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A Summary of Procedures Used to Transport and Distribute Consumer Products

Elizabeth L. Etnier
F. R. O'Donnell

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DISTRIBUTE CONSUMER PRODUCTS

Elizabeth L. Etnier and F. R. O'Donnell

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A SUMMARY OF PROCEDURES USED TO TRANSPORT AND DISTRIBUTE CONSUMER PRODUCTS

Elizabeth L. Etnier and F. R. O'Donnell

ABSTRACT

A wide variety of consumer products that contain radionuclides are available to the general public. Estimation of radiation doses to man from exposures to these products requires that the entire life span of each product be defined in a manner that identifies persons who may be exposed and quantifies the conditions under which exposures may occur.

This paper presents models of steps which make up the paths for transportation and distribution of consumer products. Fire probabilities and damage rates to parcels during transportation are included. Transportation steps considered include those used to move parcels via truck, air, first-class mail, and parcel delivery. Distribution steps include handling in distribution centers, warehouses, and retail stores. A hypothetical distribution scheme is presented to illustrate application of the exposure scenarios described in the model.

1. INTRODUCTION

1.1 Background

A wide variety of consumer products that contain radionuclides but are exempt from licensing requirements are available to the general public.¹ Man may be exposed throughout the life spans of such products to radiations emitted during radioactive decay of the contained radionuclides. To assess the potential impacts of such exposures, the life spans of the products must be modeled in a way that allows identification of potentially exposed persons and quantification of the conditions under which they might be exposed.

The CONDOS methodology² was conceived as an aid for modeling the life spans of consumer products and as a tool for using the resultant models to estimate potential radiation doses to man. Applications of the methodology have shown that certain stages in the life spans of products can be represented by combinations of relatively few steps.

Figure 1 is a general overview of the flow of consumer products from a manufacturer to a user. A product could proceed directly from a manufacturer to a user; it could follow a complicated path that involves warehouses, distribution centers, and retail stores; or it could follow a path intermediate to the above. Each path is a combination of a number of specific steps, each of which can be modeled to meet assessment needs.

Fig. 1. General flowchart for the transfer of goods from the manufacturer to the user.

1.2 Objectives

The objectives of this report are (1) to list and discuss basic steps used in transportation and distribution of consumer products, (2) to present models of the steps that are suitable for use with the CONDOS methodology, and (3) to discuss ways to combine the steps to simulate complete paths for transportation and distribution of specific products.

1.3 Scope

This report considers steps commonly used to transport consumer products via truck, air, first-class mail, and parcel delivery and to distribute products through warehouses, distribution centers, and retail stores. Many sources of information, including the open literature and personal contacts with transportation and distribution workers, were used to model the steps and to learn how to combine them. (Personal contacts are not referenced in deference to the wishes of many contacts.) The resulting transportation models are similar to those used in studies of the transportation of radioactive materials.^{3,4} However, our models are designed to accommodate normal consumer products (these include exempt, radionuclide-containing products),¹ rather than licensed, radioactive materials with specified handling requirements.

We have attempted to construct models that contain reasonable estimates of the working (exposure) conditions encountered by transportation and distribution workers and by members of the general public. However, transportation and distribution procedures are extremely variable, especially when the actions of individual workers are considered, and our information base is limited. Therefore, although we have chosen exposure conditions that would tend to maximize workers' exposures, care should be exercised in using the models.

1.4 Format

Because at least one mode of truck transport is used in all paths followed by consumer products, common modes of truck transport are discussed first. These include local, regional, and over-the-road

delivery procedures. Cargo handling in truck terminals is included. Air transport procedures are described next, and interactions between truck and air transport are noted. This is particularly apparent in the descriptions given of specialized parcel service and first-class-mail handling procedures. (Transport by rail and water usually are reserved for shipments that are larger than those of consumer products and are therefore not considered in this report.) Distribution procedures include the handling of products in various types of warehouses and retail stores as well as the flow of products between the several facilities. Special consideration is given to potential transportation accident scenarios. Finally, methods for combining and using the models of various steps are discussed.

2. TRUCK TRANSPORT

Figure 2 illustrates the trucking model that includes three modes of delivery. Local truck delivery (LD) is assumed to include all deliveries

Fig. 2. Flowchart for the delivery of consumer products via truck.

within 32 km (20 miles) of the origin (the facility at which the truck is loaded) and is therefore assumed to be used in the transport of consumer goods by all paths. A regional delivery (RD) is one made over a maximum distance of 400 km (250 miles) (a 5-hr drive). An over-the-road delivery (OTRD) involves distances greater than 400 km and is represented by a series of two or more regional deliveries. (Of 18,243,000 trucks registered in 1972, 88% made local deliveries, 9% made regional deliveries, and 3% made over-the-road deliveries.)⁵

Each truck delivery mode is discussed separately. In modeling a real problem, the applicable modes would be combined, depending on the shipping distance and the size of the shipment involved.

2.1 Local Delivery

A local delivery (Fig. 3) may be made by use of a small or a large delivery truck or a tractor-trailer, depending on the size of the shipment. It may involve a single stop (origin to one destination) or

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Fig. 3. Flowchart for the local delivery of consumer products.

multiple stops (origin to many destinations). Loading and unloading of trucks is almost always done by delivery-truck drivers. The actions of the driver depend on the size and weight of the shipment and are assumed to be the same for both loading and unloading a single-stop delivery truck. (These actions constitute the driver's exposure conditions if the shipment contains radioactive consumer products.)

2.1.1 Small truck

A small delivery truck is assumed to have a cargo space that is 305 cm long, 180 cm wide, and 130 cm high. The driver's seat is located 30 cm from the front and 180 cm from the center of the cargo space. Shielding may be provided by intervening cargo and parts of the truck, but it is ignored in this model.

A single-stop driver is assumed to be in the driver's seat for 30 min during a delivery run (Table 1). While loading and unloading, the driver is assumed to carry each package at an average distance of 30 cm from the body for a total of 1 min (0.017 hr); the total duration of this handling exposure would be $0.017 N$ hr, where N is the number of packages in the shipment. The driver would also be 90 cm and 210 cm from stacks of $0.5 N$ packages for 5 and 10 min, respectively, both while loading and unloading the truck.

A multiple-stop driver is assumed to be on the road for 2 hr. Of this time, 0.75 hr is spent in the driver's seat with $0.5 N$ packages in the truck and 1.25 hr is spent delivering packages. While delivering packages, the driver is assumed to be 1524 cm from $0.5 N$ packages for 0.25 hr and to handle (carry) each package for 1.5 min (0.025 hr) at 30 cm from the body. Loading a multiple-stop truck results in exposures of the driver which are similar to those for a single-stop truck (Table 1).

2.1.2 Large delivery truck

A large delivery truck is assumed to have a cargo space that is 500 cm long, 220 cm wide, and 230 cm high. The driver's seat is 60 cm from the front and 335 cm from the center of the load. Shielding is ignored.

Table 1. Exposure conditions for local delivery

Action	No. of exposed persons	Average exposure distance (cm)	Exposure time (hr) ^a	Source ^b
<u>Single stop</u>				
Driver, small truck	1			
Driving		180	0.5	1 shipment
Loading and unloading				
Handle cargo		30	0.017 <i>N</i>	1 carton
Near cargo		90	0.17	1/2 shipment
Near cargo		210	0.34	1/2 shipment
Driver, large truck	1			
Driving		335	0.5	1 shipment
Loading and unloading				
Handle cargo		30	0.017 <i>N</i>	1 carton
Near cargo		90	0.50	1/2 shipment
Near cargo		305	1.5	1/2 shipment
Driver, tractor-trailer	1			
Driving		825 ^c	0.5	1 shipment
Loading and unloading				
(Volume) Handle cargo		30	0.017 <i>N</i>	1 carton
Near cargo		90	1.0	1/2 shipment
Near cargo		460	4.0	1/2 shipment
(Over flow) Handle cargo		30	0.017 <i>N</i>	1 carton
Near cargo		90	0.5	1/2 shipment
Near cargo		610	1.5	1/2 shipment
(Less-than-truck-load) Handle cargo		30	0.017 <i>N</i>	1 carton
Near cargo		90	1.0	1/2 shipment
Near cargo		460	4.0	1/2 shipment
Forklift operator	1			
(Volume) Handle cargo		120	0.017 <i>P</i>	1 pallet
Near cargo		305	2.0	1/2 shipment
(Overflow) Handle cargo		120	0.017 <i>P</i>	1 pallet
Near cargo		305	0.5	1/2 shipment
(Less-than-truck-load) Handle cargo		120	0.017 <i>P</i>	1 pallet
Near cargo		305	2.0	1/2 shipment
<u>Multiple stop</u>				
Driver, small truck	1			
Driving		180	0.75	1/2 shipment
Loading				
Handle cargo		30	0.0083 <i>N</i>	1 carton
Near cargo		90	0.085	1/2 shipment
Near cargo		210	0.17	1/2 shipment
Unloading				
Handle cargo		30	0.025 <i>N</i>	1 carton
Near truck		1524	0.25	1/2 shipment
Driver, large truck	1			
Driving		335	1.0	1/2 shipment
Loading				
Handle cargo		30	0.0083 <i>N</i>	1 carton
Near cargo		90	0.25	1/2 shipment
Near cargo		305	0.75	1/2 shipment
Unloading				
Handle cargo		30	0.025 <i>N</i>	1 carton
Near truck		1524	2.0	1/2 shipment

^aTotal exposure times are the numbers given multiplied, where indicated, by the number *N* of cartons handled or *P* of pallets handled.

