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A STUDY OF PACKAGE DYNAMICS IN SMALL PARCEL ENVIRONMENT OF UNITED PARCEL SERVICE AND FEDERAL EXPRESS

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A STUDY OF PACKAGE DYNAMICS IN SMALL PARCEL ENVIRONMENT OF UNITED PARCEL SERVICE AND FEDERAL EXPRESS

By

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ABSTRACT

A STUDY OF PACKAGE DYNAMICS IN SMALL PARCEL ENVIRONMENT OF UNITED PARCEL SERVICE AND FEDERAL EXPRESS

By

Amritpal Singh Cheema

The purpose of this study was to measure and characterize free fall drops, kicks and tosses occurring in the overnight small parcel environment of United Parcel Service and Federal Express. Five Drop Height Recorders (DHR) were repeatedly sent through UPS "Next Day Air" and Federal Express "Priority" services, respectively, to five destinations in the U.S. from East Lansing. These destinations were Monterey (CA), Atlanta (GA), Rochester (NY), Portland (OR), and Memphis (TN). In a total of 50 roundtrips, 2394 impact events were recorded. The data showed that a package encounters 24 shock events on an average one-way trip which consists of 31% drops, 43.6% kicks, and 25.4% tosses. The highest free fall drop height was from 77.8 inches. The maximum kick level was 233 in./sec, and highest equivalent drop height in a toss was 31.4 inches. Of all the drops, 95% were from less than 16 inches drop height, 95% of the kicks were from less than 135 in./sec, and 95% of tosses were from less than 10.5 inches. equivalent drop height. The packages received 51.1% of impacts on edges, 42% on corners. Only 6.9% of all impacts occurred on flat faces.

Dedicated to my Parents

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1.0 INTRODUCTION

Packaged goods have been moved from one place to another using various forms of transportation. There has been a continuous increase in the number of goods that are shipped and handled. The distribution environments that packaged goods are subjected to are continuously improved to handle and deliver more packages with increasing efficiencies for time and cost. Several of these emerging distribution systems therefore consist of complex networks. These distribution systems have been operated by both Federal as well as private companies. These carrier companies employ various modes of transportation such as trucks, rail, air, and water.

United Parcel Service (UPS) and Federal Express are two of the major private U.S. companies offering a one class service for door to door shipment of small parcel packages. These companies handle millions of packages every day.

UPS is a major force in the flow of commercial goods, both on the ground and in the air. Its development has spanned much of the modern transportation age, beginning early in this century. The UPS was originally established in 1907 under the name of American Messenger Company (UPS,1993). Over the years the company merged and evolved into UPS in 1919. In the early 1950's UPS decided to acquire common carrier rights to compete with U.S. Postal Service, a Federal agency. In 1987, UPS became the first package delivery company to provide service to every address in the U.S. The air delivery system was started in 1929 when UPS opened United Air Express, offering package delivery along the west coast. This service was terminated in 1931, then restarted in 1953. By 1980, "UPS 2nd Day Air" service was started and in 1982 entered the overnight air delivery business with "UPS Next Day Air" service. By 1985, overnight air delivery was available to every address in the U.S. and now includes more than 185 other countries (UPS, 1993).

UPS has a fleet of 197 jet aircraft and 260 chartered aircraft covering a total of 961 domestic and 536 international daily flight segments. Today, UPS has an average daily air delivery volume of 875,000 packages (UPS Next Day Air and 2nd Day Air combined). This accounts for about 8% of a total daily delivery volume of 11.5 million parcels and documents handled by this company. The bulk of the packages are delivered by ground transport (UPS, 1993).

Federal Express first started its business in 1973 from Memphis, TN. Federal Express has grown since then and has specialized only in air delivery systems. In 1989, with the acquisition of Tiger International Co. and the integration of Flying Tigers Co. into its system, Federal Express became the worlds largest full service all-cargo international airline.

Federal Express now provides overnight air deliveries to virtually every address in the U.S. through its next day "Priority" and "Standard" services (Federal Express, 1993). The "Priority" service guarantees delivery of a parcel by 10 a.m. the next working day, whereas the "Standard" service ensures that the packages will be delivered by 5 p.m. the next day. Federal Express handles an average daily package volume of 1.7 million parcels in its combined air delivery services. A total of 465 aircraft are used to make daily connections to 186 countries worldwide.

1.1 NEXT DAY AIR SYSTEM

Both UPS "Next Day Air" and Federal Express "Priority" services use the "Hub-and-Spoke" system to deliver packages. The local operating centers all around the U.S. serve as the "spokes". Each operating center provides pickup and delivery service within an individual territory. The all-cargo aircraft connect these local operating centers with the Central Air-Hub. The "Hub" is a single central sorting facility. The aircraft called "Feeders" take a consignment of packages from the local operating centers to the Central Air-Hub for sorting every night. These packages are sorted at the Air-Hub in a matter of approximately three hours. After sorting the packages, the aircraft depart with a load of packages to be delivered the next morning at the destination operating center. The UPS operates 2250 local service centers while Federal Express has approximately 1400 such operating centers worldwide (UPS, 1993). While the concept of picking up and delivering documents and packages is simple, systems that make it operate efficiently and reliably are innovative, complicated, and expensive. The task of sorting over a million packages at one facility, and placing these in containers for return shipments in a matter of hours, without errors is a continuous challenge.

During the distribution of packaged goods, damage during handling and sorting is inevitable. Once the packaged product is shipped through a distribution system such as of UPS or Federal Express, it is subjected to a series of hazards such as drops, impacts, crushing forces, vibration, climatic, and pressure changes, before it reaches the customer.

All manufacturing, engineering, and quality efforts are in vain if the product reaches its destination in a damaged condition. The factors that contribute to the damage of a product during handling and distribution are numerous.

Shock is one of the more severe and commonly occurring hazards in the small parcel shipping environment. Shock occurs when a moving package comes in contact with a stationary object, either a package or a surface. Shocks often result from packages being dropped, tossed, and sorted.

All these can occur as packages are handled and sorted manually or by automatic sorting equipment.

Many studies have been done to uncover primary features of shock and vibration that relate to product damage during transportation. The distribution environment may be mainly categorized into handling environment and in-transit environment. The damage in a handling environment generally results from operations such as loading-unloading, stacking, lifting, and conveying packages that occur in sorting and storage areas.

On the other hand, damage during in-transit environment result from transport on vehicles (trucks, railcars, aircraft, etc.). The severity of the damage varies with distance as well as surface of travel.

Most of the previous studies have investigated the dynamic characteristics of the in-transit environment. Some of the recent studies are reviewed in this section. Hausch (1975) studied vibration and its interaction with package systems in the transportation environment. The study showed that the truck vibration environment seems to be the most severe at low frequencies. The rail environment showed severe shocks resulting from switching of boxcars. The aircraft shipping environment had higher acceleration levels at higher frequencies when compared to truck and rail.

In another study conducted by Marcondes (1988), the dynamics of three different package types were studied in a Less-Than-Truckload (LTL) shipment. The study showed that accelerations as high as 10 G's (1G = 386.4 in./sec^2) were encountered during vibration in packages at the top of the stack. Packages with low natural frequency show more bouncing and larger acceleration levels than those with higher natural frequencies. Singh et al. (1992) compared the lateral and longitudinal vibration levels with vertical vibration levels in the truck distribution environment over various highway conditions. Power Density Spectrums were developed for various road conditions. The study showed that lateral and longitudinal vibrations above 20 Hz were similar to vertical vibrations, but were very low at frequencies below 20 Hz.

Pierce et al.(1992) studied the effect of suspension types in the ride qualities in trailers. The results showed that the air ride suspension produced lower vibration levels on all road conditions examined as compared to leaf spring suspension. Also, the damaged air ride suspension systems showed similar response frequencies to the leaf-spring suspension systems but caused higher acceleration levels.

There have been fewer studies that have monitored the dynamics of individual packages as they are handled and sorted. Ostrem and Godshall (1979) compiled an assessment of the common carrier shipping environment. The major shipping hazards of shock, vibration, impact, temperature, and humidity associated with the handling, transportation, and warehousing operations of typical distribution cycles were documented. The loads imposed during handling operations have been reported in terms of drop heights. The study reported the occurrence of a large number of low level drops, and very few drops with higher levels. The study concluded that heavier and larger packages were dropped from smaller heights. Also most packages got dropped on their bases representing over half of all drops experienced by the package. The drop height data in the Ostrem and Godshall study was collected by several methods including observation, camera, and instrumented package. Some of these methods could result in large errors. Data on several loading conditions on the cargo deck of the C-5A and C-141 aircraft during normal operations like run-up, takeoffs, cruise, landings, taxi and extended flights was also analyzed. It was reported that worst conditions occurred while flying in turbulent air and during landing.

Voss (1991) measured the dynamics of the small parcel environment in the UPS ground shipping environment. The effect of weight and size was also studied. The study used packages of different sizes and weights that were instrumented with drop height recorders. The results showed that the highest drop height measured was 42.1 inches. The size of the package had no significant effect on drop heights. Weight did not have a significant effect on the medium and larger size packages. However small size lighter weight packages experienced higher drop heights. This was attributed to more automated handling for the larger and heavier packages for the UPS sorting environment. The smaller and lighter packages are often placed on top of the delivery loads and therefore are subject to higher drops.

Changes in temperature and pressure during ground-air movements in air shipments may also cause problems to some sensitive products (UPS, 1975).

There have been continuous changes in the methods by which small packages are handled and transported over the last decade. There has been a sharp increase in the number of packages handled every day to be delivered next day by companies such as Federal Express and UPS. It is important to characterize the dynamics of the next day air small parcel environment. This information can be used with product fragility information to better design and test packages for this shipping environment.

1.2 OBJECTIVES

This study had the following objectives:

a. To measure the dynamics of the next day small parcel environment for Federal Express and UPS in the U.S.

b. Develop a test protocol to test packages for the next day air small parcel environment.

2.0 EXPERIMENTAL DESIGN

The goal of this study was to evaluate the small parcel environment of overnight air delivery systems used by United Parcel Service (UPS) and Federal Express. In order to achieve the goals of this study, the test was designed to obtain and collect dynamic data that could be used to develop test methods to simulate this shipping environment. The detailed description of the test instrumentation and packaging used is presented in this chapter.

There are several types of instruments used to document and measure dynamic events that packages are subjected to. These range from single drop counters which only record that the package was dropped above a pre-set height, to recorders that measure impacts in the three axes of the package. These data recorders measure and save the acceleration-time history for the dynamic event, and such data can be used to estimate the actual height and orientation of the drop.

2.1 TEST INSTRUMENTATION AND PACKAGES

One such recorder is the "Drop Height Recorder (DHR)" manufactured by Dallas Instruments, Dallas, Texas. It is commercially available to companies to measure the shock environment of a package distribution system. The DHR unit is a portable, battery powered, microprocessor controlled, memory device which stores digitized waveforms of shock events sensed by its internal tri-axial accelerometers. Refer to Figure 1 for DHR tri-axial orientation.

Test packages were used to package the recorders (DHR) to measure the different events that the packages experienced in the next day small parcel environment. The test packages consisted of 3 components: a DHR, a static shielding bag, and six polyurethane side cushions. All the components were obtained from Dallas Instruments Inc. The cushions give the Drop Height Recorder a particular coefficient of restitution that is subsequently used in calculations. Although, the DHRs are made of rugged construction able to withstand harsh conditions, the cushions were also meant to safeguard the instrumentation from structural damages or abrasions when exposed to severe shock inputs in the distribution environment. The static shielding bags prevent electrostatic discharge buildups during handling as these may be potentially damaging to the Drop Height Recorders.

