three categories. Although the list is not exhaustive, it provides critical issues that require effective solution strategies for an L&T business to be successful. The problem areas described in category 1 are solved, in general, using optimization/heuristic approaches. Often, the optimized new L&T designs are verified and validated using computer simulation. The problems outlined in Categories 2 and 3 can be solved using several well-known techniques; however, many L&T businesses tend to utilize simulation modeling and analysis (Kell and Fullerton, 1991; Kelsey and Bisset, 1993; Mabry and Gaudiot, 1994).

1. New Design

- Network design
  - Hub and spoke
  - Direct move
- Terminal/hub planning
  - Number of terminals
  - Location
  - Size (dock dimensions, number of doors)
- Fleet planning
- Route planning
- Least-cost transportation modes

2. Evaluation of Alternative Designs

- Transportation mode alternatives (based on the type of resources)
  - On-the-road (trucks)
    - Relay operations
    - Sleeper operations
  - Rail (trains: single/double stacked)
  - Air (planes, helicopters)
  - Ocean (ships, barges)
- Intermodal alternatives
  - Combine sleeper with rail
  - Combine relay with sleeper
  - Combine rail with relay
  - Combine trucks with air
  - Combine trucks/air with ocean
- Service performance alternatives
  - Overnight service
  - Two-day service
  - Premium service

3. Refinement and Redesign of Existing Operations

- Operational performance analysis
  - On-the-road movements
    - Linehaul, regional, and group operations
    - Terminal operations
    - Operating rules
      - Hooking, unhooking, hostling, and fueling
      - Trailer loading and trailer offloading
      - Dock operations
      - Dispatching
    - Rail movements
      - Loading strategies at the railyard
      - Train timetables
      - Capacity requirements
    - Air transportation
      - Origin terminal operations
      - End-of-line operations
      - Central/distributed hub operations

In the following sections we discuss briefly the application of simulation methodology in four L&T problem domains: (1) simulation of warehousing and distribution systems, (2) simulation of trucking operations, (3) simulation of truck docks, and (4) simulation of ramp operations in aircargo hubs. For each problem domain we describe the (1) simulation modeling issues; (2) purpose of building the model; (3) entities, resources, and critical processes that need special attention; (4) what-if scenarios; (5) input data required; and (6) outputs for statistical analysis.

16.3 SIMULATION OF WAREHOUSING AND DISTRIBUTION SYSTEMS

16.3.1 Purpose of the Simulation Model

A growing number of logistics firms utilize discrete-event simulation concepts to model the various issues of large-scale logistics networks. In one extreme, a logistics simulation model may be developed to investigate and improve the operations of a warehouse; on the other extreme, it may involve modeling and analysis of the operations of an entire supply chain. In most cases there is a common goal for developing the simulation model, which is to evaluate the performance of individual value-adding (*indirect*) resources, facilities, and operations as well as the flow of transportation entities (*direct resources*) between the plants, warehouses, and customers.

The simulation models are developed to perform a variety of what-if scenarios to accomplish the objectives of a logistics network management or its customer. These include (to name a few):

1. To evaluate strategic decisions
   - Warehouse location and allocation
   - Warehouse/distribution center designs
   - Transportation mode analysis
2. To test tactical solutions
   - Inventory management policies
   - Pull ordering between customers and plants
   - Push ordering between warehouses
   - Service levels
3. To identify operation problems on an ongoing basis
   - Changes in transportation modes
   - Changes in warehouse operation parameters
   - Changes in parts and finished products
   - Customer demand fluctuations

16.3.2 Simulation Model Development for a Logistics Application

A simulation model of a logistics network is developed to investigate the impact of the variabilities associated with production schedules, customer demand, and transportation delays. The simulation model must combine the behavior of a physical logistic network with the activities and operations of the various logistics entities within the problem domain. In general, the simulation model may emphasize the internal logistics and operations of a warehouse, or the pickup and delivery of freight within a city or a zone, or the movement of physical goods across an entire country or continent. In this section our focus is to develop a simulation model of a logistics network comprised of plants, warehouses (or distribution centers), and customers located all over the world. The simulation model can be built using several world views and/or paradigms (process interaction, event scheduling, object-oriented , etc.); however, in this section we identify a list of unique processes and activities that require special attention to adequately represent the various components of a logistics simulation model.

Often, logistics simulation models incorporate a geographic map showing the physical relationships among plants, terminals/hubs, warehouses/distribution centers, and customers. It is suggested that activities at the plants, warehouses, and customer locations are separately modeled at appropriate levels of detail. These individual models are then integrated with the underlying logistics network superimposed on a geographic map. Often, a hierarchical modeling approach is preferred to represent the logistics network as well as the operations at the individual nodes (a node may refer to a plant, a customer, or a warehouse). In this way the logistics user/designer can visualize the movement of transportation entities at the map level as well as the operations at the plant or warehouse level.

Figure 16.1 indicates the movement of orders from customers to plants and the products and parts from plants through warehouses to the customers in a logistics system. Various modes of transportation are used to move items between the origin and destination locations. Most manufacturing, retail, and service industries embrace this logistics system. Depending on the level of detail specified to generate the desired results, the

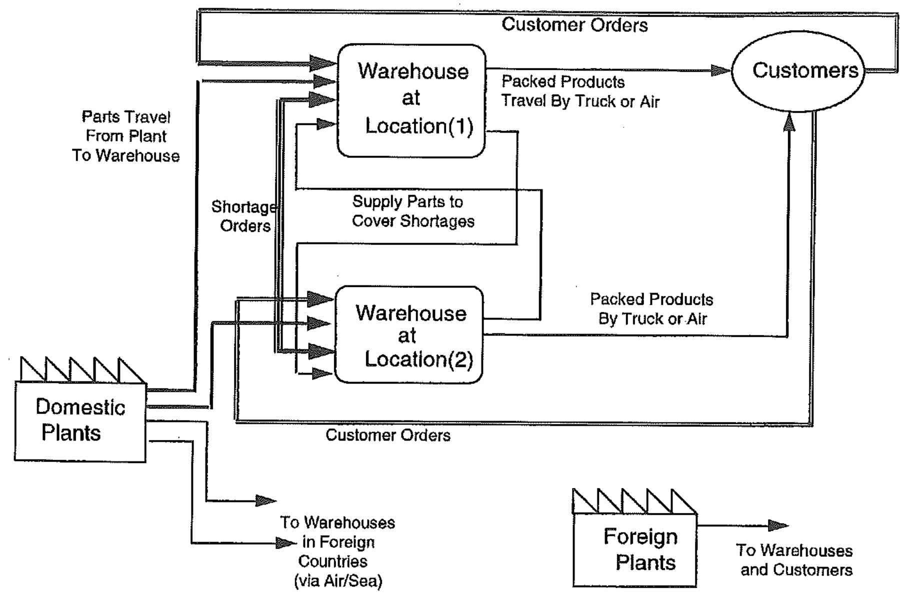


Figure 16.1 Orders and products flow between plants and customers through warehouses.

simulation modeler/analyst may represent some or all of the entities, resources, and activities in a logistics system.

An exhaustive list of processes/activities modeled and represented in a logistics simulation model follows.