^bThe actual source configuration must be determined by the individual modeler; i.e., the modeler must decide on the size of each carton and the number of cartons in each shipment.

^cThe cab of a tractor-trailer is assumed to be composed of 0.3 cm aluminum sheeting, and the body of all trucks of 0.1 cm aluminum. This provides shielding to the driver of a tractor-trailer and to all drivers when they are away from their trucks making deliveries.

A single-stop, large-delivery-truck driver is assumed to behave much as a small-delivery-truck driver. The driver is in his seat for 30 min, but is 335 cm from the center of the load. While loading and unloading, the driver carries each package in the manner assumed for the small truck driver and is located 90 and 305 cm from 0.5 N packages for 0.5 and 1.5 hr, respectively (Table 1). In some cases, loading and/or unloading may be done with a forklift (Sect. 2.1.3). This action requires that the shipment be palletized.

A multiple-stop driver is assumed to be on the road for 6 hr. Of this time, 1 hr is spent driving and 5 hr are used to deliver packages. Exposures during delivery are the same as those used for small-truck drivers, except that large-truck drivers spend more time (2 hr) near the truck. Loading exposures are the same as for loading single-stop, large trucks (Table 1).

2.1.3 Tractor-trailer

A typical tractor-trailer is about 1370 cm long, 235 cm wide, and 270 cm high. The driver's seat is in the tractor, 140 cm from the front of the trailer and 825 cm from the center of the load. The driver is assumed to drive for 0.5 hr. The walls of the cab are assumed to be 0.3-cm-thick aluminum, and the body of the trailer to be 0.1-cm-thick aluminum. These provide 0.4 cm of aluminum to shield the driver.

A shipment of a product may or may not fill a trailer. If a shipment fills a trailer, it is termed a volume load. An overflow load is that portion of a shipment that fills more than one trailer. Small shipments that are consolidated with others are known as less-than-truckload (LTL) shipments. A combination of LTL shipments may fill an entire trailer, typically as in United Parcel Service (UPS) or United States Postal Service (USPS) shipments. In 1971, motor carriers of general freight subject to Interstate Commerce Commission (ICC) regulation reported that 43% of the tonnage shipped was from LTL shipments.⁶

Exposure conditions for loading and unloading trailers vary, depending on the type of shipment (only single-stop deliveries are considered). Heavy packages are usually handled with the aid of a forklift (Table 1). Trailer drivers usually do not load or unload shipments at truck terminals.

or warehouses. The conditions listed in Table 1 for loading and unloading a tractor-trailer apply to the terminal or warehouse personnel handling the shipments (Sect. 2.2.1 and 6.1).

2.2 Regional Delivery

A regional delivery is considered to cover distances up to 400 km (250 miles). Local delivery (Sect. 2.1) is used to get shipments into and out of the regional delivery cycle.

Figure 4 is a flowchart for regional delivery. The origin may be a manufacturer, a truck terminal, a warehouse, or a retail store. The destination can be a warehouse, a store, or the consumer. If a shipment

Fig. 4. Flowchart for the regional delivery of consumer products.

is made directly to its final destination, no terminal system is involved (e.g., from a warehouse to a retail store). Unloading of the truck is the same as described in Sect. 2.1, depending on the truck size (Table 1).

Exposure conditions for drivers making regional deliveries are listed in Table 2. Note that in each case the daily driving time is 5 hr. Loading and unloading are as described in Sect. 2.1. Forklifts may be used for loading and unloading trailers.

Table 2. Exposure conditions for regional delivery

Action	No. of exposed persons	Average exposure distance (cm)	Exposure time (hr)	Source ^a
Driver, small truck				
Driving	1	180	5.0	1 shipment
Driver, large truck				
Driving	1	335	5.0	1 shipment
Driver, trailer				
Driving				
Volume	1	825 ^b	5.0	1 shipment
Overflow	1	370 ^b	5.0	1 shipment
Less-than-truck-load	1	1055 ^b	5.0	1 shipment

Loading and unloading^c

^aThe actual source configuration must be determined by the individual modeler; i.e., the modeler must decide on the size of each carton and the number of cartons in each shipment.

^bShielding is provided to the driver by the 0.3-cm-thick aluminum wall of the cab, and the 0.1-cm-thick aluminum front of the trailer.

^cLoading and unloading are handled in the same manner as for local delivery, detailed in Table 1.

2.2.1 Truck terminal

A shipment that is handled by a trucking firm is channeled through a truck terminal where goods are sorted and reloaded for further distribution. The number of terminal employees is variable, depending on the size of the warehouse and flow of goods through it. We assume ten workers in the terminal.

In this case, the origin in Fig. 4 is a shipper, and the shipment arrives at a truck terminal by local delivery (Sect. 2.1). Handling at the truck terminal depends on the load size.

A volume load is loaded at the origin and delivered (Sect. 2.1.3) to the truck terminal where it may sit for 8 to 10 hr in the terminal lot without being unloaded. A different driver will deliver the load regionally to another terminal 400 km away, where, if being delivered locally, it may remain in the terminal yard for several hours before being delivered (by tractor-trailer) (Sect. 2.1.3). If not being delivered locally, the load is handled as at the first terminal. Note that the trailer is not unloaded at either terminal.

An overflow load or LTL shipment enters the truck terminal where it is unloaded, sorted, and loaded onto other trucks as described in Sect. 2.1.3, Table 1. After a regional or an over-the-road delivery to another terminal, the shipment is unloaded, sorted, and loaded onto local delivery trucks (Sect. 2.1.1 or 2.1.2).

Most truck terminals do not have storage facilities. Therefore, terminal workers likely would not be exposed to a shipment for more than one shift (8 hr).

2.3 Over-the-Road Delivery

If a shipment is to be delivered more than 400 km (250 miles) from its point of origin, it is called an over-the-road delivery and involves the equivalent of several successive regional deliveries (Sect. 2.2, Table 2). A shipment may be volume, overflow, or LTL and is handled as described in Sect. 2.2.1 during loading and unloading.

2.4 Persons Along Truck Routes

If the consumer products under consideration contain radioactive materials, persons along transportation routes may receive radiation doses. A methodology exists for estimating in detail doses to such persons.^{3,7} We have used the results of applications of this methodology to derive effective exposure durations and perpendicular distances from

the centerline of vehicle travel to the maximally exposed (closest) and average individuals. These parameters may be used to estimate doses as if the source were stationary instead of moving. This is compatible with the CONDOS computer code.² (An effective duration of exposure is the period of exposure to a stationary point source that gives the same dose to a person as does the same source while moving along the centerline of the road. The latter calculation is not compatible with the CONDOS computer code.)

The maximally exposed individual can be assumed to be 3050 cm (100 ft) from the truck route and, based on the results of other studies,^{3,7} the average dose is to a person located 18,300 cm (600 ft) from the route. The corresponding effective durations of exposure (hr) were calculated to be $T_e = 0.08 N/v$ for the maximally exposed person and $T_e = 0.4 N/v$ for the average person. In both equations, v is the average vehicle speed (km/hr), N is the number of vehicles (shipments) passing the exposed person, and 0.08 and 0.4 are factors (km/shipment) relating the distance of vehicle travel that contributes significantly (>1%) to the dose. All persons along routes will have the trailer side (0.1 cm of Al) between them and the cargo.

To estimate a population dose to persons along truck routes, the dose to the average person should be multiplied by the number of exposed persons. This number may be obtained by multiplying the number of persons within 0.8 km (0.5 mile) of the vehicle route and the total distance (km) traveled by the vehicle. (If the population density along the route is given in persons/km², multiply by 1.6 and the total distance travelled to get the desired number of exposed persons.)

2.4.1. Shipment parameters

Some shipment parameters suggested for use in the calculation of maximum and average individual doses to persons along truck routes as well as population doses are given in NUREG-0170, vol. 1, Tables 4-6 and 4-7.⁸ The parameters are listed in Table 3 for regional or over-the-road delivery in a tractor-trailer and in Table 4 for small and large delivery trucks making primarily local deliveries.