The DHR units were encased using 1 inch thick polyurethane (open cell) cushions on all sides. The units were placed in the geometric center of double wall corrugated boxes. The cushions provided a snug fit to the recorder. All DHR's were placed in the same orientation in all packages for every shipment. The packages were closed with a 2 inch wide

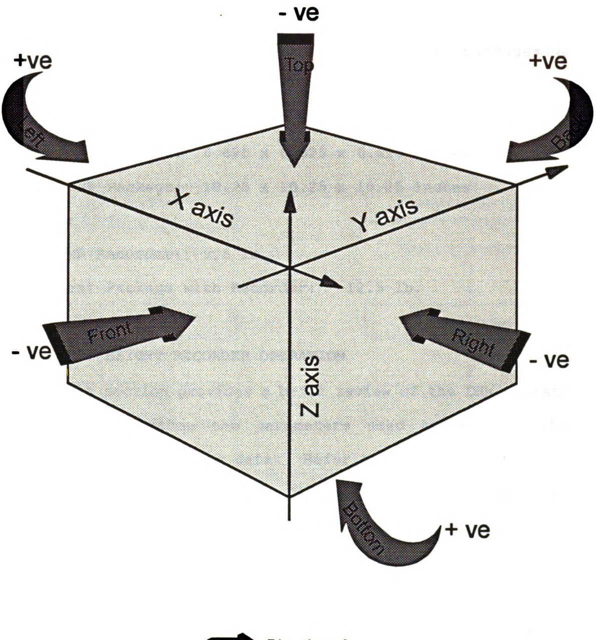

Fig 1. Drop Height Recorder Tri-axial Orientation

general purpose plastic box sealing tape (H-seal) using the 3M automatic case sealer. All the packages were of the same size, weight, and shape. The size and weight of the packages were as follows:

Size:

DHR Recorder: 6.625 x 6.625 x 6.625 inches

Test Package: 10.25 x 10.25 x 10.25 inches

Weight:

DHR Recorder: 9.5 lb.

Test Package with Recorder: 12.5 lb.

2.2 DROP HEIGHT RECORDER OPERATION

This section provides a brief review of the DHR operation and also describes the parameters used to program these devices to collect the data. Refer to Figure 2 for a block diagram of DHR operation. The model DHR-1c Drop Height Recorder is a small, light-weight, solid state device that uses a tri-axial accelerometer to record shock events. The DHR constantly monitors the environment and saves events that exceed a predetermined threshold shock level. The recorded events are saved for analysis using software provided with the recorders. The recorder acquires and stores two separate types of data. When a significant impact occurs, the tri-axial accelerometer with a built in pre-amplifier sends the

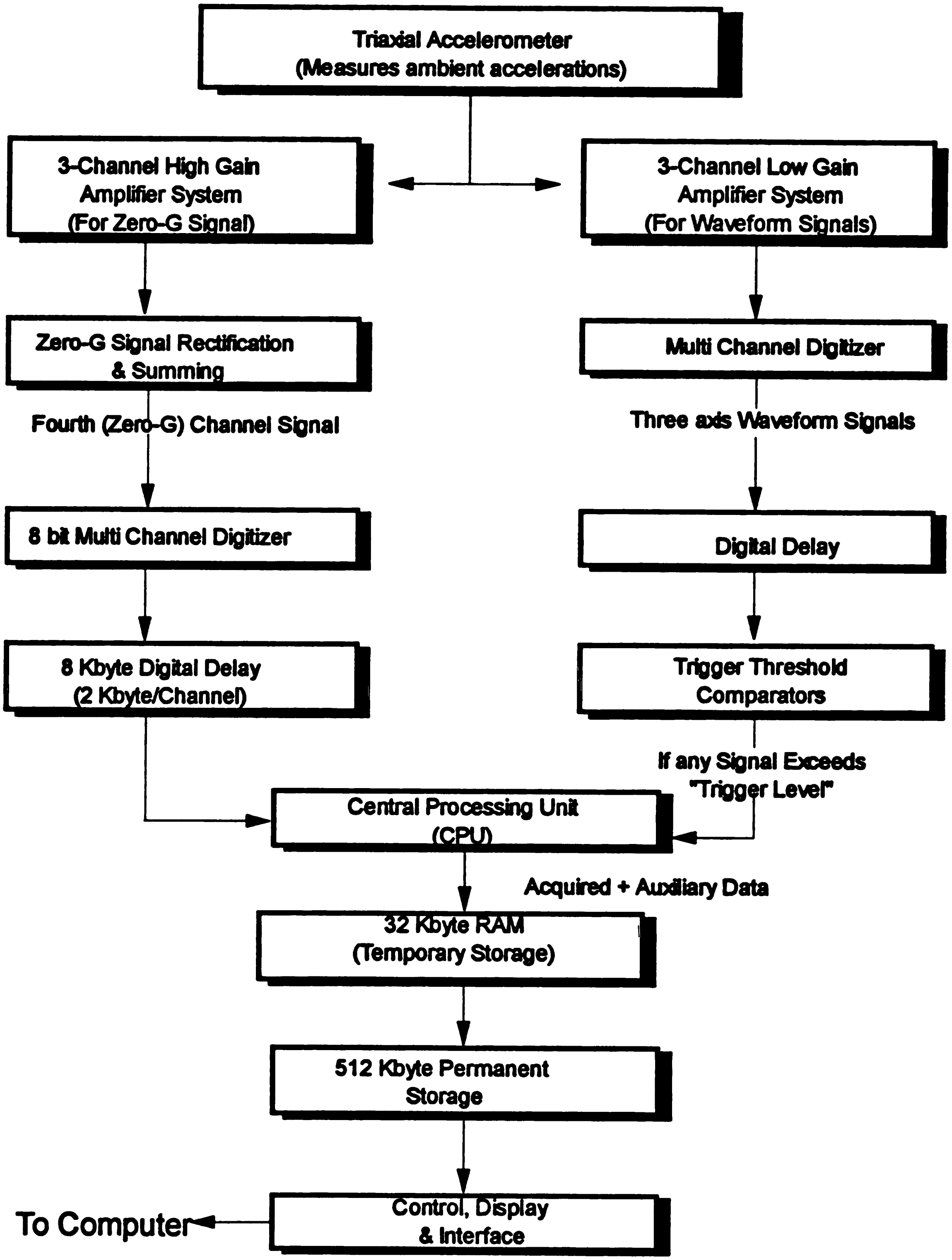

Fig 2. Block Diagram of DHR Operation

conditioned signal of an impact to two 3-channel amplifiers. One of these is a low-gain system for sensing and recording high acceleration signals and the second is a high-gain system for recording free fall (zero-G) conditions.

The tri-axial accelerometer data is processed by the high gain amplifier system which senses changes to zero-G state (free fall condition) of the unit in a drop. This data is processed as a separate fourth channel called "zero-G channel". The same tri-axial output is also processed by a 3-channel low gain amplifier and is saved as acceleration-time history for the three axis. The information for these four channels is saved in 8 K-bytes of digital delay memory.

The peak acceleration is then compared with the threshold trigger level. If the trigger level is exceeded by any of the three low gain amplifier channels the data is diverted to 32 K-bytes of RAM for temporary storage while the CPU processes the data for peak acceleration. The CPU then directs the acceleration data along with information such as time, date, temperature, battery voltage, etc., to 512 K-bytes RAM for long term storage. The CPU also stores the key summary data regarding the event in non-volatile RAM along with event pointer and wrap counter. The system is then reset by the CPU to acquire the next record.

2.3 ZERO-G DROP HEIGHT CALCULATION

The recorder calculates the drop heights using two different methods. The first method is called the Zero-G drop height calculation. The free fall time is measured by sensing the change in the recorder from a motionless state (zero-G), into a free fall (1G), and a shock state (several G). Since the time from the onset of the zero-G state of the recorder to the moment of impact is known, the free fall drop height is calculated by following relationship:

$$h_z = \frac{1}{2} g t^2 \quad \text{.................(2-1)}$$

where,

g = Acceleration due to Gravity = 386.4 in./sec^2

h_z = Free fall drop height in inches

t = Free fall time in seconds

2.4 EQUIVALENT DROP HEIGHT CALCULATION

Equivalent drop height is calculated using impact acceleration time history of the 3-channel digitized shock pulses for each event.

Velocity change is first calculated from each acceleration time curve for a given channel. Equivalent drop height is then calculated for each channel using the following equation:

$$h_e = \left(\frac{\Delta V}{1+e}\right)^2 \cdot \frac{1}{2g} \quad \text{.................(2-2)}$$

where,

h_e = Equivalent Drop Height, inches

ΔV = Velocity Change, in./sec.

e = Coefficient of Restitution

g = 386.4 in./sec^2

The coefficient of restitution (e) is determined based on actual drop tests performed during instrument calibration in the laboratory. This is used in subsequent calculations to determine equivalent drop height for the three axes. Finally, the component equivalent drop heights for each of the axes are summed to obtain resultant equivalent drop height as follows:

$$h_e = (h_x + h_y + h_z) \quad \text{.....................(2-3)}$$

where,

h_e = Total equivalent drop height, inches

$h_{x,y,z}$ = Equivalent drop height for each axis, inches

2.5 INSTRUMENT SETUP PARAMETERS

The DHR-1C software supplied with the recorders allows communication between the computer and the units. It is used to configure and calibrate the units before shipment and for uploading recorded data from DHR into the computer for tabulation and analysis. The summary reports that are generated include information such as event number, date, time, battery voltage, temperature, pulse widths, peak acceleration (each axis and resultant), normalized acceleration (%), event frequencies, velocity change, equivalent drop height, zero-G drop height, and deviation between equivalent drop height and zero-G drop height. The configuration is a set of user programmed instructions which must be defined in order to obtain useful data. The configuration allows the user to set operating parameters, trip information, time and date, and alarm settings. Once defined the configuration is downloaded into the DHR. The key configuration parameters include trigger level, memory retention mode, and data acquisition mode.

The trigger level defines the minimum G levels that have to be exceeded for an impact to be recorded by the unit. It is defined in percent of full scale acceleration level for each channel. Each 1% represents 1G of shock, if the full scale is 100 G. Setting a lower trigger level would allow more events to be recorded, rapidly filling up the available memory.

The pre- and post-trigger times also need to be set in order to capture the leading and trailing edges of the shock waveform. When the DHR is exposed to a dynamic force which exceeds the trigger level, the resulting waveforms are recorded that are within a pre-defined window of time. The duration of this window is determined from pre- and post-trigger times set earlier by the user. The size of the window limits the maximum number of events that can be recorded before filling up the DHR memory.

The memory retention mode settings determine how events are to be stored in the DHR memory. There are essentially three different ways of data storage. In the "FULL/STOP" memory mode the unit will record acceleration events until the bulk memory is full. Once full the unit automatically goes into standby mode without further event recording. This allows only the first set of events exceeding the threshold being saved.

In the "WRAP" memory mode, the unit will first record events until the bulk memory is full. The event pointer is then reset to zero and the wrap counter is advanced by one. Any subsequent/new event will overwrite the oldest data in bulk memory. This allows for retaining only the most recent events in case the memory is filled.

If the "MAX" memory mode of operation is used, the summary data from all bulk memory events is stored in a non-volatile RAM (memory). The summary data includes peak acceleration values for each axis along with date, time, event number, battery voltage and temperature. Once the primary memory is filled, the peak acceleration of a newly acquired event is compared with the lowest value in the summary data memory. The new event is recorded only if its peak value is greater than lowest peak value of one of the previously recorded events. If the criterion is met, the new waveform data and its summary data replace the lowest data in both the bulk memory and the non-volatile summary data memory. This process of reviewing the event summaries and replacing them with the new event only if it exceeds the lowest values previously recorded, results in saving the most severe events.

The data acquisition mode determines how and when the data will be acquired by the DHR. A repeat cycle timer is used to program up to 3 different modes of data acquisition in addition to normal triggered mode (NORM). The timer initiated recording programs the DHR to become active to receive and record any event during a specified window of time regulated by a cycle timer. This allows the DHR to be turned on and off at specified times. The acceleration events occurring only in that time frame are recorded. All events outside of this window of time are disregarded, no matter how severe the shock level. "NORM" is the default mode of operation in which the DHR is configured to operate in an event-triggered fashion. The DHR is continuously monitoring the environment and records acceleration event data only if one or more of the accelerometers exceed the pre-defined trigger levels.

In the "SNAP" mode the unit becomes active at a specified cycle time interval. It takes a snapshot of the environment and acquires one record regardless of signal level. It goes into "hibernation" again until the next cycle time interval is reached. It is mainly useful for sampling the distribution environment for mainly DC types of signals such as temperature, relative humidity, voltage (pressure), etc.