- Order processing at the warehouse (manual, EDI)
  - Pull ordering system
  - Push ordering system
- Terminal operations at plants, warehouse, and customers (domestic/foreign)
- Grouping and palletizing
  - At a production plant before shipping to a warehouse
  - At a warehouse before shipping to a customer
- Ungrouping
  - At a warehouse once the parts arrive from a plant
- Transportation mode selection
  - At production plants
  - At warehouses
- Handling shortages (or surplus inventory)
  - Creation at a warehouse (domestic/foreign)
  - Send an order message to another warehouse
- Movement of parts (raw materials, semifinished)
  - From domestic plants to domestic warehouses

- From foreign plants to foreign warehouses
- From domestic plants to foreign warehouses
- From foreign plants to domestic warehouses
- Movement of finished products
  - From domestic warehouse to domestic customers
  - From foreign warehouse to customers abroad
  - Between domestic warehouses
  - Between foreign warehouses
  - Between domestic and foreign warehouses
- Customer orders
  - From U.S. customers to domestic warehouses
  - From foreign customers to warehouses abroad
- Customer locations (geo-coded)
- Transportation mode selection
  - Based on a specified service level
  - Based on the availability of resources
  - Based on shipment priorities (direct)
- Direct shipments from plant to customers
  - Items in shortage
  - Emergency items (a percentage of total shipped)
  - OEM products

16.3.3 Entities and Resources in a Warehousing and Distribution Simulation Model

Entities are physical things whose behavior change over time. Primarily, there are two sets of entities in a warehousing/distribution problem domain. Again, the level of detail depends on the goals and objectives set forth by the decision maker of logistic systems.

- Product-related entities
  - Primary and nonprimary parts
    - Produced in-house
    - Vendor supplied
  - Products (semifinished, finished)
  - Palletized (or grouped) items
    - Parts
    - Semifinished products
    - Finished products
- Information-oriented entities
  - Orders from customers
  - Orders for shortage

The following resources are encountered in the simulation model to fully represent

the behavior of a logistic systems. Once again, the level of detail depends on the purpose of the simulation model. Both direct and indirect resources should be considered.

- Trucks
  - Between plants and warehouses
  - Between warehouses
  - Between warehouses and customers
- Airplanes
  - Between plants and warehouses
  - Between warehouses
  - Between warehouses and customers
- Ships and barges
  - Between domestic plants and foreign warehouses
  - Between foreign warehouses
  - Between domestic (foreign) warehouses and foreign (domestic) customers
- Internal (warehouse/plants/distribution centers/customer sites) equipment
  - Forklifts
  - Carts
  - Pallet trucks
  - Conveyors
  - AS/RS systems
  - Guided vehicles

All the static and dynamic entities, together with the resources, must be either fully or partly represented in the simulation model, depending on the level of detail desired by the logistics user(s).

16.3.4 Data Requirements for a Warehouse Simulation Model

In general, the simulation models are developed within this domain to evaluate warehouse locations and transportation modes between plants, warehouses, and customers. The input data required for these models include the following:

- Number of plants
- Number and location of warehouses
- Number of customers
- Customer demand to warehouses
- Part numbers produced at different plants
- Bill of materials
- Transportation times
- Between plants and warehouses
- Between warehouses and customers

It should be mentioned that the customer demand, transportation times, and so on, are stochastic in nature and vary over time. Accordingly, these data elements correspond to probability distributions generated using the information collected over several days, weeks, or months.

16.3.5 Simulation Outputs and Responses

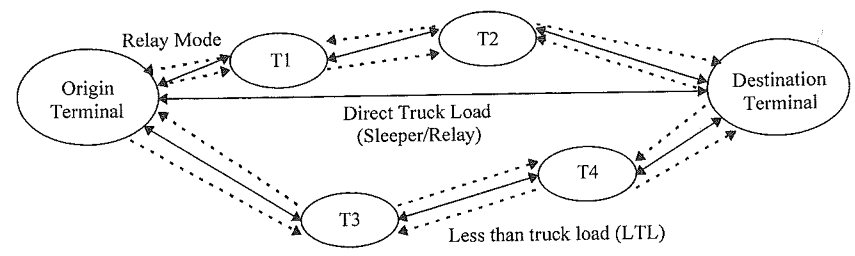
Following is a list of responses that a logistics system designer or user is often interested in knowing about.

- Average utilization
  - Warehouse
  - Trucks
  - Airplanes
  - Other resources inside a warehouse
- Inventory levels
  - Production plants
  - Warehouse
- Transportation delays
  - Between the plant and a warehouse
  - Between a warehouse and customers
- Customer orders
  - Average waiting times at a warehouse
  - Number waiting at a warehouse

In summary, a good understanding of the importance and purpose of building simulation models for logistics applications, together with a list of entities, resources and critical activities that require special attention during the model-building phases, and the key data inputs and output responses required for logistics users is essential to derive valid and useful conclusions.

16.4 SIMULATION OF TRUCKING OPERATIONS

In a trucking industry, the freight may be transported in trailers either directly to its destination with no stops or transported via several intermediate terminals where freight (in trailers) is picked up and/or dropped off. Most trucking companies move freight either in LTL (less than truckload) or in DL (direct load) mode. Accordingly, freight is often transported by straight trucks or by a tractor–trailer from an origin terminal or hub or consolidation center to the destination. A straight truck is one in which the power unit (with the driver cabin) is connected to the trailer and cannot be dislodged. In the case of a tractor–trailer pair, one, two, or three loaded trailers are hooked to a tractor by the hooking personnel (hostlers) at the yard in a terminal. Truck drivers arrive at the terminal at prespecified times to drive the hooked trucks (often referred to as a schedule or truck–tractor–driver set). The number of trailers hooked to a tractor may vary depending on the amount of freight to be transported, the number of trailers available to carry freight, and most important, the geographical location of the origin and/or destination terminal. These concepts are illustrated in Figure 16.2.



T1, T2, T3 and T4 are Intermediate Terminals

Dashed lines are used to show truck movements

Solid lines are used to show driver movements in relay mode

Figure 16.2 Fundamental concepts in a trucking operation.

A set number of loaded trailers are transported by relay, by sleeper, by meet-and-turn drivers, or by rail from each terminal, hub, or consolidation center. Occasionally, empty trailers may be transported, due to load imbalance. Load imbalance may occur when more freight moves in one direction than in another direction. For instance, more automobile components and parts may move from northeast toward midwest sections of the United States, whereas not much freight may move from the midwest toward the northeast, causing a load imbalance. This often leads to more loaded trucks going in one direction and returning empty in the opposite direction. In general, the driver pool is divided into three categories:

1. *Pickup and delivery drivers*, whose primary function is to stay within a city zone.
2. *Relay drivers*, who drive trucks from one terminal to the next for a shorter period (say, 8 to 10 hours) and return back to the origin terminal, which is their domicile location.
3. *Sleeper drivers*, where two drivers alternate driving and drive to farther destinations with minimum number of stops for a longer period.

In relay operations the freight tends to move through several intermediate terminals before reaching its destination. Tractor–trailer sets with LTL and straight trucks with direct loads both move between the origin and destination terminals using either relay or sleeper modes. When a truck driver is at a terminal location that is not his or her domicile point, the driver is at a foreign terminal and is referred to as a foreign driver. At foreign locations, drivers will be provided accommodation to rest for a period of time (say, 8 to 10 hours) before driving back to the domicile location. This depends on the availability of a schedule (and freight). In general, foreign drivers have higher priority over drivers domiciled at that terminal location, so as to reduce the cost of managing the foreign drivers. Once the drivers return to their domicile location, they go home and wait until their next assignment.

To reduce the cost of managing drivers when they are at foreign terminals, trucking companies often set up a pool of *meet-and-turn drivers*. These drivers are used to exchange trucks from two terminals moving toward each other when the total transportation time is within 8 to 10 hours. In such cases the drivers meet at a central point (or a predetermined point such as rest areas along U.S. highways), swap their trucks and turn back to their domicile terminals. Therefore, drivers will start from their domicile terminal and end up at their domicile location.