Table 3. Shipment parameters for tractor-trailer transport^a

Transport parameters	High-population areas	Medium-population areas	Low-population areas
Average vehicle speed, km/hr	24	40	88
Fraction of total distance traveled in area	0.05	0.05	0.9
Population density of area, persons/km ²	3,861	719	6

^aSource: U.S. Nuclear Regulatory Commission, *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes*, NUREG-0170, vol. 1, Office of Standards Development, Washington, D.C. (December 1977).

Table 4. Shipment parameters for delivery vehicle transport^a

Transport parameters	High-population areas	Medium-population areas
Average vehicle speed, km/hr	24	40
Fraction of total distance traveled in area	0.4	0.6
Population density of area, persons/km ²	3,861	719

^aSource: U.S. Nuclear Regulatory Commission, *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes*, NUREG-0170, vol. 1, Office of Standards Development, Washington, D.C. (December 1977).

3. AIR TRANSPORT

At a given air terminal, all airlines use similar cargo-handling procedures, which depend on the size and weight of the packages being handled. The amount of mechanization employed depends on the volume of cargo handled and the size of the air terminal. Two types of air freight terminals are considered: a small, slightly mechanized one and a large, highly mechanized one.

Figure 5 shows possible steps involved in transporting a package from a shipper to a consignee by air transport.

Fig. 5. Flowchart for air package transport.

A shipment may be delivered either to a small or large air-freight terminal or to a passenger ticket counter. Shipments made on large cargo planes are limited to the few air terminals in the United States large enough to service these planes. For this reason, we consider all air shipments of consumer products to be by passenger plane. A shipment is unloaded at its destination, a small or a large terminal, or at the baggage pickup area if handled as passenger baggage. It is then delivered to the consignee or picked up by the user.

3.1 Package Delivery — Air

A shipper may send one or more packages to an air terminal by one of several modes. Use may be made of company-owned truck and driver, an

airport pickup service truck, or a freight consolidator truck. In all situations, the conditions are the same as for local delivery (Sect. 2.1) or regional delivery (Sect. 2.2). A driver loads his own truck, but air terminal personnel generally unload it.

The consignee, or user, picks up the shipment at its destination air-freight terminal and delivers it locally or regionally (Sect. 2.1 or Sect. 2.2).

Parcels that are shipped through a passenger ticket counter are often delivered by messenger. This mode of delivery is similar to local delivery by truck (Sect. 2.1), but might involve an automobile, and usually consists of only a few parcels. The messenger would hand carry the parcels to the ticket counter (see Table 7, Sect. 3.2.3, for exposure conditions). Pickup of such shipments would involve hand carrying from the baggage pickup area at the destination airport.

3.2 Handling Procedures

Handling procedures for shipment at small or large air terminals are essentially the same, but the number of personnel involved and the size of the handling areas differ. A shipment may arrive at an air terminal already packed in containers, or it may be containerized after it reaches the freight terminal. Containers may range in capacity from 0.5 to 16 m³ (18 to 572 ft³) and may carry 270 to 6800 kg (600 to 15,000 lb), respectively. The container used for this model is assumed to be the smaller (0.5 m³) of the two and to have 5-cm-thick fiberglass walls.

3.2.1 Small air terminal

At a small air terminal, only a few people load and unload planes. They also distribute shipments within the freight terminal (see Table 5 for exposure conditions). Outgoing (planebound) shipments are unloaded at the dock and each package is weighed, labeled, and placed on pallets. The pallets are carried by forklift to a holding area. A shipment is loaded into a container that is weighed, loaded by forklift onto a cart, and transported to a passenger plane for loading. For maximum exposure to a shipment, two freight clerks are assumed to handle all shipments

Table 5. Exposure conditions for a small air terminal

Action	No. of exposed persons	Average exposure distance (cm)	Exposure time ^a (hr)	Source ^b
<u>Outgoing freight</u>				
Freight clerk	1			
Handle cargo		30	0.083 <i>N</i>	1 carton
Near container		60 ^c	0.083 <i>C</i>	Container
Near container		120 ^c	0.033 <i>C</i>	Container
Near container		180 ^c	0.25 <i>C</i>	Container
Other freight clerk	1			
Near cargo		180	0.083 <i>N</i>	1 carton
Near container		60 ^c	0.017 <i>C</i>	Container
Near container		90 ^c	0.17 <i>C</i>	Container
Near container		460 ^c	0.25 <i>C</i>	Container
Freight agent	1			
Near cargo		305	1.0	1 shipment
Near cargo		460 ^c	1.0	1 shipment
<u>Incoming freight</u>				
Freight clerk	1			
Handle container		30 ^c	0.033 <i>C</i>	Container
Near container		180 ^c	0.17 <i>C</i>	Container
Near container		305 ^c	0.25 <i>C</i>	Container
Near cargo		90	0.083	1 shipment
Near cargo		305	1.0	1 shipment
Near cargo		910	1.0	1 shipment
Other freight clerk	1			
Near container		305 ^c	0.25 <i>C</i>	Container
Unload container		90	0.033 <i>N</i>	1 carton
Near container		120 ^c	0.017 <i>C</i>	Container
Handle cargo		30	0.05 <i>N</i>	1 carton
Near cargo		90	0.083	1 shipment
Near cargo		305	1.0	1 shipment
Near cargo		910	1.0	1 shipment
Freight agent	1			
Near cargo		305	0.5	1 shipment
Near cargo		1520	6.0	1 shipment
Near cargo		2290	0.25 <i>C</i>	Container

^aTotal exposure times are the numbers given multiplied, where indicated, by the number *N* of cartons handled or *C* of containers used to pack the shipment.

^bThe actual source configuration must be determined by the individual modeler; i.e., the modeler must decide on the size of each carton and the number of cartons in each shipment.

^cContainers in which shipments are loaded provide 5.0 cm fiberglass as shielding to persons working adjacent to the containers.

during an 8-hr shift, and one freight agent supervises the work. The freight clerks are responsible for loading and unloading planes. Incoming freight is unloaded, transported to the freight terminal, sorted, and held for pickup. Because of a lack of storage area, shipments are normally picked up within 24 hr of their arrival at the terminal (therefore, an individual's total exposure time would be limited to one shift or 8-hr maximum). All sorting, weighing, labeling, and handling procedures are grouped together as handling procedures in Table 5.

3.2.2 Large air terminal

In a large air terminal, the number of workers per shift varies, and much of the handling process is mechanized. A large terminal could employ 56 freight clerks and 2 supervisors during an 8-hr shift. Thirty-six workers process outgoing freight and nineteen process incoming freight. Table 6 gives the assumed exposure conditions.

An outgoing freight shipment is unloaded at the receiving docks by one of seven clerks. If a shipment contains heavy packages or is containerized, a forklift is used to carry it directly to a conveyor system. Small parcels are unloaded manually, sorted, weighed, labeled, and put into carts that attach to the conveyor system. There are six clerks at the scales. The conveyor belt branches to 12 spurs, each operated by one clerk. Spurs lead to the area where shipments are placed in containers. Twelve clerks load containers. Loaded containers are carried by forklift to 1220-cm-long tractor-trailers, which transport the shipments to the planes. Containers that come to the airport already loaded are carried directly onto the plane by forklift. Two freight clerks load the plane. Containers filled at the airport are carried to the plane, unloaded, and the contents put into the plane.

Incoming freight is unloaded from the plane and transported to the freight terminal. The shipments are sorted by 12 clerks and moved on pallets by forklift to the staging area. Here they are stored for pickup. Total handling time for a shipment is assumed to be 6 hr. Because of the volume of freight handled, shipments are generally picked up within 4 hr of arrival. Thus, no employee should be exposed to a shipment for more than 8 hr.

3.2.3 Passenger ticket counter — baggage delivery

Parcels weighing less than 23 kg (50 lb), with a maximum total of 230 cm (90 in.) for length, width, and height, may be checked at an airlines main ticket counter. These are handled as baggage. The number of people in the airport would depend on the size of the city and the time of day. It is assumed that 100 people would be within 610 cm (20 ft) of the parcel while they are at the ticket counter and while picking up their baggage. See Table 7 for exposure conditions.

Table 6. Exposure conditions for large air terminal .