In the "TRIG" mode, the timer-initiated recording of triggering events, the DHR becomes active at a specified time interval regulated by cycle timer. The unit remains active until a triggering event occurs, which is recorded, and the unit goes back to hibernation until the next timer interval is reached. This mode is primarily useful for statistical sampling of triggering events.

In the "BOTH" mode, the functions of "NORM" mode and the "SNAP" mode are combined. The unit continuously monitors the environment and only records events that exceed the trigger level. In addition, it also becomes active at a specified time interval and records a single event regardless of signal level and then again goes into normal triggered mode.

Once the key operating parameters have been set, the configuration is downloaded into each of the DHR units. The downloading operation deletes all existing data and clears the DHR memory. The event pointer and wrap counter are reset to zero. It also sets the instrument timer to the computer's internal clock. Every time the unit records an acceleration event the time and date of occurrence is also tagged as part of the record. This allows the user to characterize any "hot spots" of the distribution environment and spread of the data over time.

The internal electronics of the DHR are powered by two attached battery packs each containing six, series connected, 4.9 Amp-hour, D cell, nickel cadmium batteries. For the DHRs to function properly, the batteries must be charged to optimum levels. Fully charged batteries may last up to 14 days depending on the temperature and sampling rate. Operating time is the longest under ambient temperatures (68° F). Any variation from the optimum temperature will reduce battery life in direct proportion to the difference of temperature from the optimum. Higher sampling rates will also decrease operating times.

The DHR units were recharged for at least 24 hours before shipment to obtain reliable data. Since a single roundtrip was completed in approximately 4 days, the batteries retained enough charge to ensure proper functioning of the DHR units.

2.6 INSTRUMENT CONFIGURATION AND CALIBRATION.

To ensure proper functioning of the instrument, simulated laboratory package impact tests were performed to calibrate the DHRs. For calibration the DHRs were dropped from known free fall drop heights of 18 and 30 inches using a Lansmont Precision Drop Tester (PDT). The recorded data was uploaded into the computer using DHR software to verify that the instrument was accurately recording and measuring the events it was exposed to.

Before laboratory calibration, the DHRs were configured with the operating parameters (variables) that would allow to acquire the most useful and accurate data. The operating variables include the trigger level, pre- and post-trigger samples, sampling rate, memory retention mode, and data acquisition mode described earlier in this chapter.

The objective is to set a high enough trigger level that would avoid continuous triggering of the DHR-1c to very low level impacts that do not cause damage to packaged products, and yet be sensitive enough to record a majority of impacts. Based on prior experience a trigger level of 10% (10G) of full scale was used for all units. The pre- and post-trigger times to be recorded were set at 750 and 1000 milliseconds, respectively. The sampling frequency was 1000 samples/sec. The memory retention mode was set to "MAX" to save events with maximum impact. The data acquisition was set to "NORM" to record events that exceeded the trigger threshold.

The impacts or shocks observed in the distribution environment may be categorized into free fall vertical drops, lateral tosses, and kicks. A free fall "drop" may occur when a package falls in vertical downward direction, due to gravity. Drops occur when packages slip out of workers hands during manual handling, fall from top of stack during shipping, drop from conveyors due to jamming caused by packages in the front. The second type of impact described as "toss" occurs most commonly during manual sorting operations. The packages are laterally tossed into different sorting bins depending on destination. As a result the packages remain in a free fall condition, or 1G condition, for a prolonged period of time before impact. The last type of impact referred to as "kicks" occur usually during automatic sorting operations. The packages experience side impacts caused by the swinging arm of sorting equipment or sliding into stationary packages.

It is important to understand how these three categories are sensed by the DHR units. For every recorded event, the DHR calculates drop height from both the zero-G channel as well as equivalent drop height channels. During a free fall, the zero-G channel shows a greater accuracy than the equivalent drop height channels. This is mainly due to the fact that the zero-G channel uses free fall time which varies directly with only the height of free fall while equivalent drop height channels use velocity change and coefficient of restitution (e) to calculate equivalent drop height. The value of "e" changes with drops on edges, corners, and faces due to the amount of cushioning. Large errors may occur in equivalent drop height calculation even though the velocity change is the same for different events.

To categorize various impacts into drops, kicks or tosses, it is important to measure the "Unit Ratio". Unit Ratio may be defined as the ratio between drop height measured using the zero-G channel and calculated equivalent drop height.

$$Unit\ Ratio = \frac{Zero - G\ \ Drop\ Height}{Equivalent\ Drop\ Height} = \frac{h_z}{h_e} \quad \text{.........(2-4)}$$

Lab simulation of all three categories of impacts was performed and unit ratios calculated for each category. In a free fall drop, the Unit Ratio lies between 0.5 and 2.0 (Voss, 1991). In a "toss" the DHR stays weightless for much longer time. The drop height calculated from the zero-G channel becomes very large and inaccurate. However, the equivalent drop height is much lower and as a result Unit Ratio becomes large. Lab simulated tosses showed that Unit Ratios higher than 2.0 are usually common. During "kicks" the DHR calculates equivalent drop height based on velocity change of the impact. However, almost no drop height is measured by the zero-G channel because the unit stays motionless before impact. This results in low Unit Ratios. Lab simulated "kicks" generated Unit Ratios of less than 0.5. Based on the lab simulation tests, the actual data was analyzed and categorized based on "Unit Ratios" as follows:

If Unit Ratio is < 0.5, the impact is a kick.

If Unit Ratio is 0.5 to 2.0, the impact is a drop.

If Unit Ratio is > 2.0, the impact is a toss.

2.7 DATA COLLECTION

The intent of this study was to measure the shock impact levels in terms of drops, tosses, and kicks, encountered in the overnight parcel shipments across the U.S. Five round-trip destinations were chosen to represent the various geographic regions (Figure 3). The five destinations chosen were:

- Monterey, CA
- Atlanta, GA
- Portland, OR
- Rochester, NY
- Memphis, TN

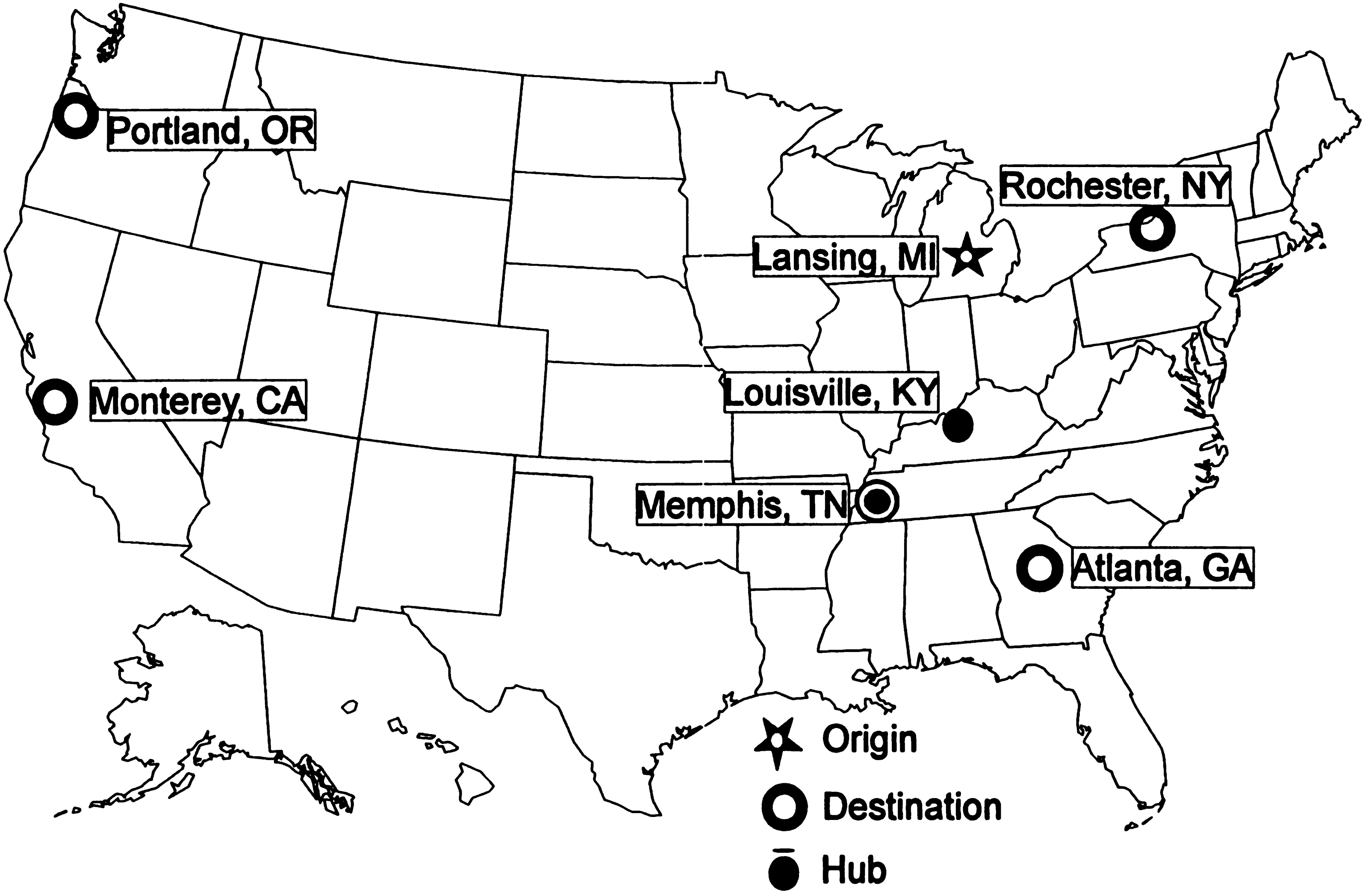

Fig 3. Map of Overnight Destinations in the U.S.

All shipments originated in East Lansing, MI. Multiple shipments were done for each destination and for each carrier to increase the reliability of collected data. Five roundtrips were made to each of the five destinations and for each of the two carriers (UPS and Federal Express) for a total of 50 roundtrips.

Figure 4 describes the flow diagram of how packages move in the UPS "Next Day Air" and Federal Express "Priority" systems. The Next Day Air Delivery Service of UPS and Federal Express both use the "Hub and Spoke" system to deliver their packages. Packages were picked up by a courier from the School of Packaging, Michigan State University and loaded in small delivery vehicle referred to as a "Package Car". The packages were taken to respective operating centers of UPS and Federal Express in the Lansing area where they were consolidated with all the other packages also meant for next day delivery. The consignment of packages were put into air transport containers which were then transported by truck to the regional air facility. The air transport containers were then loaded into the cargo aircraft which serves as the "Feeder". The aircraft then flew to the national Air-Hub with packages and documents headed for various US locations. These air hubs serve as the central sorting facilities for packages from all over the US.