Once the trucks arrive at the terminal, if it is a straight truck, it will arrive at the yard and wait its turn to offload. If it is a tractor–trailer pair, the set is unhooked and waits at the yard for offloading. The unhooked tractor may be taken for maintenance checks, refueling, and so on. Each terminal has a dock with sufficient doors for the loaded trailers or trucks to arrive at a prespecified door and offload. Offloading may involve use of manual handling or forklifts or other material handling equipment. The simulation modeling and analysis of truck docks has been studied by the terminal management to evaluate the best dock procedures.

In general, truck docks are divided into areas specifically for offloading trucks (or trailers) and reloading trucks or trailers. However, there are truck docks where the offloading and reloading may be planned to occur in the same area to reduce the length of time the freight needs to be staged before it is reloaded for transportation to its final destination.

Essentially, computer simulation is applied to several areas of trucking operations. These are divided into three major topics: (1) dock simulation, (2) terminal simulation, and (3) linehaul simulation. *Dock simulation* refers to modeling and analysis of the activities of dock processes and improve the overall performance of truck docks. *Terminal simulation* refers to modeling and analysis of all activities that take place in the terminal. *Linehaul simulation* combines dock operations and terminal operations at several terminals, either along a single traffic lane or across an entire transportation network. The complexity level increases as we move from dock simulation modeling to linehaul simulation modeling.

16.4.1 Simulation Model Development for a Linehaul Trucking Operation

In this section the application of discrete-event simulation techniques to evaluate and redesign linehaul operations is discussed. This involves the (1) origin and destination terminals, (2) arrival and departure events of trucks, (3) hooking rules and driver assignment procedures, and (4) movement of trucks (tractors, trailers, and drivers) along a lane (Northern Transcon in the United States, for instance).

Fundamental Problems and Modeling Issues. The simulation model is built to perform strategic, tactical, and operational analysis and to address a variety of problems:

- Current methods of hooking trailers
- Current procedures used to assign drivers to schedules
- Load imbalances within any lane at any terminal
- Equipment needs at any terminal in the lane
- Driver needs at any terminal within the lane
- Management of these resources within the lane

This simulation model can serve not only as an operational tool to address these issues within a specific lane but can also be used to serve as an early warning system to provide dock, terminal, and linehaul management with the capability to better control and contend with exceptions that occur during day-to-day operations.

A unified, hierarchical, object-oriented, layered architecture is necessary to represent the linehaul and trucking operations. The modeling objects are designed to be more generic and flexible. Depending on the decisions to be made by the dispatchers or the operations managers, one or more simulation models may be required for an analyst or a decision maker to evaluate the impact of moving trailers by means of relay and sleeper modes, sleeper only/relay only mode, and so on. All the necessary graphical user interfaces should be part of the modeling environment so that the user can quickly modify parameter values during and at the end of simulation.

Modeling Critical Input Processes. To perform trucking simulation, the model must be built to depict the following;

1. *Trailer Closing Times at Docks.* The trailers are loaded with freight each day at each of the origin terminals according to a trailer closing process. The trailer closing times during a day are often defined in the form of a probability distribution. Most L&T companies have either centralized or distributed data processing centers that maintain on-line databases for time and freight information.
2. *Truck Arrival Process at the Docks and Terminals.* The arrival processes associated with trailers, tractors, and drivers from other terminals or hubs that are not part of the lane under study.
3. *Terminal Open Time and Close Time*
4. *Trailers Transported by a Specific Mode*

All these features must be built into the model so that the transportation user or analyst need only to enter the information for each terminal location.

Critical Processes at the Terminals. The trucks arriving at a terminal can be one of three types (Figure 16.3):

1. Trucks that originate from a terminal along a traffic lane under study and end up in a terminal along the same lane.
2. Trucks that originate from a terminal outside a traffic lane, enter the lane, utilize part of the lane, go through one or more terminal(s), and leave the lane and end up in a terminal outside the traffic lane.

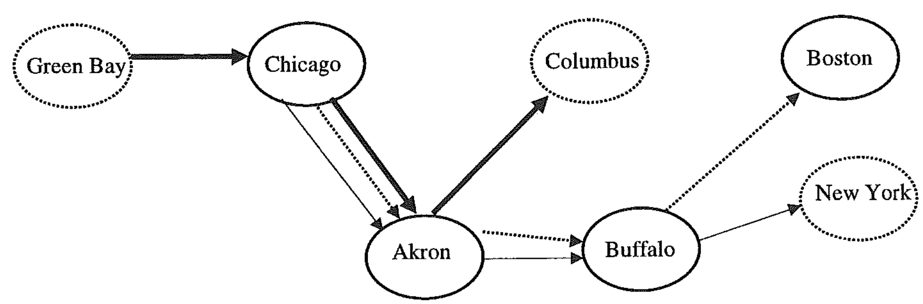


Figure 16.3 Identification of lane-specific trucks and foreign trucks.

3. Trucks that originate from a terminal inside a traffic lane, travel along the lane, utilize all or part of the lane, and leave the lane and end up in a terminal outside the traffic lane.

The terminals connected by solid and/or dashed lines form a traffic lane (under study). The trucks that originate and end up at any of the terminals along the dashed line are *type 1* trucks. Trucks moving along thick solid lines are *type 2* trucks. *Type 3* trucks are those moving along thin solid lines. A better understanding of how these types of trucks (along with drivers) are handled at various terminals is essential to represent the truck arrival and departure process in a simulation model. *Type 2* and *type 3* trucks are often called *foreign trucks*.

Modeling details at each terminal include:

- Creation of loaded trailers (dock process)
- Trailer grouping (hook assignment) rules, depending on the type of truck
- Hooking grouped trailers with a tractor
- Equipment preparation for relay or sleeper runs (hostler, hooking times associated with preparing the equipment)
- Driver assignment and management for relay, meet and turn, or sleeper runs (by employing a prespecified resource pool)
- Schedule arrival process for different types of trucks
- Unhooking trailers
- Offloading at the dock
- Schedule departure process for different types of trucks

Critical Processes at Relay Stations. The major processes and activities performed at the relay stations must be represented in the model, including:

- Driver changes (relay drivers only)
- Refueling, if needed
- Equipment preparation, if needed

Modeling Modes of Trucking Operations. Modeling details associated with the movement of trailers, tractors, and drivers include:

- Sleeper operations only (direct moves)
- Relay operations only (transport via terminals)
- Sleeper and relay operations only (transport via terminals)
- Sleeper, relay, and meet-and-turn operations (direct moves and transport via terminals)

Modeling Intermodal Issues. Often, trucking companies utilize rail to transport their loaded and empty trailers to reduce load imbalances. In this case, terminal operations are closely tied to railyard operations. The various activities related to rail operations (departure at origin and arrival at destination) should be depicted by the model. The critical processes include:

- Move rail-trailers to railyard.
- Hold trailers until train departure times.
- Split trailers at the railyard.
- Move trailers from the railyard to the terminal.
- Strip trailers and count the number of trailers.

Level of Detail Along the Traffic Lane. The simulation model must depict the flow from one or more origin terminal(s) to one or more destination terminal(s). Further, it must be easy to expand the model to handle any number of origin and destination terminals. In other words, the simulation model must encompass a variety of key processes, such as (1) truck arrival process, (2) unhooking tractors and trailers, (3) assignment of foreign and domicile drivers, (4) tractor management, (5) dock process to simulate the off loading and loading of freight from and to trailers, (6) hooking assignment, and (7) hostling and dispatch process. Each process may be parameterized individually to represent the behavior of a terminal, hub, or consolidation center.