Action	No. of exposed persons	Average exposure distance (cm)	Exposure time ^a (hr)	Source ^b
<u>Outgoing freight — single shipments</u>				
Truck unloader	1			
Handle cargo		30	0.008 <i>N</i>	1 carton
Near cargo		305	0.083	1 shipment
Other unloaders				
Near cargo	2	460	0.083 <i>N</i>	1 carton
Near cargo	8	910	0.083 <i>N</i>	1 carton
Near cargo	2	1370	0.083 <i>N</i>	1 carton
Near cargo	12	3050	0.083 <i>N</i>	1 carton
Sorters				
Sort cargo	1	30	0.008 <i>N</i>	1 carton
Near cargo	2	610	0.004 <i>N</i>	1 carton
Near cargo	3	1220	0.004 <i>N</i>	1 carton
Near cargo	1	90	0.004 <i>N</i>	1 carton
Freight clerk	1			
Load container		90	0.008 <i>N</i>	1 carton
Near container		90 ^c	0.08 <i>C</i>	Container
Near container		305 ^c	0.42 <i>C</i>	Container
Other freight clerks	11			
Near container		305 ^c	0.5 <i>C</i>	Container
Cargo transporter	1			
Near container		910 ^c	0.17 <i>C</i>	Container
Plane loader	1			
Handle container		30 ^c	0.033 <i>C</i>	Container
Near container		90 ^c	0.17 <i>C</i>	Container
Near container		460 ^c	0.25 <i>C</i>	Container
Other plane loader	1			
Near container		90 ^c	0.17 <i>C</i>	Container
Near container		460 ^c	0.25	Container
Freight agents	2			
Near cargo		3050	1.0 <i>C</i>	Container
<u>Outgoing freight — containerized</u>				
Truck unloader	1			
Forklift container		120 ^c	0.017 <i>C</i>	Container
Near container		305 ^c	0.083 <i>C</i>	Container
Near container		910 ^c	0.083 <i>C</i>	Container
Other unloaders				
Near container	2	460 ^c	0.083 <i>C</i>	Container
Near container	8	910 ^c	0.083 <i>C</i>	Container
Near container	2	1370 ^c	0.083 <i>C</i>	Container
Near container	12	3050 ^c	0.083 <i>C</i>	Container
		305 ^c	0.5 <i>C</i>	Container
		910 ^c	0.25 <i>C</i>	Container
Cargo transporter	1			
Near container		910 ^c	0.17 <i>C</i>	Container
Plane loader	1			
Near container		90 ^c	0.17 <i>C</i>	Container
Forklift container		120 ^c	0.017 <i>C</i>	Container
Near container		460 ^c	0.25 <i>C</i>	Container
Other plane loader	1			
Near container		90 ^c	0.17 <i>C</i>	Container
Near container		460 ^c	0.25 <i>C</i>	Container
Freight agents	2			
Near container		3050 ^c	1.0 <i>C</i>	Container

Table 6 (continued)

Action	No. of exposed persons	Average exposure distance (cm)	Exposure time ^a (hr)	Source ^b
<u>Incoming freight - single shipments</u>				
Plane unloader	1			
Handle cargo		30	0.033 <i>N</i>	1 carton
Near cargo		90	0.17	1 shipment
Near cargo		460	0.25	1 shipment
Other unloader	1			
Near cargo		30	0.17 <i>N</i>	1 carton
Near cargo		90	0.25	1 shipment
Near cargo		460	0.17	1 shipment
Cargo transporter	1			
Near cargo		910	0.17	1 shipment
Freight clerk	1			
Handle cargo		30	0.017 <i>N</i>	1 carton
Near cargo		305	2.0	1 shipment
Other freight clerks				
Forklift	1	120	0.017 <i>N</i>	1 carton
Near cargo	10	460	1.5	1 shipment
Near cargo	11	305	2.0	1 shipment
Near cargo	7	1524	4.0	1 shipment
Truck loader	1			
Handle cargo		30	0.017 <i>N</i>	1 carton
Near cargo		305	0.083	1 shipment
Other loaders	6			
Near cargo		460	0.17	1 shipment
Freight agents	2			
Near cargo		3048	6.0	1 shipment
<u>Incoming freight - containerized</u>				
Plane unloader	1			
Forklift container		120 ^c	0.033 <i>C</i>	Container
Near container		90 ^c	0.17 <i>C</i>	Container
Near container		460 ^c	0.25 <i>C</i>	Container
Other unloader	1			
Near container		90 ^c	0.17 <i>C</i>	Container
Near container		460 ^c	0.25 <i>C</i>	Container
Cargo transporter	1			
Near container		910	0.17 <i>C</i>	Container
Freight clerk	1			
Forklift container		120 ^c	0.033 <i>C</i>	Container
Near container		90 ^c	0.083 <i>C</i>	Container
Near container		305 ^c	2.0 <i>C</i>	Container
Other freight clerks				
Near container	10	460 ^c	1.5 <i>C</i>	Container
Near container	11	305 ^c	2.0 <i>C</i>	Container
Near container	7	1524 ^c	4.0 <i>C</i>	Container
Truck loader	1			
Handle container		90 ^c	0.017 <i>C</i>	Container
Near container		305 ^c	0.083 <i>C</i>	Container
Other loaders	6			
Near container		460	0.17 <i>C</i>	Container
Freight agents	2			
Near container		3048	6.0 <i>C</i>	Container

^aTotal exposure times are the numbers given multiplied, where indicated, by the number *N* of cartons handled or *C* of containers used to pack the shipment.

^bThe actual source configuration must be determined by the individual modeler; i.e., the modeler must decide on the size of each carton and the number of cartons in each shipment.

^cContainers in which shipments are loaded provide 5.0-cm fiberglass as shielding to persons working adjacent to the containers.

Table 7. Exposure conditions for air terminal — baggage delivery

Action	No. of exposed persons	Average exposure distance (cm)	Exposure time ^a (hr)	Source ^b
Messenger delivery	1			
Handle cargo		30	0.083 <i>N</i>	1 carton
Ticket clerk	1			
Handle cargo		30	0.025 <i>N</i>	1 carton
Passengers in terminal	100			
Near cargo		610	0.083 <i>N</i>	1 carton
Flight clerk, outgoing	1			
Handle cargo		30	0.017 <i>N</i>	1 carton
Near cargo		90	0.083 <i>N</i>	1 carton
Near cargo		180	0.083 <i>N</i>	1 carton
Baggage clerk	1			
Near cargo		460	0.25 <i>N</i>	1 carton
Near cargo		305	0.17 <i>N</i>	1 carton
Other clerk	1			
Load container		30	0.017 <i>N</i>	1 carton
Load plane		305 ^c	0.17 <i>C</i>	Container
Near container		460 ^c	0.25 <i>C</i>	Container
Handle container		30 ^c	0.017 <i>C</i>	Container
Flight clerk, incoming	1			
Unload container		30	0.008 <i>N</i>	1 carton
Near cargo		90 ^c	0.083 <i>N</i>	1 carton
Near cargo		180	0.083 <i>N</i>	1 carton
Baggage clerk	1			
Near cargo		180	0.5 <i>N</i>	1 carton
Other baggage clerks	6			
Near unclaimed baggage		460	4.0 <i>N</i>	1 carton
Passengers	100			
Near baggage pickup		610	0.083 <i>N</i>	1 carton
Messenger pickup	1			
Handle cargo		30	0.083 <i>N</i>	1 carton

^aTotal exposure times are the numbers given multiplied, where indicated, by the number *N* of cartons handled or *C* of containers used to pack the shipment.

^bThe actual source configuration must be determined by the individual modeler; i.e., the modeler must decide on the size of each carton and the number of cartons in each shipment.

^cContainers in which shipments are loaded provide 5.0-cm fiberglass as shielding to persons working adjacent to the containers.

The parcels are put into containers, transported to, and loaded into a passenger plane with the regular baggage. At the destination, the containers are taken to the baggage pickup area and unloaded onto the baggage conveyors where they await pickup by the consignee or a messenger service.

3.3 Flight

The crew of a passenger plane consists of a pilot, a copilot, an engineer, and three flight attendants. An average passenger flight is

assumed to cover a distance of 1610 km (1000 miles) and to require 2.5 hr, including 0.5 hr on the ground. An all-tourist flight with 125 passengers on board is considered. The flight attendants are assumed to move at random through the plane, and to stand over either of the cargo compartments for 25% of the flight time (30 min of 2 hr). A shipment may be loaded into either the anterior or the posterior hold, or both. The cargo compartments are directly under the floor of the passenger compartment. See Table 8 for a summary of the exposure conditions.

3.4 Persons Along Air Transport Routes

Population doses should be estimated for the persons near an airplane carrying a shipment while it is on the ground. Each airplane is assumed to stop for 1 hr at an air terminal, where the average population density is 720 people per square kilometer.⁹ To estimate population doses conservatively, we assume 1240 persons to be at an average distance of 0.3 km (1000 ft) from the parked plane and 180 persons to be at 0.12 km (400 ft). The airplane body, buildings, and intervening cargo provide shielding, but these are ignored in the model.

4. PARCEL HANDLING SERVICE

There are services that specialize in the transport of small packages. In general, the handling procedures used by all such services are sufficiently similar to be considered as one entity, a hypothetical combination of the services. Figure 6 is a flow chart for a parcel delivered by our hypothetical parcel-handling service.

A package may be picked up at a manufacturer's facility and delivered by local delivery truck to a terminal, or it may be taken directly to a receiving counter at a terminal by an individual (messenger delivery). In either case, it enters a terminal where it is loaded onto trucks or trailers for distribution. A package may be delivered to a local user, or it may require regional delivery. In this case, it is assumed to be transported 400 km to a second terminal, where it is again sorted and reloaded onto trucks for local delivery.