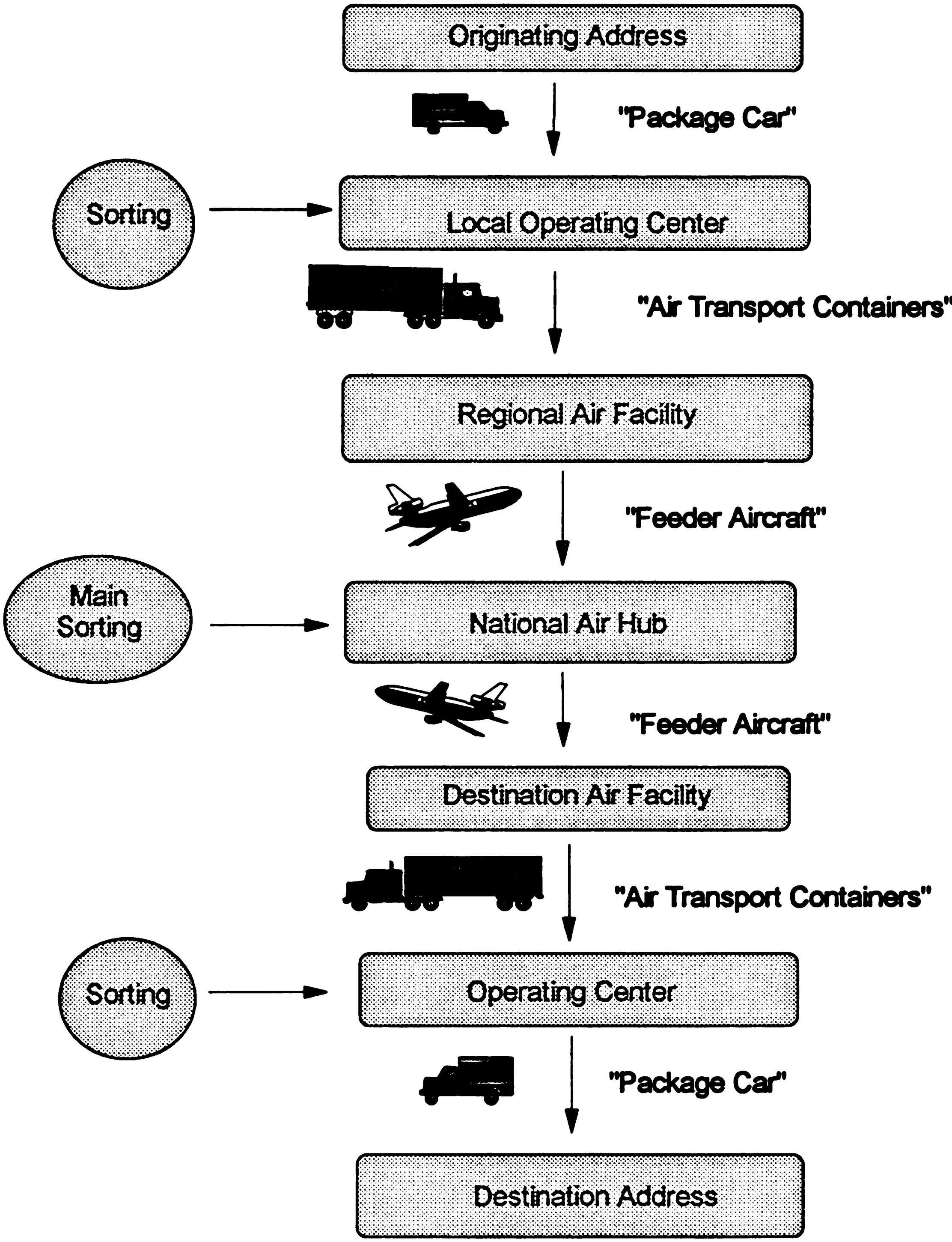

Fig 4: Flow Path of UPS and Federal Express Package Delivery System

The UPS air-hub is located in Louisville, KY, whereas the Federal Express air-hub is located in Memphis, TN, where the arriving aircraft are unloaded. The air containers are unloaded and transferred on rollers to the central sort area. Here the employees remove the packages from the containers, scan them, and send them on belts to a central sort area, where sophisticated scanners track and check the package destination and size. Packages speed through the hub on a several miles-long network of belts and chutes. Diverters, activated by information in the bar code labels activate to kick packages down chutes and onto proper sort belts. The packages are then collected by their destination and any special handling that may be required.

After sorting, the packages are consolidated together with all the other packages bound for the same destination or service area. These are then loaded into containers and onto another "Feeder" aircraft to be delivered to the destination operating center. The packages, after sorting at the local operating facility, are loaded into "Package Cars" to be delivered to the final destination.

The test packages were then return shipped to Lansing, the next day, going through the same process. The entire round-trip duration was approximately four days. The data from each DHR for each round-trip shipment was uploaded into a personal computer for analysis.

3.0 DATA AND RESULTS

The acquired data from the DHR's was uploaded into the computer and analyzed. The processed data was then imported into a spreadsheet for analysis and tabulation. Dynamic events occurring in the small parcel environment of UPS and Federal Express were separated into drops, kicks, and tosses based on the values of Unit Ratio's.

Tables 1, 2, and 3 show dynamic events separated into individual drops, kicks, and tosses for each round-trip to the five destinations. This data has been combined for the two carriers (UPS and Federal Express).

The data is summarized into number and type of impacts that occurred during the various shipments and is described in Table 4. There were a total of 2394 dynamic events that were measured in the 50 roundtrips. This averages approximately 48 dynamic events per roundtrip (24 events per shipment). The entire data (Figure 5) consisted of 742 drops (31%), 1045 kicks (44%), and 607 tosses (25%). Table 5 shows the maximum, minimum, and average levels for individual drops, kicks, and tosses measured for each destination. The average drop height for 742 free fall drops was 5.95 inches, the average velocity change for 1045 kicks was 77.91 in./sec, and the average equivalent drop height for 607 tosses was 3.92 inches.

TABLE 1. SUMMARY OF ALL DROPS

DESTINATION	TRIP No.	NO. OF DROPS	DROP HEIGHT (in.) MAX	MIN	AVG	S.D.
Monterey, CA	1	15	13.90	2.30	6.33	3.44
	2	12	20.10	2.20	8.84	5.82
	3	13	18.50	1.30	5.85	5.36
	4	15	18.70	0.80	5.12	5.03
	5	10	11.90	2.10	6.35	3.46
	6	16	13.00	1.00	4.96	3.13
	7	8	15.10	1.80	6.06	4.90
	8	15	25.90	0.70	8.14	7.17
	9	28	30.40	0.30	5.09	5.63
	10	24	77.80	0.60	10.05	16.27
	Subtotal	156	77.80	0.30	6.86	7.42
Atlanta, GA	1	4	16.10	1.70	8.90	6.20
	2	17	22.20	1.40	6.85	5.48
	3	7	13.30	1.50	7.27	3.81
	4	14	16.20	1.00	5.31	3.98
	5	16	20.50	0.50	5.93	5.52
	6	18	11.30	0.50	5.36	3.53
	7	21	14.90	0.70	4.37	3.13
	8	24	22.00	0.80	6.30	4.92
	9	9	19.30	1.40	7.83	6.55
	10	12	9.70	1.40	5.29	2.84
	Subtotal	142	22.00	0.50	5.83	4.19
Rochester, NY	1	12	16.70	0.70	5.00	5.16
	2	17	15.30	0.80	4.19	3.38
	3	13	13.60	1.40	5.15	3.26
	4	14	33.60	0.40	7.69	9.90
	5	12	18.10	0.60	5.62	4.65
	6	6	18.00	1.20	8.47	6.36
	7	13	13.20	0.90	4.62	3.72
	8	18	19.40	0.60	5.17	4.37
	9	21	13.80	1.30	5.66	3.68
	10	22	19.00	1.40	5.38	4.20
	Subtotal	148	19.40	0.60	5.86	4.47

Note: The average and standard deviation values calculated are for those impact levels that exceeded the minimum threshold level. Most impact data is skewed to very low severity levels and does not represent a normal distribution. This data is, therefore, also presented based on a frequency of occurence versus severity in Table 6.

TABLE 1. SUMMARY OF ALL DROPS (Continued)

DESTINATION	TRIP No.	NO. OF DROPS	DROP HEIGHT (in.) MAX	MIN	AVG	S.D.
Portland, OR	1	13	18.50	1.50	7.61	4.82
	2	14	12.20	1.10	6.07	3.51
	3	17	51.40	2.50	10.60	12.37
	4	9	5.00	0.40	2.76	1.41
	5	10	7.30	1.20	5.12	2.20
	6	22	16.80	0.60	5.65	3.62
	7	14	19.30	0.40	4.34	5.61
	8	22	20.50	0.60	4.62	4.56
	9	34	9.40	0.20	3.47	2.32
	10	20	9.60	0.30	3.21	2.03
	Subtotal	175	20.50	0.20	4.26	3.63
Memphis, TN	1	5	9.90	2.20	5.10	2.98
	2	7	15.90	1.00	6.33	5.86
	3	6	9.30	2.90	4.13	2.54
	4	9	13.00	1.30	6.46	4.55
	5	17	17.30	0.90	5.29	4.04
	6	20	13.70	0.30	4.78	4.12
	7	16	36.50	0.20	7.45	9.46
	8	14	18.90	1.40	6.41	4.81
	9	15	21.70	2.60	9.04	6.58
	10	12	20.50	0.50	7.19	6.46
	Subtotal	121	36.50	0.20	6.66	5.72
	Total	742	77.80	0.20	5.95	5.13

ORIGIN: EAST LANSING, MI.

TABLE 2. SUMMARY OF ALL KICKS

DESTINATION	TRIP #	NO. OF IMPACTS	IMPACT LEVEL (in./sec) MAX	MIN	AVG	S.D.
Monterey, CA	1	12	139.00	39.00	78.58	31.15
	2	15	113.00	35.00	74.33	28.01
	3	24	135.00	49.00	86.13	25.36
	4	18	155.00	42.00	92.78	37.00
	5	17	153.00	39.00	80.76	32.47
	6	12	127.00	30.00	66.75	29.29
	7	23	180.00	30.00	76.74	36.43
	8	25	142.00	43.00	70.16	23.41
	9	30	114.00	48.00	75.70	18.65
	10	16	146.00	32.00	79.63	31.87
	Subtotal	192	180.00	30.00	73.80	27.93
Atlanta, GA	1	7	128.00	42.00	82.71	36.62
	2	26	179.00	40.00	80.50	34.71
	3	11	211.00	36.00	106.60	49.29
	4	17	180.00	52.00	104.20	38.77
	5	25	194.00	44.00	94.68	36.81
	6	20	138.00	30.00	82.80	23.36
	7	14	206.00	41.00	117.90	42.33
	8	19	133.00	42.00	79.05	28.18
	9	20	172.00	41.00	83.70	34.67
	10	20	177.00	10.00	84.70	39.82
	Subtotal	179	206.00	10.00	89.63	33.67
Rochester, NY	1	22	149.00	33.00	70.23	29.50
	2	19	136.00	18.00	80.90	31.70
	3	26	153.00	19.00	68.20	30.60
	4	25	109.00	14.00	64.20	23.80
	5	25	125.00	24.00	71.40	26.60
	6	16	155.00	33.00	78.81	33.64
	7	17	112.00	42.00	74.65	18.31
	8	25	130.00	30.00	68.16	27.96
	9	28	128.00	34.00	67.68	28.42
	10	24	141.00	16.00	75.29	30.54
	Subtotal	227	155.00	16.00	72.92	27.77

Note: The average and standard deviation values calculated are for those impact levels that exceeded the minimum threshold level. Most impact data is skewed to very low severity levels and does not represent a normal distribution. This data is, therefore, also presented based on a frequency of occurence versus severity in Table 6.

TABLE 2. SUMMARY OF ALL KICKS (Continued)

DESTINATION	TRIP #	NO. OF IMPACTS	IMPACT LEVEL (in./sec) MAX	MIN	AVG	S.D.
Portland, OR	1	18	139.00	16.00	79.17	31.61
	2	20	122.00	34.00	81.25	24.35
	3	21	143.00	17.00	63.95	31.08
	4	31	224.00	42.00	82.52	43.20
	5	19	133.00	23.00	68.32	29.81
	6	29	142.00	44.00	85.76	24.85
	7	21	121.00	37.00	71.95	25.52
	8	27	126.00	32.00	79.59	27.88
	9	22	141.00	36.00	68.09	28.62
	10	32	217.00	31.00	76.91	39.01
	Subtotal	240	217.00	31.00	76.46	29.18
Memphis, TN	1	10	138.00	36.00	65.90	28.93
	2	12	142.00	12.00	73.75	32.95
	3	12	233.00	43.00	108.40	50.50
	4	24	153.00	8.00	87.42	38.95
	5	22	146.00	30.00	72.95	32.86
	6	22	131.00	28.00	67.68	25.05
	7	30	109.00	29.00	67.37	21.46
	8	25	163.00	28.00	71.76	35.47
	9	23	164.00	33.00	85.70	39.44
	10	27	184.00	13.00	70.78	34.42
	Subtotal	207	184.00	8.00	74.81	32.52
	Total	1045	233.00	12.00	78.33	32.47

ORIGIN: EAST LANSING, MI.