As mentioned previously, a hierarchical modeling paradigm is preferred for simulating the trucking operations in order to represent the behavior or the various entities and resources. If object orientation is considered, the model can be built rapidly through the use of a template of objects, simply by placing the consolidation center object on a geographic map. The consolidation centers are linked together by arcs that are either (1) static and/or (2) dynamic links. The static arcs essentially used for offline analysis (i.e., during scenario playing or in strategic studies), whereas the dynamic links between terminals are used to visualize the actual movement of trucks on a lane in real time (primarily for monitoring and control purposes). Each consolidation center object placed on the map is parameterized or modified using the model-building tools to represent the specific behavior or characteristics of the terminal.

Once the simulation model is developed to represent a specific scenario, the model is tested and verified. The scenario under study is simulated for a prescribed time period, say for a period of 3 to 4 weeks of linehaul operations. The results generated is exhibited to the user in the form of visual graphs and/or tabular outputs. These are discussed in Section 16.4.3.

16.4.2 Entities, Resources, and Activities

The following entities, resources, and activities are considered in a typical simulation model. The movement of trailers, tractors, and drivers and linehaul operations at terminals or hubs or consolidation centers are focused on in this section. Sample entities, activities, and resources are provided below.

Entities

- Empty trailers at terminals
- Loaded trailers (through or closed at terminals)
  - Waiting to be grouped with other trailers
  - Waiting to be sent by relay, sleeper, or meet-and-turn (or rail) mode
- Transport operators (sleeper, relay, meet-and-turn drivers)

- Tractors (currently all tractors are considered equal)
- Trains at the railway station (if the rail mode is activated)

Resources

- Hostlers
- Dispatchers
- Fuelers

Activities/Processes That Require Special Attention. The processes that require special attention while developing the simulation model are divided into two categories.

1. If only sleeper, relay, and meet-and-turn operations are considered, the following activities are performed in a model:
   (a) Off load the loaded trailers after a trip at the dock.
   (b) Load the empty trailers at the dock.
   (c) Unhook trailers at a terminal.
   (d) Prepare (hostle) equipment at a terminal.
      - Get service from the hostler to hook/unhook trailers with tractor.
      - Get service at the fueling land or the inspection area.
   (e) Drive the truck to the next location (may be destination) via sleeper mode.
   (f) Drive the truck to the next location (may be destination terminal) via relay or meet-and-turn mode.
2. If the rail mode needs to be modeled, the following activities are performed:
   (a) Move trailers to the railyard.
   (b) Transport the trailers from the railyard to the terminal (no capacity restrictions on the pickup and deliver drivers working within city limits).
   (c) At the destination terminal, split trailers at the railyard and dispatch to the terminal.

Dynamic Processes and Associated Information. Various stochastic processes should be represented in the simulation model. These include:

- Trailer information
  - Trailers that are closed at a terminal on this lane and end up in a lane
  - Trailer closing time distribution (or)
  - Freight creation process and trailer loading time distribution
- Through trailer arrival process
  - Trailers that travel a lane but are not closed at a terminal on a lane
  - Originate from a terminal not part of a lane but end up at a terminal on a lane
  - Originate from a terminal part of a lane but do not end up at a terminal on a lane
  - Originate from a terminal not part of a lane but do not end up at a terminal on a lane

  - Scheduled arrival time distribution
  - Trailer information for each schedule
    - Lane destination
    - Load destination
- Empty trailer availability information
- Sleeper team arrival process at the origin terminals (call time frequency, etc.)
- Relay (or meet and turn) driver arrival process at the origin terminals
- Tractor availability information
- Other pertinent information related to any other dynamic process

16.4.3 Data Requirements and Outputs from the Model

The simulation model involves the following data for sleeper, relay, meet and turn, and rail (if included in the study) combination along a specific traffic lane under study:

Operation Data

- Hostling times (hooking or unhooking) at each terminal for tractors
- A set of intermediate locations where sleeper (or relay) trucks stop for unhooking and/or hooking and/or refueling
- Fueling/inspection times at a terminal
- Fueling/inspection times at a third-party vendor location
- Tractor service (inspection, etc.) times at terminals
- Current number of hostlers per shift at each of the terminals under consideration
- Current number of sleeper, relay, and meet-and-turn drivers
  - Standard driver roster
    - Arrival times at the terminal
    - Number of drivers
    - Assigned destination
  - Extra driver roster
    - Number of drivers
- Driver work rules and DOT regulations associated with sleepers, relay, and meet-and-turn drivers

Outputs from the Simulation Model. Using the operations data and the simulation model with features specified in Sections 16.4.1 to 16.4.2, several output statistics are collected during a simulation run. Each of these output statistics may be generated on-line as the simulation is in progress or by accumulating the results over a period of time. In the former case it is preferred that the outputs be generated in the form of visual graphs and expected arrival times (ETAs); however, in the latter case, the outputs may be created as cumulative statistics (e.g., average number and/or time, minimum and maximum values, standard deviation, etc.) in the form of tables stored in external files for further analysis and dissemination. Although the specific output reports vary depending on the purpose of the simulation study, some of the most useful outputs generated in a trucking simulation study include the following list:

- Utilization of empty trailers at each terminal
- Empty trailer buildup rate and its usage rate over a period of time
- Utilization of drivers at each terminal (both foreign and domicile) over a period of time
- Tractor utilization at each terminal and tractor buildup rate and usage rate at a terminal over a period of time
- Number of trailers transported by sleeper teams, relay drivers, or meet-and-turn drivers separately at all destination terminals for each day
- Number of trucks on the road over a period of time (both time-persistent statistics and cumulative statistics)
- Number of trailers delayed at each terminal due to the unavailability of tractors
- Delay times for trailers at each terminal due to the unavailability of tractors
- Number of drivers delayed due to the unavailability of schedules at all terminals
- Delay times for the drivers at each terminal due to unavailability of schedules
- Number of tractors delayed due to the unavailability of trailers at each terminal
- Delay times for tractors at each terminal due to unavailability of trailers
- Hostler utilization

Sample Simulation Outputs for Conducting Operational Analysis. Two kinds of outputs may be generated from a simulation model used to design, evaluate, and improve the linehaul operations. These include (1) daily, weekly, monthly behavior; and (2) snapshots at any point in time. In this section, sample output reports generated by the simulation model are presented for further analysis and communication to trucking management.

Among other reports that are essential for strategic, tactical, and operational control, some of essential reports from the simulation model include (1) traffic summary, (2) empty trailer usage, (3) driver by type usage, (4) tractor by type usage, and (5) schedule delays at terminals. The sample outputs are shown in the following tables (the values in tables are provided to illustrate the concepts and are fictitious).

Traffic Summary Report (Daily, Weekly, Biweekly, or Monthly). Table 16.1 provides the throughput information, which can be used as an effective measure to determine the operational performance of the lane being studied.

TABLE 16.1 Traffic Summary

Origin Terminal	Lane Destination Terminal	Load Destination Terminal	Total Number of Trucks Available	Average Number of Trucks in Use
Chicago	Buffalo	Akron	53	14.89
Chicago	Boston	Akron	48	23.56
Chicago	Akron	Akron	64	19.44

TABLE 16.2 Empty Trailer Usage

Terminal Location	Average Number of Trailers Waiting	Average Waiting Time (hours)	Average Percentage Trailer Utilization
Akron	4.5	2.7	89.57
Buffalo	0.5	1.3	90.01
Boston	2.5	2.2	88.76

Empty Trailer Usage Report (Daily, Weekly, Biweekly, or Monthly). This is an important statistics that assists dispatchers at various terminals along a traffic lane to learn about trailer usage at different points in time (see Table 16.2). This report also helps decision makers to identify load imbalances and potential bottlenecks along a traffic lane and take appropriate remedial actions to relieve the problems.