Table 8. Exposure conditions for passenger plane flight

Action	No. of exposed persons	Average exposure distance ^a (cm)	Exposure time (hr)	Source ^b
Flight crew	3			
Anterior hold		1077	2.5	1 shipment
Rear hold		2444	2.5	1 shipment
Flight attendants	3			
Either hold		90	0.5	1 shipment
		200	2.0	1 shipment
Both holds		90	1.0	1 shipment
		200	1.5	1 shipment
Avg. passenger	1			
Anterior hold		280	2.5	1 shipment
Rear hold		288	2.5	1 shipment
Both holds		200	2.5	1 shipment
Closest passenger	1			
Either hold		90	2.5	1 shipment

^aThe exposure distance to be used depends on which hold or holds the shipment is loaded into.

^bThe actual source configuration must be determined by the individual modeler; i.e., the modeler must decide on the size of each carton and the number of cartons in each shipment.

Fig. 6. Flowchart for package delivery service.

If the package is to be transported over a distance greater than 400 km, it would enter a terminal for sorting and reloading every 400 km and travel as in over-the-road delivery, LTL.

A package might be handled by the parcel service but sent by air. In this case, it could be delivered to an airport, loaded into a container, and entered into the "air package transport system." At its destination airport, the package is again picked up by a parcel service and delivered regionally or locally to a user. Shipment in containers will be made only over large distances. Table 9 summarizes working conditions for each operation in the parcel delivery system.

4.1 Package Delivery

Parcels delivered by such a service are normally limited in weight (23 kg) and in size (total length plus girth, less than 275 cm). There is a 46-kg weight limit per shipment per consignee.

Table 9. Exposure conditions for parcel delivery service

Action	No. of exposed persons	Average exposure distance (cm)	Exposure time ^a (hr)	Source ^b
<u>Messenger delivery</u>				
Messenger	1			
Handle carton		30	0.083 <i>N</i>	1 carton
Desk clerk	1			
Handle carton		90	0.008 <i>N</i>	1 carton
Near carton		150	1.0 <i>N</i>	1 carton
Near carton		610	1.0 <i>N</i>	1 carton
Cargo transporter	1			
Near cargo		150	0.083 <i>N</i>	1 carton
Processing, sorting, loading trailer: see regional delivery, below				
<u>Truck pickup</u>				
Driver, large truck	1			
Handle cargo		30	0.033 <i>N</i>	1 carton
Driving		330	1.0	1 shipment
Away from truck		1520 ^u	2.0	1 shipment
Processing, loading trailer: see local delivery — incoming parcel, below				
<u>Regional delivery</u>				
Unloader, trailer	1			
Handle cargo		30	1.0E-3 <i>N</i>	1 carton
Near cargo		610	0.5	1 shipment
Other unloaders				
Near cargo	2	460 ^d	0.5	1 shipment
Near cargo	2	910 ^e	0.5	1 shipment
Near cargo	2	1370 ^f	0.5	1 shipment
Near cargo	2	1830 ^g	0.5	1 shipment
Processor	1			
Handle cargo		90	1.0E-3 <i>N</i>	1 carton
Near cargo		610	1.0 <i>N</i>	1 carton
Other processors	8			
Near cargo		610	1.0 <i>N</i>	1 carton
Sorter	1			
Handle cargo		90	1.0E-3 <i>N</i>	1 carton
Near cargo		610	1.25 <i>N</i>	1 carton
Other sorters	14			
Near cargo		610	1.25 <i>N</i>	1 carton
Loader, trailer	1			
Handle cargo		30	1.33E-3 <i>N</i>	1 carton
Near cargo		610	1.25	1 shipment
Other loaders				
Near cargo	2	610 ^d	1.25	1 shipment
Near cargo	2	460 ^e	1.25	1 shipment
Near cargo	2	910 ^f	1.25	1 shipment
Near cargo	2	1370 ^g	1.25	1 shipment
Near cargo	2	1830 ^h	1.25	1 shipment
Near cargo	2	2290 ⁱ	1.25	1 shipment
Near cargo	2	2750 ^j	1.25	1 shipment
Driver — LTL	1			
Near cargo		1055 ^c	5.0	1 shipment

Table 9 (continued)

Action	No. of exposed persons	Average exposure distance (cm)	Exposure time ^a (hr)	Source ^b
<u>Local delivery - incoming parcel</u>				
Unloader, large truck	1			
Handle cargo		30	0.008 <i>N</i>	1 carton
Near cargo		305	0.17	1 shipment
Near cargo		460	0.333	1 shipment
Processing, loading trailer: as in regional delivery				
Other workers	52			
Near loaded trailers		1830 ^c	1.5	1 shipment
Supervisors	6			
Near loaded trailers		1830 ^c	1.5	1 shipment
<u>Local delivery - outgoing parcel</u>				
Unloading, processing: as in regional delivery, trailer				
Sorter	1			
Handle cargo		90	1.0E-3 <i>N</i>	1 carton
Near cargo		610	0.5	1 shipment
Other sorters	2			
Near cargo		150	1.0E-3 <i>N</i>	1 carton
Near cargo		610	0.5	1 shipment
Loader, large truck	1			
Handle cargo		30	0.017 <i>N</i>	1 carton
Near cargo		90	0.25	1 shipment
Near cargo		305	0.25	1 shipment
Other loaders				
Near cargo	4	460	0.25	1 shipment
Driver - LTL	1			
Near cargo		1055 ^c	5.0	1 shipment

^aTotal exposure times are the numbers given multiplied, where indicated, by the number *N* of cartons handled.

^bThe actual source configuration must be determined by the individual modeler; i.e., the modeler must decide on the size of each carton and the number of cartons in each shipment.

^cA shielding of 0.1 cm aluminum is assumed.

^dA shielding of 0.2 cm aluminum is assumed.

^eA shielding of 0.4 cm aluminum is assumed.

^fA shielding of 0.6 cm aluminum is assumed.

^gA shielding of 0.8 cm aluminum is assumed.

^hA shielding of 1.0 cm aluminum is assumed.

ⁱA shielding of 1.2 cm aluminum is assumed.

^jA shielding of 1.4 cm aluminum is assumed.

A parcel may be delivered by an individual to a local receiving counter, as in local delivery - small or large delivery truck (Sect. 2.1). A clerk weighs and labels the parcel. The parcel is driven by truck to the terminal, where the parcel is handled along with other truck deliveries.

Parcels picked up from a manufacturer in service trucks are handled as in local delivery — large truck — multiple stops (Sect. 2.1.2). The driver picks up the package and carries it to his truck for loading.

Delivery of a parcel to its destination is made as in local delivery — large delivery truck — multiple stop (Sect. 2.1.2).

4.2 Handling Procedures — Terminal

A parcel handling service may operate four main shifts, each 3-hr long. A typical shift might have 52 people working on regional delivery and 20 on local delivery. Six supervisors work 8-hr shifts, and all other employees work part-time, typically for 3 hr/day.

4.2.1 Regional delivery — parcel service

A trailer holds 1800 to 2000 packages and can be unloaded by one individual at a rate of 1000 packages/hr (3.6 sec/package) or in about 2 hr. The parcels are put onto conveyor belts running through the terminal and are assumed to be handled (weighed and sorted) at the same rate throughout the terminal. Packages intended for regional delivery are loaded into trailers at a rate of about 750 packages/hr (4.8 sec/package). Therefore, it would take a person about 2.5 hr to load a trailer.

Upon leaving the terminal, a trailer travels as in regional delivery — trailer (Sect. 2.2). Recall that a regional delivery terminates at a local terminal.

4.2.2 Local delivery

Incoming local delivery trucks are unloaded in about 0.25 hr. Parcels are weighed, sorted, placed on a conveyor system, and distributed to outgoing trailers. The parameters for processing (weighing and labeling), sorting, and loading the trailer are the same as for parcel service — regional delivery (Table 9).

Parcels that are delivered to a local terminal by regional delivery (Sect. 2.2) and that are destined for local delivery move off the conveyor system after being unloaded and weighed. They are sorted and loaded into large delivery trucks and are delivered as in local delivery — large delivery truck — multiple stop (Sect. 2.1.2).

Since local delivery trucks usually are loaded in the early morning, packages may remain on the conveyor system for some time before being loaded. The six supervisors could be near the packages for a maximum of 8 hr, but all other employees would be in the area for no more than 3 hr.

5. FIRST CLASS MAIL

Delivery procedures for first-class mail are similar to those used in trucking (Sect. 2), with some variations in handling procedures within terminals. Depending on availability and schedules, air transport also may be used. See Fig. 7 for flow chart.

Local post offices are generally small and service a town or a section of a city. Sectional post offices are collecting centers for all nearby local post offices and handle deliveries made on a regional or a local delivery basis. Sectional offices are located about 400 km apart, as are truck terminals, and any combination of three or more would constitute over-the-road delivery (Sect. 2.3).