TABLE 3. SUMMARY OF ALL TOSSES

DESTINATION	TRIP #	NO. OF TOSSES	DROP HEIGHT (in.) MAX	MIN	AVG	S.D.
Monterey, CA	1	5	6.40	1.60	3.38	1.94
	2	12	6.50	1.50	3.76	1.46
	3	11	5.60	1.10	2.75	1.58
	4	8	5.70	0.80	2.67	1.68
	5	12	15.20	1.40	4.67	4.76
	6	8	15.60	1.70	4.95	4.64
	7	14	11.00	0.50	4.02	2.79
	8	12	11.20	1.20	5.72	3.29
	9	16	13.60	0.60	4.32	3.71
	10	16	16.80	1.00	3.89	4.16
	Subtotal	114	16.80	0.50	4.58	3.72
Atlanta, GA	1	3	7.80	0.50	4.10	3.65
	2	13	18.50	0.90	3.11	2.54
	3	8	31.40	0.70	4.18	3.87
	4	16	22.80	0.90	5.24	4.44
	5	16	23.00	0.10	4.54	5.37
	6	6	7.70	3.00	5.33	2.00
	7	20	19.50	0.90	3.79	3.98
	8	15	6.50	1.00	3.77	2.00
	9	16	18.40	1.40	5.06	4.24
	10	14	11.60	1.40	4.99	3.01
	Subtotal	127	19.50	0.90	4.59	3.05
Rochester, NY	1	10	7.50	1.30	3.12	1.75
	2	8	4.50	1.00	2.01	1.07
	3	10	6.90	1.00	3.35	2.03
	4	13	10.90	1.10	3.97	3.04
	5	8	4.90	0.90	3.36	1.38
	6	13	21.60	0.60	5.89	6.14
	7	15	14.60	0.10	5.41	4.94
	8	7	10.70	1.00	4.21	3.13
	9	14	15.60	0.60	3.39	3.80
	10	15	14.00	0.40	3.39	3.34
	Subtotal	113	21.60	0.10	4.46	4.27

Note: The average and standard deviation values calculated are for those impact levels that exceeded the minimum threshold level. Most impact data is skewed to very low severity levels and does not represent a normal distribution. This data is, therefore, also presented based on a frequency of occurence versus severity in Table 6.

TABLE 3. SUMMARY OF ALL TOSSES (Continued)

DESTINATION	TRIP #	NO. OF TOSSES	DROP HEIGHT (in.) MAX	MIN	AVG	S.D.
Portland, OR	1	9	9.20	0.20	5.40	2.86
	2	13	11.90	1.30	4.19	3.13
	3	8	10.70	1.70	4.95	3.45
	4	9	9.60	1.80	4.77	2.68
	5	13	13.60	0.80	4.41	3.70
	6	5	7.30	1.70	4.24	2.74
	7	20	17.80	0.90	3.07	3.71
	8	14	9.20	0.60	3.19	2.90
	9	17	10.50	0.40	3.58	2.93
	10	14	5.20	0.20	1.86	1.27
	Subtotal	122	17.80	0.20	3.19	2.71
Memphis, TN	1	3	7.50	2.40	4.90	2.55
	2	9	7.30	0.70	2.90	2.42
	3	7	9.30	1.30	4.57	3.47
	4	15	17.10	1.20	5.87	5.79
	5	20	11.60	0.30	3.26	3.20
	6	17	5.70	0.60	1.85	1.26
	7	17	15.70	0.30	3.52	3.56
	8	15	10.80	1.10	3.33	2.75
	9	11	3.60	0.80	2.01	0.97
	10	17	8.90	1.10	3.90	2.01
	Subtotal	131	17.10	0.30	3.39	2.79
	Total	607	31.40	0.20	3.90	2.70

ORIGIN: EAST LANSING, MI.

TABLE 4. CUMULATIVE DATA FOR ALL SHIPMENTS

			IMPACT TYPE			IMPACT TYPE		
ROUNDTRIP DESTINATION	TRIP No.	TOTAL IMPACTS	KICKS No.	DROPS No.	TOSSES No.	KICKS %	DROPS %	TOSSES %
MONTEREY, CA	1	32	12	15	5	37.5	46.9	15.6
	2	39	15	12	12	38.5	30.8	30.8
	3	48	24	13	11	50.0	27.1	22.9
	4	41	18	15	8	43.9	36.6	19.5
	5	39	17	10	12	43.6	25.6	30.8
	6	36	12	16	8	33.3	44.4	22.2
	7	45	23	8	14	51.1	17.8	31.1
	8	52	25	15	12	48.1	28.8	23.1
	9	74	30	28	16	40.5	37.8	21.6
	10	56	16	24	16	28.6	42.9	28.6
Total	10	462	192	156	114			
Avg/Trip	1	46	19	16	11	41.6	33.8	24.7
S.D		12	6	6	4			
ATLANTA, GA	1	14	7	4	3	50.0	28.6	21.4
	2	56	26	17	13	46.4	30.4	23.2
	3	26	11	7	8	42.3	26.9	30.8
	4	47	17	14	16	36.2	29.8	34.0
	5	57	25	16	16	43.9	28.1	28.1
	6	44	20	18	6	45.5	40.9	13.6
	7	55	14	21	20	25.5	38.2	36.4
	8	58	19	24	15	32.8	41.4	25.9
	9	45	20	9	16	44.4	20.0	35.6
	10	46	20	12	14	43.5	26.1	30.4
Total	10	448	179	142	127			
Avg/Trip	1	45	18	14	13	40.0	31.7	28.3
S.D		14	6	6	5			
ROCHESTER, NY	1	44	22	12	10	50.0	27.3	22.7
	2	44	19	17	8	43.2	38.6	18.2
	3	49	26	13	10	53.1	26.5	20.4
	4	52	25	14	13	48.1	26.9	25.0
	5	45	25	12	8	55.6	26.7	17.8
	6	35	16	6	13	45.7	17.1	37.1
	7	45	17	13	15	37.8	28.9	33.3
	8	50	25	18	7	50.0	36.0	14.0
	9	63	28	21	14	44.4	33.3	22.2
	10	61	24	22	15	39.3	36.1	24.6
Total	10	488	227	148	113			
Avg/Trip	1	49	23	15	11	46.5	30.3	23.2
S.D		8	4	5	3			

TABLE 4. CUMULATIVE DATA FOR ALL SHIPMENTS (Continued)

ROUNDTRIP DESTINATION	TRIP No.	TOTAL IMPACTS	IMPACT TYPE KICKS No.	DROPS No.	TOSSES No.	IMPACT TYPE KICKS %	DROPS %	TOSSES %
PORTLAND, OR	1	40	18	13	9	45.0	32.5	22.5
	2	47	20	14	13	42.6	29.8	27.7
	3	46	21	17	8	45.7	37.0	17.4
	4	49	31	9	9	63.3	18.4	18.4
	5	42	19	10	13	45.2	23.8	31.0
	6	56	29	22	5	51.8	39.3	8.9
	7	55	21	14	20	38.2	25.5	36.4
	8	63	27	22	14	42.9	34.9	22.2
	9	73	22	34	17	30.1	46.6	23.3
	10	66	32	20	14	48.5	30.3	21.2
Total	10	537	240	175	122			
Avg/Trip	1	54	24	18	12	44.7	32.6	22.7
S.D		11	5	7	4			
MEMPHIS, TN	1	18	10	5	3	55.6	27.8	16.7
	2	28	12	7	9	42.9	25.0	32.1
	3	25	12	6	7	48.0	24.0	28.0
	4	48	24	9	15	50.0	18.8	31.3
	5	59	22	17	20	37.3	28.8	33.9
	6	59	22	20	17	37.3	33.9	28.8
	7	63	30	16	17	47.6	25.4	27.0
	8	54	25	14	15	46.3	25.9	27.8
	9	49	23	15	11	46.9	30.6	22.4
	10	56	27	12	17	48.2	21.4	30.4
Total	10	459	207	121	131			
Avg/Trip	1	46	21	12	13	45.1	26.4	28.5
S.D		16	7	5	5			
Grand Total	50	2394	1045	742	607			
Avg/Trip	1	48	21	15	12	43.7	31.0	25.4
S.D		13	6	6	4			

ORIGIN: EAST LANSING, MI.

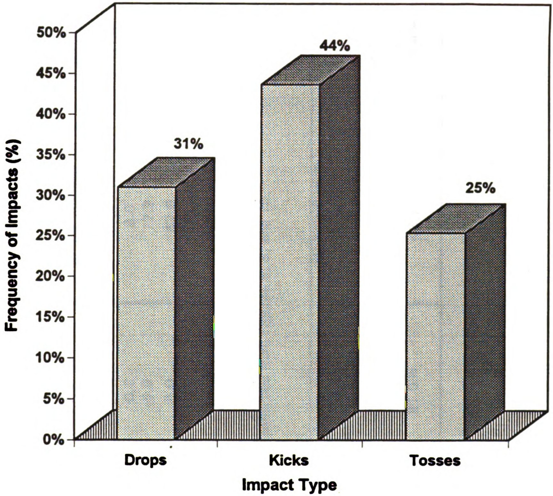

Fig 5. Distribution of Impacts for All Shipments

TABLE 5. SUMMARY OF IMPACTS FOR ALL SHIPMENTS

SUMMARY	IMPACT TYPES		
	DROPS (in.)	KICKS (in./sec)	TOSSES (in.)
Maximum	77.8	233.0	31.4
Minimum	0.2	8.0	0.1
Average	5.9	77.9	3.9
Mode*	5.0	67.0	2.0
99% Occurence	26.0	175.0	17.0
95% Occurence	17.0	140.0	11.0
90% Occurence	12.0	123.0	8.0

* The mode values are determined from Figures 6, 8, and 10.

SUMMARY	IMPACT TYPES		
	DROPS	KICKS	TOSSES
Total Number	742.0	1045.0	607.0
Average/Trip	15.0	21.0	12.0
All Impacts	31.0%	43.7%	25.4%

The data shows that the maximum free fall drop height was 77.8 inches, the maximum velocity change for kicks was 233 in./sec, and the maximum equivalent drop height in a toss was 31.4 inches.

The information obtained in this study is useful to develop lab simulated drop tests to be used with ASTM package test methods. The maximum drop height from which up to 95% of these impacts occur is usually a standard test level used by industry for developing simulated lab testing. This information can also be used to estimate the potential of a package to survive damage when it is shipped via the overnight package delivery systems of UPS or Federal Express.

The cumulative number of occurrences expressed in percent were plotted against impact level for each of the three main categories of impacts (drops, kicks and tosses). These levels are shown in Table 6. Figure 6 is a histogram showing the number of drops occuring at a given drop height level. The data in Figure 7 shows that 95% of drops occur below 16 inches. Similarly, Figure 8 shows the number of kicks occuring at a given velocity change. From Figure 9, 95% of kicks occur below a velocity change of 135 in./sec. Also, the number of tosses that occur at a given equivalent drop height is shown in Figure 10. Figure 11 shows that 95% of the tosses occur below an equivalent drop height of 10.5 inches.