Driver-by-Type Usage Report (Daily, Weekly, Biweekly, or Monthly). This information, shown in Table 16.3, is highly critical to understanding the need for different types of drivers at various locations. Using this statistic the decision maker can evaluate several options to utilize the most critical resource in a linehaul trucking operation: the drivers.

Tractor Usage Report (Daily, Weekly, Biweekly, or Monthly). This information, depicted in Table 16.4, is essential to understanding the need for additional tractors at various terminal locations. Using this statistic the decision maker can evaluate several options to ensure an adequate supply of tractors, thereby keeping a smooth linehaul operation along the traffic lane.

Schedule Delays at Terminals (Daily, Weekly, Biweekly, or Monthly). This information, provided in Table 16.5, is the single most important performance measure for the decision maker to evaluate the alternative policies. The set of policies that lead to the least amount of delay time at various terminals or consolidation centers is ideal for deriving the best performance from a linehaul trucking system.

In summary, the results are generated in the form of tables and visual graphs (both off-line and real-time) to include (1) rate of change of quantities with respect to empty trailers, tractors, and drivers at each terminal due to the new arrival and movement of freight; (2) average utilization levels of empties, tractors, and drivers during a speci-

TABLE 16.3 Driver Utilization

Terminal Location	Driver by Type	Average Number of Drivers Waiting	Average Waiting Time (hours)	Average Percentage Driver Utilization
Akron	Relay only	5	2.5	85.65
Buffalo	Relay and sleeper	2	1.5	74.56
Boston	Sleeper only	3	1.0	35.00

TABLE 16.4 Tractor Usage Summary

Terminal Location	Average Number of Tractors Waiting	Average Waiting Time (hours)	Average Percentage Tractor Utilization
Akron	5	2.2	84.34
Buffalo	2	4.6	76.77
Boston	3	3.5	67.55

fied time period; (3) average number of trucks (or schedules) moved between terminals during a time period; (4) average number of trailers, tractors, and drivers delayed due to unavailability of resources; and (5) average delay times associated with the unavailability of one or more transportation resources.

16.4.4 Benefits of Trucking Simulation

By performing a series of what if scenarios and establishing a gaming environment (frequently set up by large trucking companies in a "war room" format), both terminal management and central planners can gain many benefits. We categorize these benefits as follows:

1. As a strategic tool
   (a) Evaluate and test operational strategies through an interactive, user-friendly *gaming* environment (via simulation and animation) before actually implementing the strategies.
   (b) Determine the load imbalances caused by loaded trailers, drivers, and tractors at various terminals by visual graphs.
   (c) Determine the equipment needs at various terminals, empty trailers, and tractors.
   (d) Evaluate the number of drivers (sleeper/relay/meet-and-turn drivers) and their domicile locations.
2. As a tactical tool
   (a) Estimate the resource requirements (empties, drivers, tractors) on a weekly basis based on the freight movement characteristics at different terminals.

TABLE 16.5 Cumulative Statistics to Evaluate the Overall Performance

Origin Terminal	Lane Destination Terminal	Maximum Number of Trucks Delayed	Average Number of Trucks Delayed	Average Delay Time (hours)
Chicago	Buffalo	12	1.49	3.49
Chicago	Boston	7	1.05	1.25
Chicago	Akron	4	1.66	3.20

3. As an operational tool
   (a) Manage resources, reduce the delay times at terminals, and cut down penalty pay by performing simulation experiments on a daily basis.
   (b) Handle exceptions through an early warning capability, thereby accomplishing better control. This is done by visualizing the progress of freight over time, tractor–trailer–driver movements among terminals, hostling and hooking/unhooking, and expected arrival times and departure times of schedules on one or more computer screen(s).

16.5 SIMULATION OF TRUCK DOCK OPERATIONS

Application of computer simulation techniques to model, analyze, and improve the performance of a truck dock has been gaining enormous impetus in recent years. A typical truck dock includes five major components: (1) a yard where trucks arrive and wait for an empty door; (2) doors; (3) transporters operating at the dock, such as forklifts and conveyors; (4) staging areas where the freight is temporarily stored prior to sorting and shipping; and (5) sorting systems. Trucks arrive at the yard as straight trucks or as tractor-trailer combinations. Different types of freight from the trucks are offloaded by forklifts at the doors. Depending on the freight type and its destination, they are moved either directly into another truck or staged on the dock for reloading to trucks at a later time. In most situations, a truck dock is nothing but a flowthrough center.

Primarily, forklifts move the freight from the trucks to various locations. As trucks arrive at the yard, they are assigned to doors depending on (1) the current trailers being offloaded or reloaded at the dock, and (2) the availability of dock handlers and forklifts. Only one truck is assigned to a door and offloading/loading begins immediately. The pickup and dropoff times for the forklifts depend on the freight being offloaded. As the size and shape of each type of freight vary, there is greater variation in the offloading/reloading behavior. Further, the forklift speeds, movement times, forklift turning behavior, and the level of congestion at the dock change depending on the freight type.

Several work rules are used to assign, manage, and control forklifts during the offloading or reloading process. Forklifts are assigned to a specific door or a set of door(s). During the offloading process, the forklifts may transfer loads to other trailers being loaded or to a staging area. However, they tend to stay with the doors assigned until the current truck is fully offloaded.

The staging areas are commonly located between the dock doors. These are among the most congested areas, where loose freight is offloaded from all doors by forklifts. This means that forklifts need to travel to this area more often than to other areas of the truck dock. The size, number, and exact location of staging areas play a vital role in determining the overall dock space, as do the number of doors and assignment of doors to trucks arriving from an origin terminal and departing to destination terminals. Figure 16.4 shows the facility layout of a simple truck dock in which the inbound trucks arrive at one end of the dock and depart at the opposite end. In other configurations, the inbound and outbound trucks are assigned adjacent to each other on the same side of the dock.

Often, two fundamental objectives are set forth for the simulation study: (1) studying the ways and means of increasing the throughput of a truck dock, and (2) studying the impact of changes in a facility design before implementing it, to avoid making very

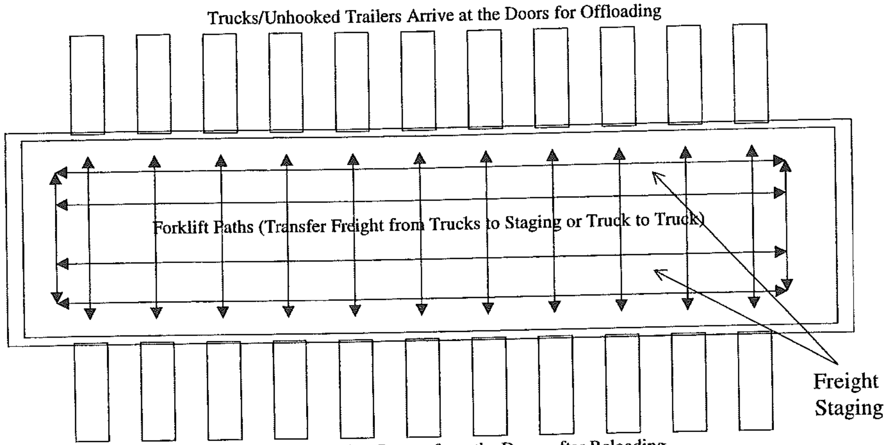


Figure 16.4 Truck dock showing the offloading and reloading processes.

costly errors. Although hundreds of what-if scenarios using a truck dock simulation model are investigated, those most frequently studied ones are:

1. To develop a simulation model that has the ability to show operation managers the existing processes, trouble spots, and changes in behavior of the existing truck dock as it undergoes changes in terms of new equipment, facility, and operations.
2. To study the impact of changes in processes and policies within each area of the truck dock.
3. To change the distances traveled and capacity/size/number of forklifts and determine the impact on performance at the truck dock area.