Table 10 summarizes exposure conditions involved in transport of first-class mail. Either letters or parcels may be sent first class, but for convenience we call everything letters.

5.1 Package Delivery — U.S. First-Class Mail

All items to be mailed first-class are delivered directly by messenger to the receiving counter of a local post office. All local deliveries to another post office (local or sectional) are assumed to be by large delivery truck — single stop (Sect. 2.1.2). Mail pouches are loaded on the back of the truck behind the parcel-post packages. Local deliveries to users are assumed to be by small truck — multiple stop (Sect. 2.1.1), but shorter handling durations are assumed.

Regional deliveries are made by tractor-trailer (Sect. 2.2.3). Mail sacks holding first-class mail are always loaded in the rear end of a trailer, so that the driver is assumed to be 1510 cm (50 ft) from mail items.

Fig. 7. Flowchart for U.S. Post Office — first-class mail.

Table 10. Exposure conditions for first-class mail delivery

Action	No. of exposed persons	Average exposure distance (cm)	Exposure time ^a (hr)	Source ^b
<u>Local post office - outgoing mail</u>				
Messenger	1			
Handle letter		90	0.083 <i>N</i>	1 letter
Window clerk	1			
Handle mail		90	4.17E-3 <i>N</i>	1 letter
Near mail		150	4.0 <i>N</i>	1 letter
Mail clerk	1			
Sack mail		90	0.033 <i>N</i>	1 letter
Other mail clerks	11			
Near mail		1524	5.0 <i>N</i>	1 letter
Driver	1			
Handle mail		90	0.017	1 shipment
Near mail		460	0.083	1 shipment
Local delivery		460	0.5	1 shipment
<u>Local post office - incoming mail</u>				
Mail clerk	1			
Sort mail		90	4.7E-4 <i>N</i>	1 letter
Deliveryman	1			
Case mail		90	5.5E-4 <i>N</i>	1 letter
Near mail		90	2.0 <i>N</i>	1 letter
Handle mail		90	8.33E-3 <i>N</i>	1 letter
Near mail		305	0.133	1 shipment
Deliver mail		90	8.33E-3 <i>N</i>	1 letter
Near mail		90	2.0	1 shipment
Other workers	20			
Near mail		460	2.0	1 shipment
Near mail		920	0.133	1 shipment
Other employees	12			
Near mail		1524	2.0	1 shipment
<u>Sectional post office - incoming mail</u>				
Mail transporter	1			
Near mail		90	0.02	1 shipment
Processor	1			
Near mail		90	2.77E-4 <i>N</i>	1 letter
Other processor	1			
Near mail		150	2.77E-4 <i>N</i>	1 letter
Sort transporter	1			
Near mail		90	8.33E-3	1 shipment
Sorter	1			
Handle mail		90	4.44E-3 <i>N</i>	1 letter
Near mail		150	1.0	1 shipment
Other sorters	23			
Near mail		460	1.0	1 shipment
Other workers	16			
Near mail		1524	1.0	1 shipment
Loader	1			
Seal sack		90	0.038	1 shipment

Table 10 (continued)

Action	No. of exposed persons	Average exposure distance (cm)	Exposure time ^a (hr)	Source ^b
Driver	1			
Handle cargo		90	0.017 <i>N</i>	1 letter
Near cargo		460	0.083	1 shipment
Driving, local delivery		460	0.5	1 shipment
<u>Air mail — outgoing</u>				
Air mail clerk	1			
Handle mail		90	0.017	1 shipment
Near mail		1524	1.0	1 shipment
Freight clerk	1			
Transport to plane		910	0.17	1 shipment
Plane loaders: See Table 6 — Outgoing freight — single shipments				
Flight: See Table 8				
<u>Air mail — incoming</u>				
Plane unloaders: See Table 6 — Incoming freight — single shipments				
Freight clerk	1			
Transport to office		910	0.17	1 shipment
Air mail clerk	1			
Handle mail		90	0.017	1 shipment
Near mail		1524	1.0	1 shipment
Deliveryman	1			
Handle mail		90	0.017	1 shipment
Near mail		460	0.083	1 shipment
Local delivery		460	0.5	1 shipment

^aTotal exposure times are the numbers given multiplied, where indicated, by the number *N* of letters handled.

^bThe actual source configuration must be determined by the individual modeler; i.e., the modeler must decide on the size of each carton and the number of cartons in each shipment.

Mail destined for air transport is delivered from a local or a sectional post office as in local delivery — large delivery truck — single stop (Sect. 2.1.2). Each driver unloads his truck.

5.2 Handling Procedures

Mail moves through a post office in a series of steps, including weighing, canceling, sorting, and putting into sacks. The number of people involved depends on the size of the post office. Truck drivers are always responsible for loading and unloading their vehicles.

5.2.1 Local post office

Items originating at a local post office are weighed, stamped, sorted, put into sacks, and loaded into trucks for local or regional

delivery (see Sect. 5.1 — package delivery). Incoming mail (from regional deliveries or local deliveries) is sorted first by route and then by the deliveryman according to his stops. In a moderate-size post office, 12 mail clerks work an 8-hr shift, and 20 drivers deliver mail to addressees.

5.2.2 Sectional post office

Mail delivered to a sectional post office is canceled, faced, sorted, and bundled. Much of this is done mechanically. Bundles are put into sacks and loaded onto large or small delivery trucks for local delivery or onto trailers for regional delivery.

Forty clerks process out-of-town mail, and forty process local mail. A sectional post office is sufficiently large that work going on in one area is effectively isolated by distance and intervening structures from other areas.

5.2.3 Airmail

Airmail is delivered by local delivery (Sect. 2.1) to a postal station at an airport. One clerk operates this station. Sacks of mail are picked up by air terminal personnel while transporting regular air freight to a plane for loading. From this point on, a sack of mail is handled in the same manner as a package in air freight (Sect. 3).

Upon reaching the destination airport, mail is received at the postal station, loaded onto delivery trucks, and reenters the post office system.

6. DISTRIBUTION SCHEME

Products that are manufactured and distributed to the public through retail stores are generally routed through a warehouse system that is separate from the transportation system. The warehouses involved are known as distribution centers. Goods may be stored in these centers for varying periods of time, depending on supply and demand. The size of the warehouse and the personnel, equipment, and time involved in

distributing products are related to the size and number of retail stores it services.

For purposes of this model, retail stores are categorized as large (chain) or small (neighborhood) stores. Products are displayed on shelves in the sales area and stored in a storage area. The quantities of goods as well as the number of salespeople involved depend on the size of the store and the characteristics of the product.

Tables 11 and 12 list exposure conditions for distribution center workers and retail store workers, respectively.

6.1 Distribution Centers

6.1.1 Chain warehouse

A large warehouse might employ 10 storeroom clerks and 20 persons to load and unload trucks. Each works an 8-hr shift each day (2000 hr/year).

Incoming shipments are loaded onto pallets at the dock and carried by forklift to a storage area. Pallets are stored on shelves, and clerks are assumed to be 305 cm from them for 1 hr each day.

The products are reloaded onto dollies to be trucked out to the retail stores. It is assumed the products turn over every 3 months. For a working model, it is also assumed that a given number of packages (N) are delivered X times a year to the warehouse from the manufacturer. In the storeroom, the workers are near an average of $N/2$ packages at all times. In Table 11, P represents the number of packages that can be loaded on a pallet or dolly. If there are Y packages per shipment to a store, NX/Y gives the number of shipments going out to the stores in a year, and Y/P results in the number of dollies per shipment.

Each chain warehouse is assumed to service 100 chain stores.

6.1.2 Distributor's warehouse

A distributor's warehouse, servicing 100 small retail stores, is assumed to have ten people working at the docks and five people in the storage area. In all other respects, it is similar to a large warehouse.