The data was also analyzed to determine the package

TABLE 6. Cumulative Percent as a Function of Impact Level for All Shipments

Drops (in.)	Cumulative Percent (%)	Number	Kicks (in./sec)	Cumulative Percent (%)	Number	Tosses (in.)	Cumulative Percent (%)	Number
0	0.0	0	0	0.0	0	0	0.0	0
2	17.4	129	5	0.0	0	0.5	2.0	12
4	45.6	209	10	0.2	2	1	8.9	42
6	67.0	159	15	0.5	3	1.5	20.4	70
8	77.0	74	20	1.0	5	2	34.9	88
10	85.7	65	25	1.2	3	2.5	44.3	57
12	90.3	34	30	2.5	13	3	54.4	61
14	93.0	20	35	5.2	28	3.5	61.6	44
16	94.2	9	40	8.1	31	4	66.9	32
18	96.1	14	45	13.4	55	4.5	72.2	32
20	97.4	10	50	19.8	67	5	76.8	28
22	98.5	8	55	26.0	65	5.5	79.4	16
24	98.8	2	60	33.2	75	6	82.0	16
26	99.1	2	65	41.7	89	6.5	84.7	16
28	99.2	1	70	48.4	70	7	86.5	11
30	99.2		75	56.4	83	7.5	88.8	14
32	99.3	1	80	61.1	49	8	89.8	6
34	99.5	1	85	65.5	46	8.5	90.8	6
36	99.6	1	90	71.0	58	9	91.4	4
38	99.7	1	95	75.1	43	9.5	92.8	8
40	99.7		100	78.2	32	10	93.6	5
42	99.7		105	80.3	22	10.5	93.9	2
44	99.7		110	83.9	38	11	95.1	7
46	99.7		115	86.4	26	11.5	95.4	2
48	99.7		120	88.8	25	12	96.2	5
50	99.7		125	90.9	22	12.5	96.2	
52	99.9	1	130	92.8	20	13	96.4	1
54	99.9		135	94.2	14	13.5	96.7	2
56	99.9		140	95.4	13	14	97.7	6
58	99.9		145	96.5	11	14.5	97.7	
60	99.9		150	96.9	5	15	97.9	1
62	99.9		155	97.5	6	15.5	98.0	1
64	99.9		160	98.1	6	16	98.5	3
66	99.9		165	98.7	6	16.5	98.7	1
68	99.9		170	98.8	1	17	99.0	2
70	99.9		175	98.9	1	17.5	99.2	1
72	99.9		180	99.2	4	18	99.3	1
74	99.9		185	99.3	1	18.5	99.5	1
76	99.9		190	99.3		19	99.5	
78	100.0	1	195	99.4	1	19.5	99.7	1
			200	99.5	1	20	99.7	
			205	99.5		20.5	99.7	
			210	99.6	1	21	99.7	
			215	99.7	1	21.5	99.7	
			220	99.8	1	22	99.8	1
			225	99.9	1	22.5	99.8	
			230	99.9		23	100.0	1
			235	100.0	1			
TOTAL DROPS =		742	TOTAL KICKS =		1045	TOTAL TOSSES =		607