16.5.1 Input Data for Truckdock Simulation

For the purpose of building a truck dock simulation model, two types of input data are collected.

1. The first type involves freight types, door information, resources used, and equipment specifications.

- Door information (number of doors, door size, door locations)
- Freight types [containerized, bulk (sorted/unsorted), loose (hand-carried, top loads) freight]
- Resources [doors, forklifts, sortation conveyors (indexing)]
- Operators (forklift drivers, freight handlers, dock workers, loaders/unloaders)
- Queue locations (staging, sortation conveyors, door locations)
- Forklift specifications (number and types, length and width of forklifts by type, acceleration and deceleration, top speeds, forklifts by type, loaded speed by freight type, unloaded speed by forklift type, park locations, work assignment, turning rules, pickup and deposit rules)

- Conveyor specifications [conveyor type (indexing, roller, belt, etc.), number of segments, input station characteristics, output station characteristics, segment speed, conveyor selection rules, freight movement/stopping rules]

2. The second type of data involves rigorous data collection at the truck dock. This includes statistical distributions describing the behavior of truck dock operations, which change from day to day or night to night. These include the truck (by type) arrival process at different locations of the truck dock; pickup and dropoff times for forklifts based on freight type; operational times at the sort conveyor, staging, and so on; and the truck contents.

- Arrival process
- Type of trucks based on freight carried
- Frequency of truck arrivals (type of truck and Percentage of occurrence)
- Truck contents (freight type and Statistical distribution w/parameters)
- Truck hostling time distributions
- Door preparation time before offloading (when the truck is full)
- Door occupancy time by trucks after offloading (when the truck is empty)
- Loading/offloading times
- Forklift pickup time by freight type (at staging area, sortation conveyor, and inside trucks)
- Forklift set-down time by freight type at destination points

Both types of information are incorporated in the simulation model to describe the truck dock as well as day-to-day variabilities.

16.5.2 Controllable Factors and Performance Measures

In truck dock operations, several factors are controllable, and the decision maker is often interested in knowing about their impact on the output performance. In this section a list of factors and responses (output reports) usually generated using a truck dock simulation model are outlined. The essential factors are:

1. Number of dock doors
2. Number of forklifts
3. Number of operators
4. Number of trucks
5. Forklift operating speed

Similarly, the responses are (1) capacity, measured in number of pieces moved; (2) average number of trucks unloaded; (3) forklift utilization, measured in percentage of time the equipment is busy; and (4) average time to move a piece across a dock measured in units of time and on an hourly basis. The simulation model should be built to provide answers to many issues involving these factors. The report generator should be designed to provide all the responses listed in this section.

16.5.3 Simulating Critical Processes in a Truck Dock

Several processes and activities need to be simulated to represent the behavior of the truck dock operations. An exhaustive list of the fundamental processes that require special attention during the simulation model building phase follows.

1. Determine door assignments to trucks (based on arrival behavior) at the unloading (inbound) doors.
   - *Option 1:* Assign trucks to doors starting from left to right.
   - *Option 2:* Assign trucks based on origin or destination terminal to the preassigned door.
2. Determine door assignments to trucks (based on departure process) at the loading (outbound) doors.
   - Employ a round-robin method of door assignment, if not waiting at the yard
   - Send trucks directly to next-available door, if not waiting at the yard
   - Send trucks to doors based on origin or destination terminal
   - Send trucks to a common waiting area and to next-available door
3. Capture door arrival process.
   - Enter the dock door area for offloading.
   - Consider truck/door preparation time.
   - Read the information pertaining to the type of truck.
   - Read the information pertaining to the contents of the truck.
   - Wait for one or more forklift(s) to offload the truck contents.
4. Specify doors to forklifts
   - Assign each forklift to its door location for offloading or reloading.
5. Assign, schedule, move, and control forklifts for offloading trucks
   - Move forklift into truck to begin offloading.
   - Determine the freight picked up for transport.
   - Keep the fork forward/backward, depending on freight type.
   - Transport forklift to freight destination.
   - Drop off freight at its destination.
   - Move forklift back to its door.
   - Repeat until the entire truck is offloaded.
6. Assign, schedule, move, and control forklifts for loading trucks
   - Determine the freight picked up for loading.
   - Pick up freight from either staging area or a truck.
   - Keep the fork forward/backward, depending on freight type.
   - Transport forklift to the truck depending on freight destination.
   - Move forklift into truck to begin loading.
   - Drop off freight at its destination inside the truck.
   - Move forklift back to staging area or truck where freight is offloaded.
   - Repeat until the entire truck is offloaded.

7. Pickup and dropoff times for truck dock forklifts
   - Specify the pickup and dropoff times by freight type.
8. Select a sortation conveyor (if required)
   - Specify a list of segments for each door using one of the selection rules.
     - Nearest-neighbor rule
     - Next-available-segment rule
     - Waiting rules if no segment available
   - Select an appropriate conveyor to offload or pickup for reload.

The processes described in this section are representative of a typical truck dock and there may be some variations depending on the function, size, and purpose of the truck dock.

16.5.4 Experimental Setup to Perform What-If Scenarios

One of the fundamental reasons for developing a truck dock simulation model is to evaluate its behavior and make necessary strategic changes to facility design, work rules, and/or operational characteristics. The simulation model is usually linked with an experimental setup. These setup programs are developed to include many predesigned truck dock configurations. Occasionally, it may be necessary to make changes to both the model and the input data prior to conducting a prespecified set of simulation experiments (or scenarios). However, in the majority of cases, changes are made with the input data (and not with the model). Essentially, the experimental setup for the truck dock simulation model is developed to facilitate this function as well as to keep track of all the simulation results for further analysis. This, in essence, helps to keep the simulation model as a blackbox and make intelligent decisions. During strategic design and analysis, each experiment for a scenario is executed 10 (to 30) times and the average values for each of the responses are computed to generate statistically valid conclusions. This is mainly because the operational behavior of the truck dock varies nightly (stochastic in nature) and one replication of the simulation model is not sufficient to make useful recommendations to truck dock management.

16.5.5 Analysis Using Truck Dock Simulation Results

In this section, sample analyses and scenarios generated for improving the performance of a truck dock are discussed. As mentioned earlier, a simulation analyst may virtually perform many what-if scenarios using the truck dock model. However, a few representative case examples that are critical and often studied by a truck dock management team are described.