Table 11. Exposure conditions for distribution center workers

Action	No. of exposed persons	Average exposure distance (cm)	Exposure time ^a (hr)	Source ^b
<u>Chain warehouse</u>				
Trailer unloader	1			
Handle cargo		30	0.017 <i>N</i>	1 carton
Near cargo		90	1.0	1/2 shipment
Near cargo		460	4.0	1/2 shipment
Other unloaders				
Near cargo	2	460 ^c	5.0	1/2 shipment
Near cargo	2	910 ^d	5.0	1/2 shipment
Near cargo	2	1370 ^e	5.0	1/2 shipment
Near cargo	2	1830 ^f	5.0	1/2 shipment
Near cargo	1	2290 ^g	5.0	1/2 shipment
Forklift operator	1			
Near cargo		120	0.17 <i>P</i>	1 pallet
Storeroom clerk	1			
Handle cargo		30	4.17E-3 <i>N</i>	1 carton
Near cargo		120	0.083 <i>P</i>	1 pallet
Near cargo		305	60.0	1/2 shipment
Other storeroom clerks	9			
Near cargo		305	60.0	1/2 shipment
Trailer loader	1			
Handle cargo		30	0.017 <i>N</i>	1 carton
Near cargo		90	1.0	1/2 shipment
Near cargo		460	4.0	1/2 shipment
Other loaders				
Near cargo	2	460 ^c	5.0	1/2 shipment
Near cargo	2	910 ^d	5.0	1/2 shipment
Near cargo	2	1370 ^e	5.0	1/2 shipment
Near cargo	2	1830 ^f	5.0	1/2 shipment
Near cargo	1	2290 ^g	5.0	1/2 shipment
<u>Distribution warehouse</u>				
Trailer unloader	1			
Handle cargo		30	0.017 <i>N</i>	1 carton
Near cargo		90	1.0	1/2 shipment
Near cargo		460	4.0	1/2 shipment
Other unloaders				
Near cargo	2	460 ^c	5.0	1/2 shipment
Near cargo	2	910 ^d	5.0	1/2 shipment
Forklift operator	1			
Near cargo		120	0.17 <i>P</i>	1 pallet
Storeroom clerk	1			
Handle cargo		30	4.17E-3 <i>N</i>	1 carton
Near cargo		120	0.083 <i>P</i>	1 pallet
Near cargo		305	60.0	1/2 shipment
Other storeroom clerks	4			
Near cargo		305	60.0	1/2 shipment
Trailer loader	1			
Handle cargo		30	0.017 <i>N</i>	1 carton
Near cargo		90	1.0	1/2 shipment
Near cargo		460	4.0	1/2 shipment

Table 11 (continued)

Action	No. of exposed persons	Average exposure distance (cm)	Exposure time ^a (hr)	Source ^b
Other loaders				
Near cargo	2	460 ^c	5.0	1/2 shipment
Near cargo	2	910 ^d	5.0	1/2 shipment

^aTotal exposure times are the numbers given multiplied, where indicated, by the number *N* of cartons handled or *P* of cartons loaded onto one pallet.

^bThe actual source configuration must be determined by the individual modeler; i.e., the modeler must decide on the size of each carton and the number of cartons in each shipment.

^cA shielding of 0.1 cm aluminum is assumed.

^dA shielding of 0.2 cm aluminum is assumed.

^eA shielding of 0.4 cm aluminum is assumed.

^fA shielding of 0.6 cm aluminum is assumed.

^gA shielding of 0.8 cm aluminum is assumed.

Table 12. Exposure conditions for retail store workers

Action	No. of exposed persons	Average exposure distance (cm)	Exposure time ^a (hr)	Source ^b
<u>Chain store</u>				
Sales clerk	1			
Handle product		30	0.083 <i>N</i>	1 package
Near stored product		150	250.0	1/2 shipment
Near displayed product		305	250.0	1/2 shipment
Other activities		910	1500.0	1/2 shipment
Other sales clerks	3			
Near stored product		150	250.0	1/2 shipment
Near displayed product		305	250.0	1/2 shipment
Other activities		910	1500.0	1/2 shipment
<u>Small store</u>				
Sales clerk	1			
Handle product		30	0.083 <i>N</i>	1 package
Near stored product		150	250.0	1/2 shipment
Near displayed product		305	250.0	1/2 shipment
Other activities		910	1500.0	1/2 shipment
Other sales clerks	1			
Near stored product		150	250.0	1/2 shipment
Near displayed product		305	250.0	1/2 shipment
Other activities		910	1500.0	1/2 shipment

^aTotal exposure times are the numbers given multiplied, where indicated, by the number *N* of cartons handled.

^bThe actual source configuration must be determined by the individual modeler; i.e., the modeler must decide on the size of each carton and the number of cartons in each shipment.

6.2 Retail Stores

6.2.1 Chain store

A chain store is departmentalized, and the departments frequently operate independently of each other. Typically, four employees work overlapping 8-hr shifts (2000 hr/year) in one department of a large chain store. A few samples of a product are displayed in the sales area, and the remainder are stored in a storeroom nearby. Each worker spends 1 hr/day in the storeroom (150 cm from the product) and 6 hr/day at 910 cm from it. Each worker is 305 cm from the display area for 1 hr/day and 910 cm from it for 6 hr/day. An employee making a sale is assumed to be 30 cm from a product for 5 min during the sale.

6.2.2 Small retail store

In a small retail store, two people work overlapping 8-hr shifts (2000 hr/year). Each person is assumed to be 150 cm from products stored in a storeroom and 305 cm from the products in the display area for 1 hr/day (250 hr/year) and 910 cm from these areas for 6 hr/day. A sales clerk is assumed to handle a product (at 30 cm) for 5 min while making a sale.

7. ACCIDENTS

7.1 Truck Accidents

In 1971 the Department of Transportation, Division of Motor Carrier Safety, published a summary of accident reports of motor carriers which involved cargo damage of more than \$250.¹⁰ From this information, an accident frequency rate of 4.0×10^{-6} accidents per kilometer (2.5×10^{-6} accidents per mile) is found for motor carriers. Fire occurred in 1.6% of the accidents reported for all trucks.¹¹

In an analysis of transportation accidents by the U.S. Atomic Energy Commission,⁷ accidents are categorized by degree of severity in terms of vehicle velocity as well as by incidence and duration of fires.

These data, in conjunction with those found in NUREG-0170 (ref. 3) and Clark, et al.¹² describing accident severities, have been used to define three severity classifications for package damage. Because the truck accidents reported all involve some degree of cargo damage, accidents in which there is no damage to the package or contents are not considered.

7.1.1 Accident severity classes

Class I represents accidents in which there is exterior package damage but in which the package contents are not damaged unless they are fragile. Class II refers to accidents in which the cargo is smashed, and Class III accidents involve a fire in which the cargo is burned. It is assumed that the maximum duration of a fire is 0.5 hr.

7.1.2 Fractional occurrences

The probabilities of occurrence of severity Classes I and II are estimates based on data found in references 3 and 7, and that of Class III, is the 1.6% cited in reference 11.

Fractional occurrences for a truck accident in a given population density zone for each of the severity classes are listed in Tables 13 and 14 for tractor-trailers and delivery trucks, respectively.³ High-density

Table 13. Probability of tractor-trailer accidents for accident severity class and population density zone

Severity class	Probability for severity class	Fractional occurrence for population density zone ^a		
		Low	Medium	High
I	0.6	0.3	0.4	0.3
II	0.38	0.6	0.25	0.15
III	0.02	0.8	0.1	0.1

^aSource: U.S. Nuclear Regulatory Commission, *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes*, NUREG-0170, vol. 1, Washington, D.C. (Dec. 1977), Table 5-3.

Table 14. Probability of delivery truck accidents for accident severity class and population density zone

Severity class	Probability for severity class	Fractional occurrence for population density zone ^a		
		Low	Medium	High
I	0.6	0.01	0.44	0.55
II	0.38	0.01	0.50	0.49
III	0.02	0.01	0.50	0.49

^aSource: U.S. Nuclear Regulatory Commission, *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes*, NUREG-0170, vol. 1, Washington, D.C. (Dec. 1977), Table 5-4.

population zones have an average of 3861 persons/km², medium-density zones have 719 persons/km² and low-density zones have 6 persons/km².¹³

The probabilities represented in these tables may be used for either local or regional deliveries and are not dependent on average speed because the fractional occurrence data takes speed into account.

7.2 Airplane Accidents

A detailed analysis of transportation accidents has been made by Clarke et al.¹² and, from this information, the probabilities of three classes of airplane accidents occurring have been derived. An accident rate of 1.6×10^{-8} accidents/km is given for U.S. air carrier accidents in which there is substantial aircraft damage,¹⁴ and this rate will be used to estimate the probability of an accident occurring in which the contents of a package are damaged.

7.2.1. Accident severity classes

The accident severity classes chosen for airplane accidents are basically the same as those defined for truck accidents (Sect. 7.1.1), although the severity of a truck versus an airplane accident should not really be compared. Class I represents those accidents in which there is no damage to the contents of the package even though there may be a

fire or an impact. Class II accidents occur whenever there is an impact force strong enough to crush a package and its contents. Class III accidents are those in which there is a fire resulting in burning of the cargo.

7.2.2. Fractional occurrences

The probability of an accident being of a given severity class and the fractional occurrence of an accident in a given population density zone may be found in Table 15.

Class I accidents are by far the most frequent and are assumed to occur at airports during takeoff or landing operations. The data from Clark et al¹² show that about 18% of all airplane accidents involve fires of only short duration or in localized areas, with no resulting cargo damage. These accidents were combined with the many minor accidents not involving fire to form Class I.

Class II accidents, which result in crushing of the cargo, occur infrequently because of the elaborate tie-down procedures used in air cargo compartments. The crushing experienced in these accidents is generally caused by interaction with airplane parts rather than cargo-cargo interactions. These accidents are assumed to occur in areas of low-density population.