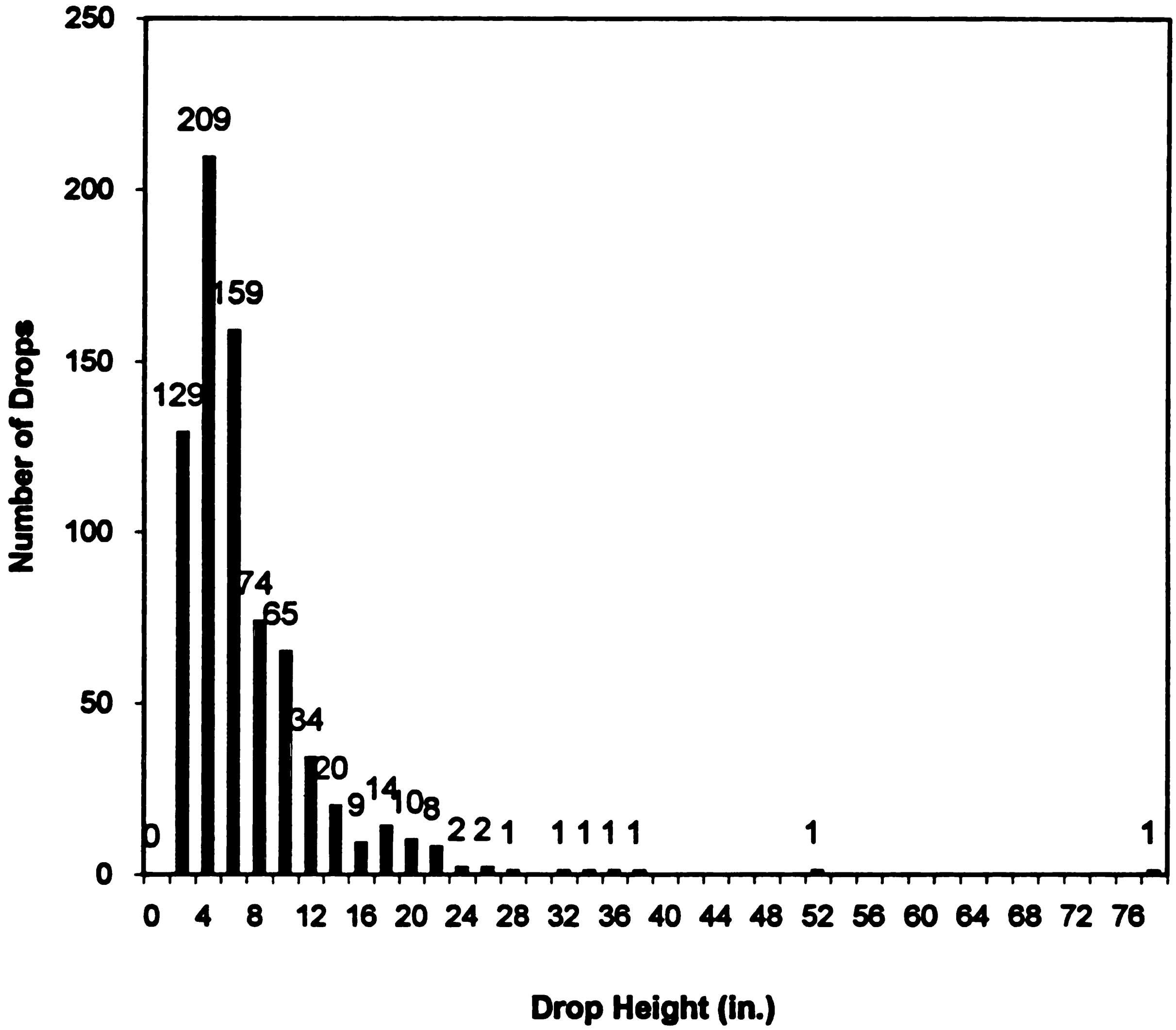

Fig 6. Number of Drops versus Drop Height for All Shipments

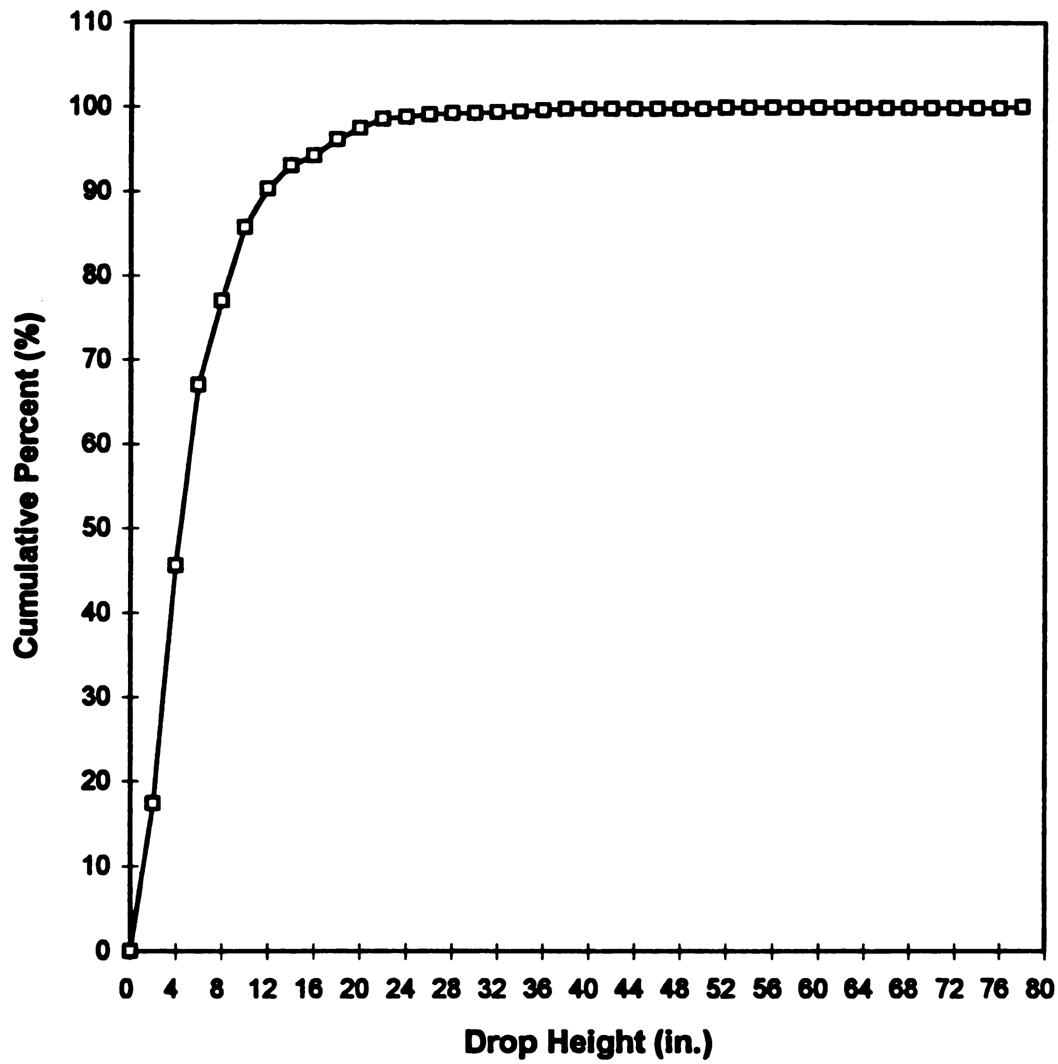

Fig 7. Cumulative Percent versus Drop Height for Drops in All Shipments

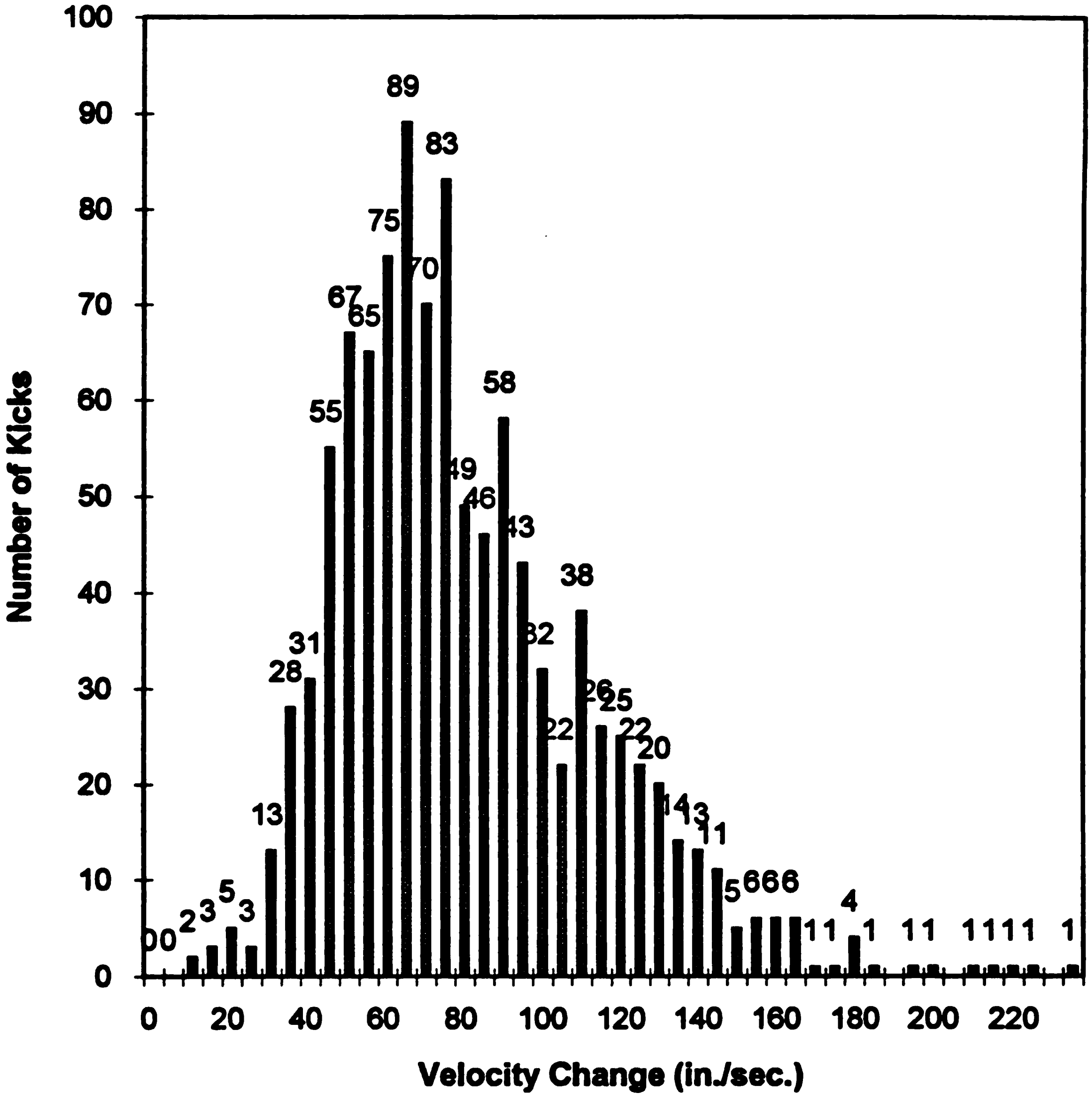

Fig 8. Number of Kicks versus Velocity Change for All Shipments

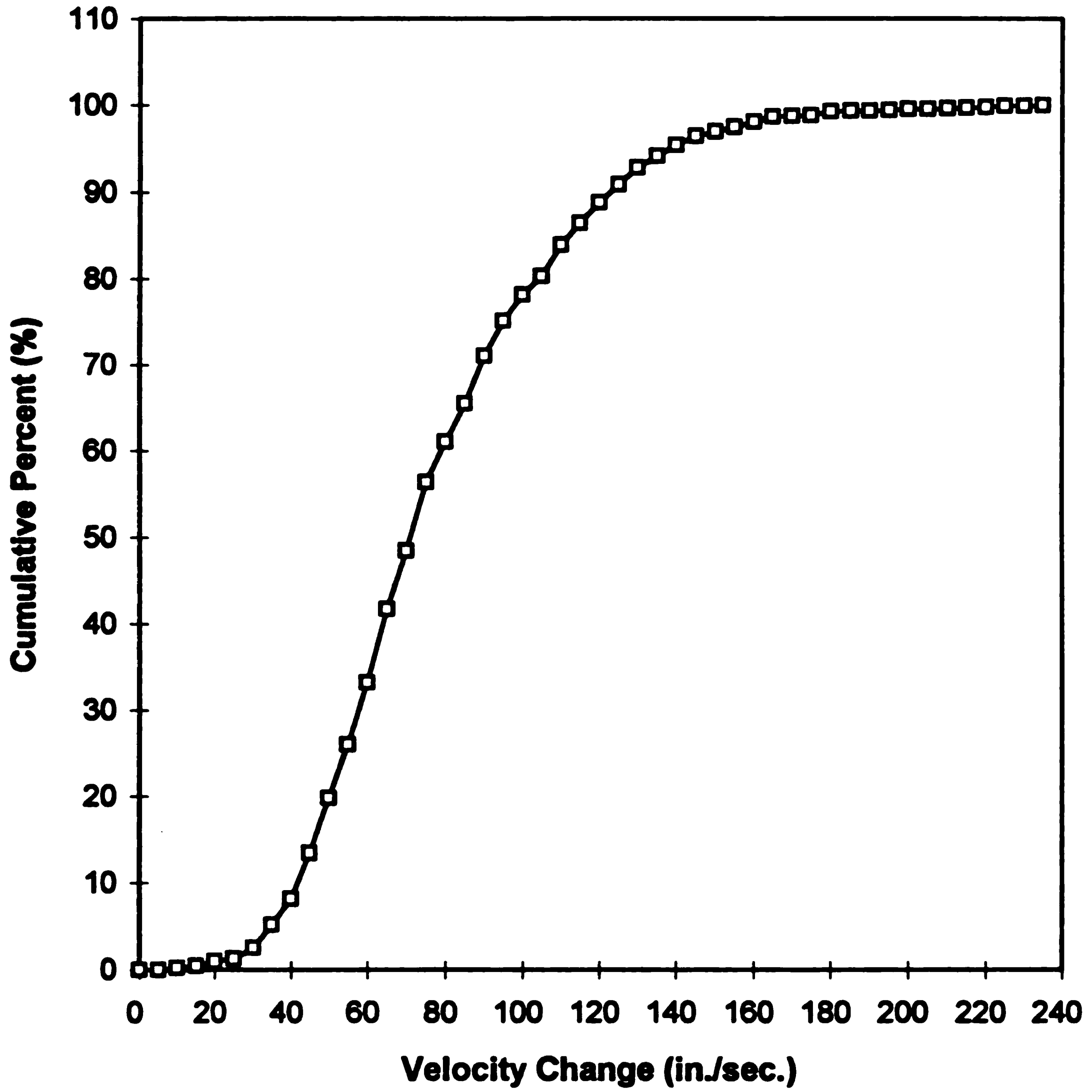

Fig 9. Cumulative Percent versus Velocity Change for Kicks in All Shipments

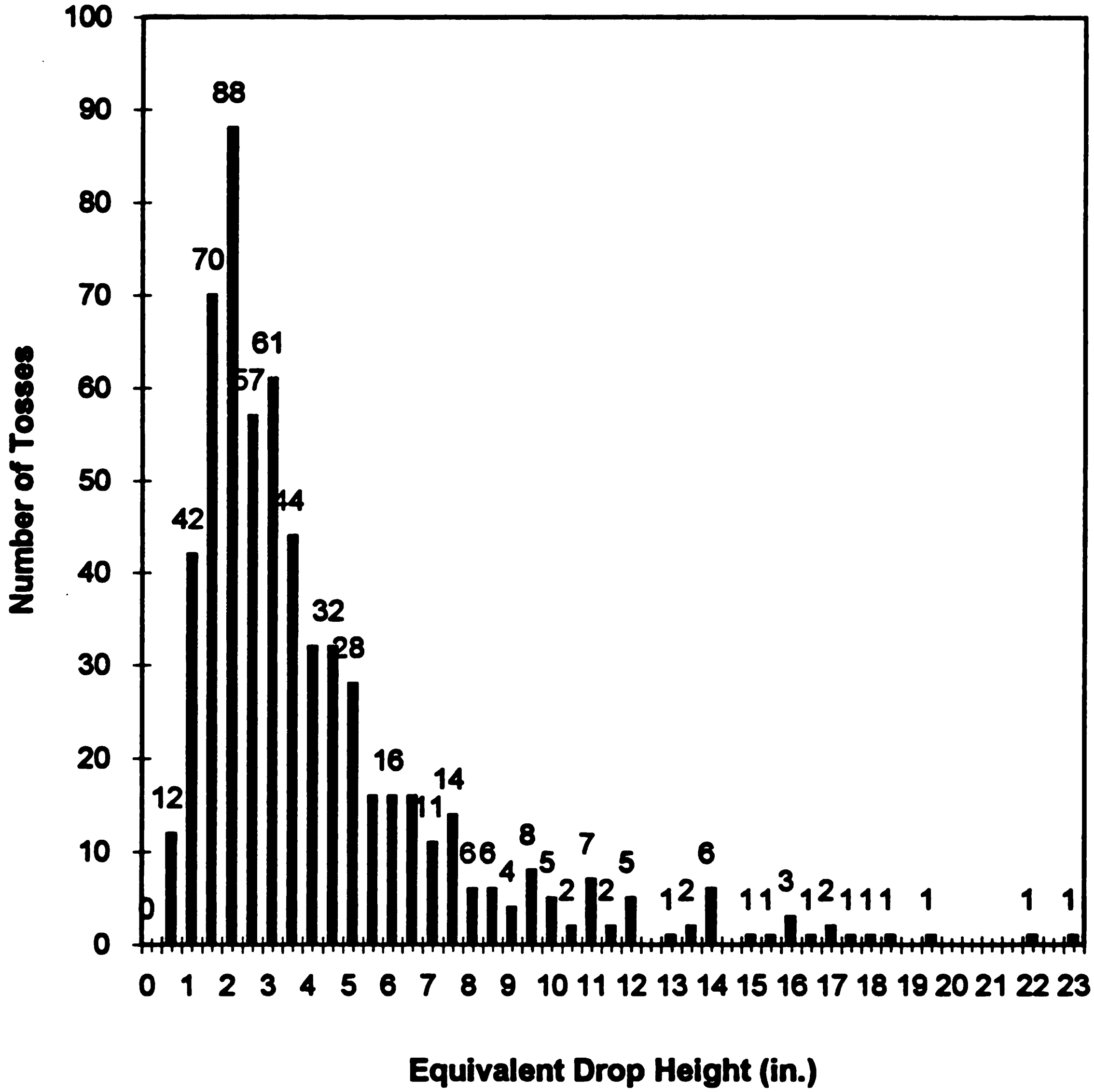

Fig 10. Number of Tosses versus Equivalent Drop Height for All Shipments

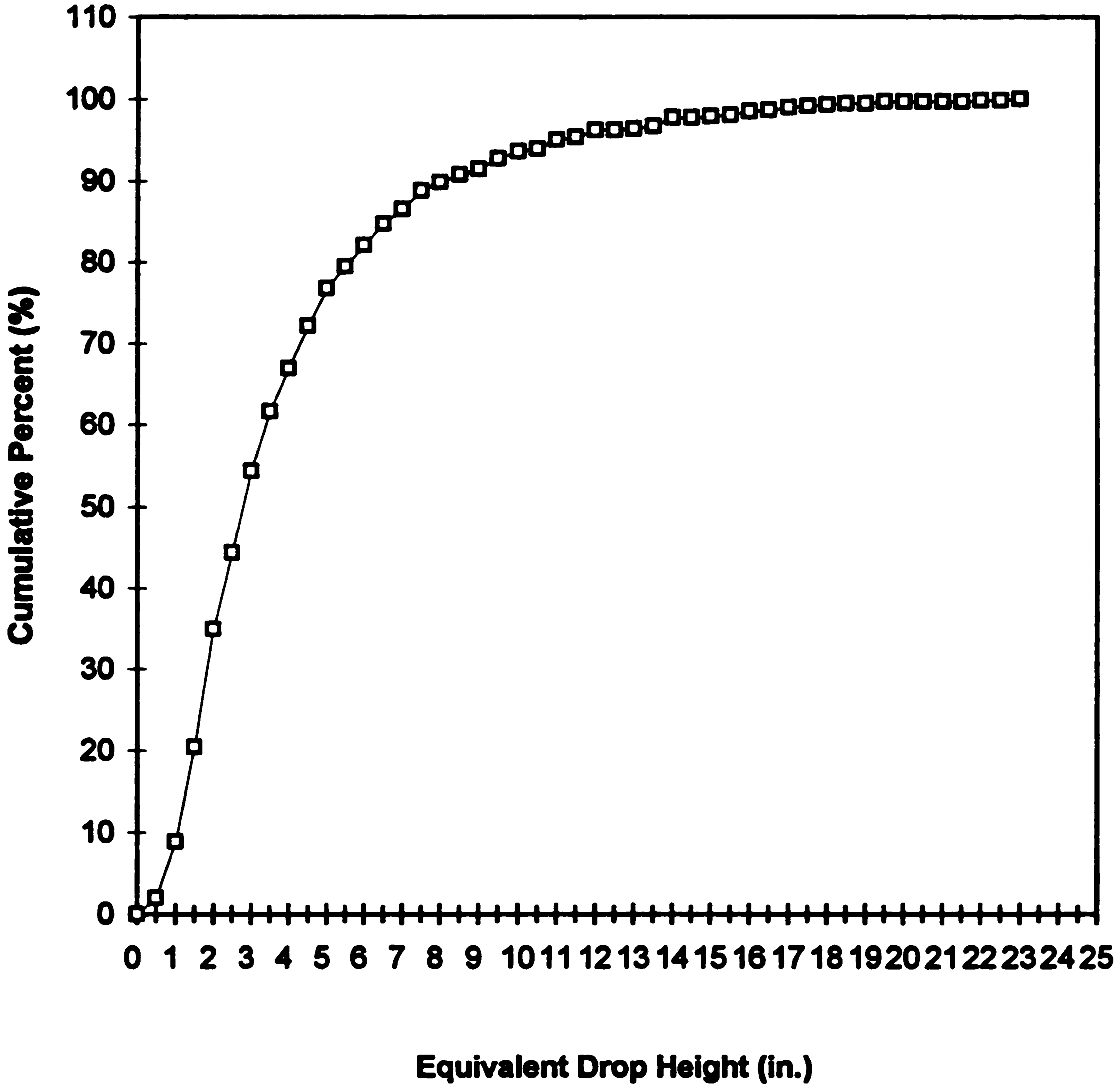

Fig 11. Cumulative Percent versus Equivalent Drop Height for Tosses in All Shipments

orientation at impact. Each event was classified as either a flat, edge, or corner impact. The individual velocity changes were analyzed in each axis and represented by ΔV_x, ΔV_y, and ΔV_z. The sum of velocity change was calculated using the following equation:

$$\Delta V_{Total} = \Delta V_x + \Delta V_y + \Delta V_z \quad \text{..................(2-5)}$$