Impact of Eliminating Certain Truck Types at Inbound Dock. Table 16.6 shows the impact of eliminating certain types of trucks on the performance of a truck dock. For instance, the elimination of trucks carrying a certain type of freight (say, containerized freight) from the inbound doors during busy periods may affect the *average trip time* for forklifts. However, it may not affect greatly the *average number of trucks unloaded* during a certain time period. Similarly, the removal of trucks carrying bulk freight for an origin–destination pair from the doors during busy periods may affect the *average number of trucks unloaded.*

TABLE 16.6 Impact of Eliminating Certain Classes of Trucks

Description	Average Process Time at the Dock (minutes)	Average Number of Trucks
Trucks carrying no containerized freight	88.407	—
Trucks carrying containerized freight	93.082	—
Trucks carrying bulk parcels	—	29
Trucks carrying no bulk parcels	—	36

Impact of Additional Doors. Another interesting scenario involves the impact of changes in the total number of doors at the inbound and outbound ends of a truck dock. In such cases the decision maker is interested in knowing about the average increase in truck dock capacity, forklift utilization (one forklift per door), average trip time, and so on. Table 16.7 summarizes the estimated *forklift utilizations, average trip times,* and *average number of trucks unloaded* for a fictitious truckdock with 18-door (existing) and 40-door configurations, respectively. *New end* refers to the outputs associated with the additional 22 doors only.

Impact of Forklift Assignment Policies to Doors. The assignment of number of forklifts per door at the inbound and outbound ends of a truck dock is critical to operate and manage a truck dock effectively. This simulation study often leads to identifying the work rules on the dock, the number of forklifts and dock workers, and the best scheduling policies. Let x_1 denote the number of forklifts assigned to each door at the inbound side of the truck dock, and let x_2 denote the number of forklifts assigned to each door at the outbound side of the truck dock. A total of four scenarios are possible, depending on the number of forklifts assigned per door at the inbound and outbound ends as shown in Table 16.8.

For each of these four cases, the truck dock simulation model may be set up and executed for a prespecified number of replications. Several responses, including the average throughput, average utilization of forklifts at inbound and outbound ends, and average operation times, can be collected in each case. The results may be compared to estimate the best procedures for forklift assignment at the inbound and outbound ends of a truck dock.

In essence, the truck dock simulation models are set up to perform operation planning on an ongoing basis in a variety of logistics, trucking, and other transportation applications. Following is a list of operations planning issues studied on an ongoing basis for a given truck arrival and departure process:

TABLE 16.7 Estimated Forklift Utilization, Average Trip Times, and Trucks Offloaded/Loaded

	Forklift Utilization (%)		Average Trip Time (minutes)		Average Number of Trucks	
Doors	18 Doors	40 Doors	18 Doors	40 Doors	18 Doors	40 Doors
Inbound	63.742	59.705	88.407	96.536	34.387	14.9
Outbound	48.740	53.867	113.506	112.142	12.00	12.0
New end	—	38.141	—	102.207	—	35.5

TABLE 16.8 Four Forklift Assignments to Inbound and Outbound Doors

Option	Number of Forklifts/Door (Inbound), x_1	Number of Forklifts/Door (Outbound), x_2
1	1.0	0.5
2	1.0	1.0
3	2.0	0.5
4	2.0	1.0

- Peak and lean hours during an operating period (day, week, or month)
- Number of doors required and forklift assignment policies
- Time window to complete offloading, staging, and reloading all the trucks
- Amount of workload expected at all areas that may receive freight during a time period

16.6 SIMULATION OF RAMP OPERATIONS IN AN OVERNIGHT AIR CARGO HUB

In this section we describe the design, development, and testing of a simulation model depicting the operations of ramp operations at a central hub in an air cargo company. During the past two decades, several air cargo operations and airport terminals (Hart, 1986) have been modeled (Thompson, 1964; Stafford and Stafford, 1969; Walton and Rosenbloom, 1977), analyzed, and redesigned (Harris, 1974; Crawford, 1977; Horojeff and McKelvey, 1983; Hamzawi, 1986). However, a growing number of air cargo companies have recently begun to apply computer simulation techniques. The major benefits of an air cargo simulation model are as follows:

1. On an ongoing basis, pinpoint strategic and operational improvements on current plane offloading and reloading processes, equipment use, and facility layout due to changes in the behavior of the freight handled at the hub. This helps decision makers to improve continuously the productivity and throughput of air cargo operations.
2. Determine a priori, the appropriate levels of capital equipment, equipment needs, and a suitable facility layout due to an increase (or decrease) in the number of planes, changes in the amount and/or characteristics of freight, and unexpected exceptions. This helps decision makers to better utilize the investment dollars before spending on new equipment purchases.
3. Utilize the simulation model, on a daily (or nightly) basis, to estimate the ramp completion time for the number of planes specified and their expected times of arrival (ETAs).

Often, a simulation model built for studying the air cargo ramp operations utilizes the aircraft tail sheet information, chronological order of plane arrivals and departure data, and ATC rules that designate gates for arriving aircraft. A variety of material handling equipment, such as tug and dolly (to transport freight in containers), forklifts, and K-loaders, are used to load and offload aircraft on the ramp. The number of dollies per tug, number of tugs per plane, and total number of tugs on the ramp are design factors, and changes in these design factors affect the operation performance. The major goals for a ramp simulation model are as follows:

1. To develop a simulation model that has the ability to show ramp operations crew the problems, trouble spots, and changes in behavior of the existing ramp operations as the air cargo hub undergoes changes in terms of additional/modified K-loaders, tugs and dollies, and other auxiliary equipment.
2. To study the impact of changes in operations and policies within each area of the ramp.
3. To perform a comparative analysis: current versus new layout of aircraft parking, current versus new communication procedures, current versus new tug and dolly assignment rules, and so on.
4. To study the impact of additional aircrafts and gates on the ramp and determine the number of K-loaders and tug and dollies. Identify the changes to work rules, if any, to maximize throughput and number of planes/containers offloaded at the ramp and to minimize the average time to offload an aircraft.
5. To study the impact of changing the number of dollies per tug and number of tugs per plane on the average time required to offload a plane. Study the impact of these operation parameters on the varying number of planes that arrive at the hub during a night.

Items 1 through 5 are critical problems that require in-depth analysis before making valid recommendations to hub management. Often, an extensive statistical analysis is conducted using one or more simulation model(s) to derive the necessary conclusions.

16.6.1 Static and Dynamic Data

The ramp simulation model requires two types of input information. The first type involves the technical specifications associated with the freight, planes, gates, tugs, dollies, forklifts, and sortline conveyor. In addition, it includes material flow behavior, work rules, park location assignment rules, control rules for tugs and forklifts, and other factors. In general, a ramp simulation model includes the following representative data:

- Number of gates
- Ramp maps
- Technical specifications of sortline conveyors, tugs, dollies, and forklifts
- Plane types
- Flight information
- Tail sheet and chronological arrival/departure information
- Number of container positions that each plane type can carry
- Number of bellies

- Number of containers each belly fills up by plane type
- Number of dollies per tug
- Team makeup for offloading/reloading containers from/to a plane
- Number of tugs and dollies
- Number of forklifts designated for offloading and reloading a plane
- Sortation conveyor locations and physical characteristics
- Plane parking location rules
- Runway behavior

The second type of information involves a set of input distributions to represent the day-to-day (or hour-to-hour) variabilities found in the ramp operations. It includes the plane arrival process at different locations of the ramp, pickup times and dropoff times for tugs and forklifts based on freight type and number of containers, operation times at the conveyor, freight profile, and container contents in the plane.