Table 15. Probability of air transport accidents for accident severity class and population density zone

Severity class	Probability for severity class	Fractional occurrence for population density zone ^a		
		Low	Medium	High
I	0.83	0.05	0.9	0.05
II	0.02	0.98	0.01	0.01
III	0.15	0.2	0.7	0.1

^aSource: U.S. Nuclear Regulatory Commission, *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes*, NUREG-0170, Vol. 1, Washington, D.C. (Dec. 1977), Table 5-2.

Airplane accidents in which the cargo burns (Class III) usually involve fires lasting more than 15 min. Clark et al.¹⁵ estimate that 98% of the fires involve the aircraft fuel and that larger aircraft (because of greater fuel loads) have a higher probability of having cargo damaged by fire than do smaller planes when involved in an accident.

7.3 Damage Probability

To determine the probability of a particular shipment receiving damage in an accident, let R be the accident rate per kilometer, D the distance (km) traveled by the shipment, $P.S.C.$ the probability of a particular accident severity class occurring, and $F.O.$ the fractional occurrence of an accident in a given population density zone.

Then, to determine the probability of a shipment being involved in an accident:

$$\text{Probability 1} = R \times D ;$$

the probability of a shipment receiving a severity class of damage is:

$$\text{Probability 2} = \text{Probability 1} \times P.S.C. ;$$

and the probability of a shipment receiving a severity class of damage in a given population density zone becomes:

$$\text{Probability 3} = \text{Probability 2} \times F.O.$$

8. USE OF DISTRIBUTION SCENARIOS

A brief distribution scheme for a hypothetical product is used to illustrate application of the parameters given in the preceding exposure scenarios. Recall that all parameters relate to one shipment through a designated facility. Therefore, when constructing a distribution scheme, the modeler must know how many shipments will be involved, the number of cartons per shipment, and how these shipments will be distributed

through each facility along the transportation route. Knowing this, he must decide how the shipments will be handled within each facility. For example, of the ten people working on an unloading dock, does one unloader handle all the shipments of concern or do all the unloaders take turns in unloading the shipments? Also, for dose calculations, the modeler must specify the particular source configuration. For example, if the source is a carton, the modeler must choose an appropriate source representation (point, sphere, etc.) and give needed variables such as dimensions of the carton and radionuclide quantity and distribution in the carton.

8.1 Shipping Scheme

A manufacturer is assumed to make 30 shipments, each containing 120 cartons, to each of 30 chain warehouses during the period of 1 year. Each carton contains 144 items. All shipments travel by local delivery truck (trailer, single-stop) to one truck terminal where they are unloaded by one person and loaded by another onto trailers destined for over-the-road, less-than-truckload, deliveries for a distance of 1200 km. Each OTRD involves three regional delivery drivers (Sect. 2.2), three truck terminals (Sect. 2.2.1), and one local delivery driver. (Ninety terminals, 90 RD drivers, and 30 LD drivers are required to make all deliveries.) Upon arrival at the chain warehouse, a shipment is handled as in Sect. 6.1.1, and distributed by four drivers to each of four chain stores (regional delivery-LTL-one carton/shipment - Sect. 2.2). (A total of 120 drivers and stores are involved.) In the chain stores, the items are handled as in Sect. 6.2.1. One-half of the 144 items in a carton are assumed to be in a store at all times.

Table 16 lists the shipping parameters used for this scheme as well as a reference to the section and table where these parameters appear.

8.2 Population Exposure Scheme

Parameters used to describe exposures of persons along truck transport routes are discussed in Sect. 2.4 and are listed in Table 3. As an

Table 16. Exposure conditions for hypothetical distribution scheme

Action	No. of persons	Average exposure distance (cm)	No. of shipments handled annually	Annual exposure time (hr)	Source	Section and table reference
<u>Local delivery - tractor trailer</u>						
Driver Driving	2	825	15	7.5	120 cartons	Sect. 2.1.3, Table 1
<u>Truck terminal - local delivery</u>						
Unloader-LTL	1					
Handle cargo		30	30	61.0	1 carton	Sect. 2.2.1, Table 1
Near cargo		90	30	30.0	60 cartons	
Near cargo		460	30	120.0	60 cartons	
Other unloaders	8					
Near cargo		460	30	150.0	60 cartons	
Loader-LTL	1					
Near cargo		30	30	61.0	1 carton	
Near cargo		90	30	30.0	60 cartons	
Near cargo		460	30	120.0	60 cartons	
<u>Regional delivery - tractor trailer</u>						
Driver Driving	90	825	1	5.0	120 cartons	Sect. 2.3.3, Table 2
<u>Truck terminal - regional delivery</u>						
Unloader-LTL	90					
Handle cargo		30	1	2.0	1 carton	Sect. 2.2.1, Table 1
Near cargo		90	1	1.0	60 cartons	
Near cargo		460	1	4.0	60 cartons	
Other unloaders	720					
Near cargo		460	1	5.0	60 cartons	
Loading	90					
Handle cargo		30	1	2.0	1 carton	
Near cargo		90	1	1.0	60 cartons	
Near cargo		460	1	4.0	60 cartons	
<u>Local delivery - tractor trailer</u>						
Driver Driving	30	825	1	0.5	120 cartons	Sect. 2.1.3, Table 1
<u>Chain warehouse</u>						
Unloading-LTL	30					
Handle cargo		30	1	2.0	1 carton	Sect. 6.1.1, Table 11
Near cargo		90	1	1.0	60 cartons	
Near cargo		460	1	4.0	60 cartons	
Other unloaders						
Near cargo	60	460	1	5.0	60 cartons	
Near cargo	60	910	1	5.0	60 cartons	
Near cargo	60	1,370	1	5.0	60 cartons	
Near cargo	60	1,830	1	5.0	60 cartons	
Near cargo	30	2,290	1	5.0	60 cartons	

Table 16 (continued)

Action	No. of persons	Average exposure distance (cm)	No. of shipments handled annually	Annual exposure time (hr)	Source	Section and table reference
Forklift operator	30					
Near cargo		120	1	0.50	1 pallet ^a	
Storeroom clerk	30					
Handle cargo		30	1	0.50	1 carton	
Near cargo		120	1	0.25	1 pallet ^a	
Near cargo		305	1	60.0	60 cartons	
Other storeroom clerks	270					
Near cargo		305	1	60.0	60 cartons	
Trailer loader-LTL	30					
Handle cargo		30	1	0.017	1 carton	
Near cargo		90	1	0.5	1 carton ^b	
Near cargo		460	1	2.0	1 carton ^b	
Other loaders						
Near cargo	60	460	1	2.5	1 carton ^b	
Near cargo	60	910	1	2.5	1 carton ^b	
Near cargo	60	1,370	1	2.5	1 carton ^b	
Near cargo	60	1,830	1	2.5	1 carton ^b	
Near cargo	30	2,290	1	2.5	1 carton ^b	
<u>Regional delivery - tractor-trailer</u>						
Driver	3,600					
Driving		825	1	5.0	1 carton	Sect. 2.2, Table 1
<u>Chain store</u>						
Sales clerk	3,600					
Near product		150	1	250.0	36 items	Sect. 6.2.1, Table 12
Near product		305	1	250.0	36 items	
Other activities		910	1	1,500.0	36 items	
Handle product		30	1	6.0	72 items	
Other clerks	10,800					
Near product		150	1	250.0	36 items	
Near product		305	1	250.0	36 items	
Other activities		910	1	1,500.0	36 items	

^aOne pallet is assumed to hold 40 cartons.

^bBecause only one carton is involved, the exposure time is halved rather than considering only 1/2 carton as the source.

example of their use, Table 17 lists derived effective exposure time for the average person and the number of exposed persons in each of the three population zones along one of the 90 regional delivery segments required by the hypothetical transport scheme. (The number of persons listed must be multiplied by 90 to obtain the total number of persons exposed along the 90 segments.)

The effective exposure time (hr) for the average person in a population zone is given by $T_e = 0.4 N/v$ (Sect. 2.4), where N ($= 1$ here) is the number of shipments passing the population zone and v (see Table 3) is the average vehicle speed (km/hr) for the population zone.

Table 17. Exposure conditions for persons along one regional delivery route

Action	No. of exposed persons	Exposure distance (cm)	Effective exposure time (hr)	Source
High-population density	123,552	18,300	0.02	1 shipment
Medium-population density	23,008	18,300	0.01	1 shipment
Low-population density	3,456	18,300	0.0045	1 shipment

One regional delivery segment covers a distance of 400 km: 360 km in low- and 20 km in both medium- and high-population density zones (Sects. 2.2 and 2.4). The numbers of exposed persons per population zone are obtained by multiplying these distances by the number of exposed persons per linear kilometer of vehicle travel in a population zone (1.6 times the population density given in Table 3, Sect. 2.4). In all cases, the average person is taken to be 18,300 cm from the centerline of the truck route.

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