16.6.2 Factors and Responses

It is important to identify a list of controllable factors and responses to evaluate alternative ramp designs. This helps immensely during the model-building stage if the simulation model has been built to represent all the necessary factors and responses. If the model does not incorporate these factors and responses, the decision maker can hardly use the model to study air cargo operations. Again, these factors and responses are decided based on a list of questions that the hub management is interested in getting answers for. For the ramp simulation model, the major factors are as follows:

- Number of planes
  - Flight profile
  - Plane arrival-time distributions
- Total number of tugs
- Number of tugs per plane
- Number of dollies per tug
- Number of K-loaders

The responses that are of interest include the following:

- Plane offload/load capacity
  - Total number of containers offloaded or loaded
  - Total number of planes offloaded or loaded
- Average time to offload/load an aircraft
- Completion time for offload/load all aircraft on the ramp

16.6.3 Simulation Model Development

A ramp simulation model should be built to interface with input data files and variables that can easily be modified to perform what-if scenarios. The model is frequently developed to represent the following critical processes that occur on a ramp:

- Plane arrival/departure process
- Gate assignment of planes
- Freight creation and movement at the aircraft
- K-loader/forklift/tug interface
- Ramp map for plane gates, container waiting, and tug parking areas
- Tug and dolly movement system
- Forklift movements
- Tracking freight by type (e.g., huts, palletized, belly freight)
- Sortation conveyors

In the simulation program, the plane arrival process is often implemented with a rule base to mimic the tower rules and parking procedures used to park the planes. The rule base utilizes the flight profile to get all pertinent information on arriving flights during a night (or day). It is important that the rule base be tested using many different flight profiles and arrival times to ensure that all arriving planes are parked at the gate locations specified.

In general, the simulation model is built with a ramp map to include the tug and dolly movement paths, the parking locations for planes and tugs, waiting areas for tugs, interaction zones for transfer forklifts to pick up containers from the tugs, and intersection blocks to prevent collision between the tugs and link blocks to keep sufficient space between tugs.

With respect to the tug and dolly system, it is preferred that the ramp simulation model be designed to depict a very explicit and in-depth representation of their behavior to perform a rigorous analysis of equipment usage. Often, a smart algorithm is designed to incorporate the plane assignment rules to tugs and dollies (belonging to a team), tugs per plane rules, tug waiting rules, offloading crew rules, collision avoidance rules, right-of-way rules, parking rules, and passing rules. In addition, the algorithm may use tug specifications such as acceleration; deceleration; loaded and unloaded speeds; and forward, reverse, and curve speeds to determine precise travel times between the aircraft and transfer areas.

The simulation logic development is one of the most important steps. The ramp model (essentially, a computer program) includes the logic and data interfaces. If the logic is incorrect or inaccurate, the output (responses) from a model cannot be utilized to make intelligent decisions (Law and Kelton, 1991). Sufficient time and effort should be spent in the design and development of the model logic to ensure quality outputs as well as flexibility to extend the model to conduct many what-if scenarios on an ongoing basis at the air cargo hub.

16.6.4 Report Generator

Often, it is suggested that a ramp simulation model be implemented with an interactive built-in output processor to create many useful on-line reports for use in making strategic and operational decisions. The results generated during each run may be stored in output files for further analysis and hub management review. The output reports from a ramp simulation model include the following information:

- The total number of containers offloaded during an hour, total number of planes

offloaded during an hour, average time to offload a plane, and completion time for offloading all the planes that arrived during a night (or a day). This helps decision makers to determine exactly when the ramp completes its offloading activity.
- Offloading or reloading times for 10 planes, 20 planes, 30 planes, and so on. This provides the time at which the top side and belly are fully offloaded or reloaded. This helps the decision maker to understand the progress of ramp process during the operation window and accordingly, to determine the lean and peak periods.
- Gates for all arriving planes as created by the simulation model. This information can be utilized to park planes every day or night.
- Actual time at which each aircraft is fully offloaded or reloaded.
- Offloading time (the total time it took to offload the plane since its arrival at the park location) for each aircraft that arrived during a night (or day). Information on the aircraft reloading time for each plane is generated similarly. This information assists the decision maker to determine trouble spots during ramp operations involved in plane offloading and reloading.

16.6.5 What-if Scenarios Using Ramp Simulation Model

The ramp model can be utilized to simulate and analyze the impact of many alternative approaches to assigning tugs to aircraft and the equipment/facilities used for offloading. In addition, several critical issues can be investigated using the simulation model to study the impact of:

- Changes in number of tugs per plane
- Changes in number of dollies hooked to each tug
- Changes in total number of tugs used on the ramp
- Changes in aircraft arrival process/departure process
- Changes in number of K-loaders
- Changes in number of transfer forklifts
- Changes in work rules
- Impact of changes in the tug assignment to aircraft
- Impact of changes in the communication system used to manage tugs, K-loader, etc.

In each case the ramp simulation model can be set up to run a series of experiments, and the results discussed in Section 16.6.4 can be generated to perform in-depth statistical analyses. Based on the analyses, valid recommendations can be made to hub management to improve the operational performance of the ramp.

From the foregoing discussions it is inferred that the modeling and analysis of overnight air cargo operations pose a greater challenge to simulation experts. It is evident that a carefully designed simulation study leads to operational improvements, processing time-window reduction, and substantial cost reduction. Hence it is highly recommended that detailed simulation models combined with good experimental designs and rigorous statistical analysis procedures are set up to generate the best ramp configuration(s) and implementable operational design(s).

16.7 L&T SIMULATION SOFTWARE

Today, many commercial software packages are being employed by L&T industries, depending on the level of complexity and size of the problem investigated. These software tools range from standard linear programming packages such as LINDO, CPLEX, and OSL to special-purpose software shells such as INSIGHT, SUPERSPIN, and CAPS which are built to provide decision support in a wide range of L&T domains. With respect to commercial simulation software, a large number of vendors provide packages, built on a variety of world views and hardware platforms, that focus on modeling and analysis of simple material handling systems to complex flowthrough centers and transportation networks. These software packages provide both animation and statistical analysis capabilities for L&T domain experts to fully represent a variety of entities, resources, and critical processes. These simulation packages include Arena, AUTOMOD II, GPSS/H, MODSIM III, PROMOD, and SIMPLE ++, among many others.

16.8 CONCLUSIONS

As the degree of industrialization of an economy increases, there is a shift in preponderance from basic manufacturing industries, sometimes referred to as primary industries, to the service industries, which are secondary, tertiary, and quarternary in character. The primary industries have a greater need for freight transportation, and the existing L&T systems will continue to grow bigger and bigger and become more and more complex. To build transportation systems that are efficient, easy to operate and manage, and still cost-effective, it is crystal-clear that L&T companies will have to invest their time, money, and other resources in scientific and structured approaches for many years to come. This means that applications of mathematical modeling and numerical solution techniques such as simulation will continue to grow in L&T companies.

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CHAPTER 17

Simulation in Healthcare

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17.1 INTRODUCTION

The spiraling increase in healthcare costs, the increasing restrictions on reimbursed payments to hospitals, the impact of managed care, and the continuing move from inpatient services to outpatient services have combined to put many hospitals in a financial bind. As hospitals came under increasing pressure to reduce costs and increase profitability, long-held beliefs (or fears) delayed the introduction of simulation. Some of those beliefs are:

1. Practices designed for manufacturing are not transferable to healthcare.
2. Efforts to increase efficiency will shortcut patient care.
3. Efforts to increase efficiency will be interpreted by the public as a reduction in the quality of medical care provided to patients.

By the mid-1990s, the resistance was greatly reduced. General acceptance of the benefits of total quality management (TQM) or continuous quality improvement (CQI) facilitated the acceptance of other efforts designed to increase efficiency in hospitals. Simulation is one of the technologies that has benefited from improvements realized from TQM/CQI efforts. Process simulation has proven to be effective as a tool used for process improvement in healthcare.

17.2 COMPARISON OF SYSTEM TYPES

17.2.1 Manufacturing

Manufacturing systems involve the transformation of a raw material into a finished product. The finished product may be designed for an end user, or it may be the raw mate-

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