Where,

$\Delta V_{x,y,z}$ = Velocity Change in each axis

To determine the orientation of impact, the velocity change in each axis was compared to ΔV_{Total}. If the velocity change in a particular axis was 90% or more of ΔV_{Total}, that impact was classified as a flat impact on that axis. The axis showing ΔV values of less than 10% of ΔV_{Total} were not considered to have a significant level, and therefore were not considered for impact orientation. The summarized impact orientation data is presented in Table 7. Of the 2394 total number of impacts measured, 165 (6.9%) occurred on flat faces, 1224 (51.1%) on edges, and 1005 (42%) on corners. The edges of the packages received the most impacts (Figure 12).

From the data in Table 8 and as shown in Figure 13, all 165 impacts received on the flat faces of the packages

TABLE 7. FREQUENCY OF TOTAL IMPACTS AS A FUNCTION OF ORIENTATION

IMPACT ORIENTATION	IMPACT DIRECTION	TOTAL IMPACTS (No.)	(%)
FLAT	L = Left	12	0.5
	R = Right	36	1.5
	Bk = Back	4	0.2
	F = Front	27	1.1
	B = Bottom	70	2.9
	T = Top	16	0.7
	Subtotal	165	6.9
EDGE	F-T	95	4.0
	F-B	208	8.7
	R-B	226	9.4
	R-T	109	4.6
	L-B	144	6.0
	L-T	63	2.6
	R-Bk	46	1.9
	R-F	102	4.3
	L-Bk	25	1.0
	L-F	51	2.1
	Bk-B	98	4.1
	Bk-T	57	2.4
	Subtotal	1224	51.1
CORNER	L-BK-B	81	3.4
	L-Bk-T	64	2.7
	L-F-B	164	6.9
	L-F-T	70	2.9
	R-Bk-B	152	6.3
	R-Bk-T	0	0.0
	R-F-B	252	10.5
	R-F-T	222	9.3
	Subtotal	1005	42.0
	TOTAL	**2394**	**100.0**

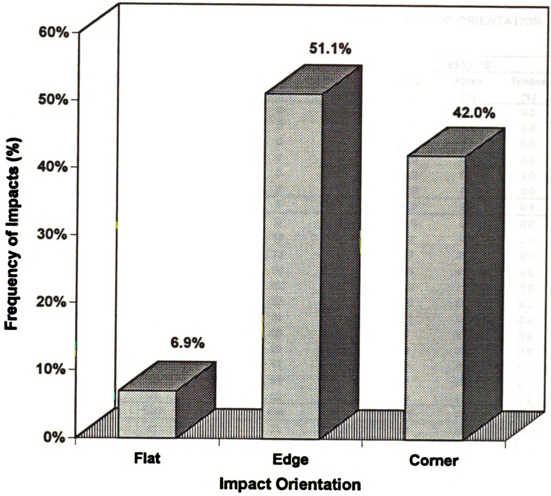

Fig 12. Frequency of Impacts as a Function of Package Orientation

TABLE 8. FREQUENCY OF DROPS, KICKS, AND TOSSES AS A FUNCTION OF ORIENTATION

IMPACT ORIENTATIO	IMPACT DIRECTION	TOTAL IMPACTS (No.)	EVENTS			EVENTS		
			Drops (No.)	Kicks (No.)	Tosses (No.)	Drops (%)	Kicks (%)	Tosses (%)
FLAT	L = Left	12	12	0	0	100.0	0.0	0.0
	R = Right	36	36	0	0	100.0	0.0	0.0
	Bk = Back	4	4	0	0	100.0	0.0	0.0
	F = Front	27	27	0	0	100.0	0.0	0.0
	B = Bottom	70	70	0	0	100.0	0.0	0.0
	T = Top	16	16	0	0	100.0	0.0	0.0
	Subtotal	**165**	**165**	**0**	**0**	**100.0**	**0.0**	**0.0**
EDGE	F-T	95	95	0	0	100.0	0.0	0.0
	F-B	208	198	10	0	95.2	4.8	0.0
	R-B	226	153	73	0	67.7	32.3	0.0
	R-T	109	55	54	0	50.5	49.5	0.0
	L-B	144	42	102	0	29.2	70.8	0.0
	L-T	63	10	53	0	15.9	84.1	0.0
	R-Bk	46	7	39	0	15.2	84.8	0.0
	R-F	102	9	93	0	8.8	91.2	0.0
	L-Bk	25	2	23	0	8.0	92.0	0.0
	L-F	51	4	47	0	7.8	92.2	0.0
	Bk-B	98	2	94	2	2.0	95.9	2.0
	Bk-T	57	0	52	5	0.0	91.2	8.8
	Subtotal	**1224**	**577**	**640**	**7**	**47.1**	**52.3**	**0.6**
CORNER	L-BK-B	81	0	71	10	0.0	87.7	12.3
	L-Bk-T	64	0	52	12	0.0	81.3	18.8
	L-F-B	164	0	126	38	0.0	76.8	23.2
	L-F-T	70	0	44	26	0.0	62.9	37.1
	R-Bk-B	152	0	78	74	0.0	51.3	48.7
	R-Bk-T	0	0	0	0	0.0	0.0	0.0
	R-F-B	252	0	34	218	0.0	13.5	86.5
	R-F-T	222	0	0	222	0.0	0.0	100.0
	Subtotal	**1005**	**0**	**405**	**600**	**0.0**	**40.3**	**59.7**
	TOTAL	**2394**	**742**	**1045**	**607**	**31.0**	**43.7**	**25.4**

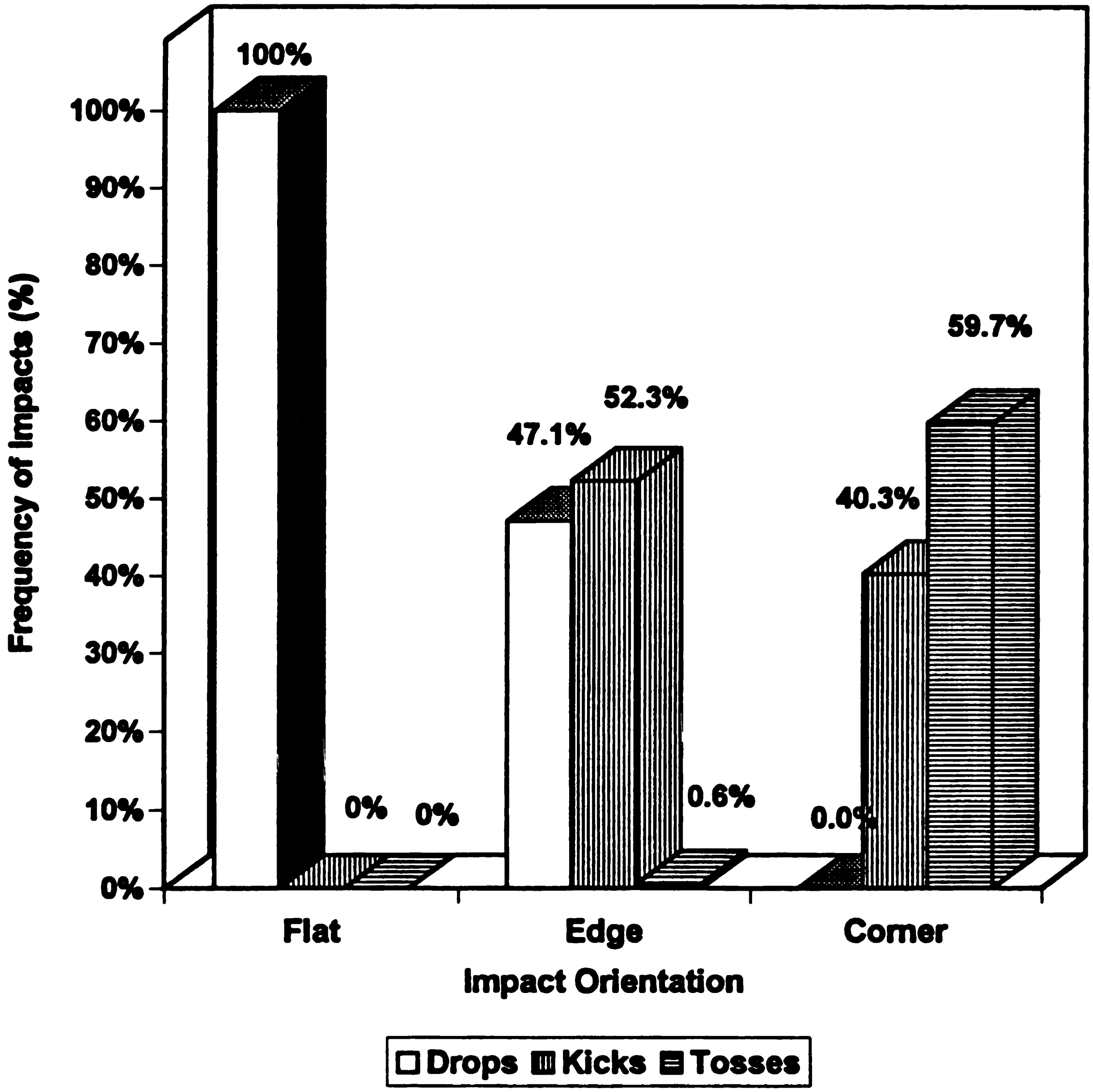

Fig 13. Distribution of Impact Type as a Function of Package Orientation

resulted from free fall drops, and most of those occurred on the bottom face.

Of the 1224 edge impacts, 47.1% resulted from drops, 52.3% resulted from kicks, and only 0.6% were due to tosses (Figure 13). One of the bottom edges (Bottom-Right) received the majority of impacts.

All the corner impacts resulted mainly from kicks and tosses. Out of 1005 impacts received by corners 40.3% were kicks, 59.7% were tosses, and none were due to drops (Figure 13). One of the corners (Right-Front-Bottom) received the most impacts.

Table 9 shows that of all the drops that occurred in the study, 77.8% occurred on the edges, 22.2% occurred on the flat faces of the package. There were no drops on the corners (Figure 14).

Of all the kicks, 61.2% were received by the edges, 38.8% were received by the corners of the packages. There were no kicks received by flat faces (Figure 14).

Of all the tosses, 98.8% were received by the corners of the packages. Flat faces did not receive any toss impact (Figure 14).

TABLE 9. DISTRIBUTION OF IMPACT ORIENTATION AS A FUNCTION OF DROPS, KICKS, AND TOSSES

IMPACT ORIENTATION	IMPACT DIRECTION	DROPS		KICKS		TOSSES	
		No.	%	No.	%	No.	%
FLAT	L = Left	12	1.6	0	0.0	0	0.0
	R = Right	36	4.9	0	0.0	0	0.0
	Bk = Back	4	0.5	0	0.0	0	0.0
	F = Front	27	3.6	0	0.0	0	0.0
	B = Bottom	70	9.4	0	0.0	0	0.0
	T = Top	16	2.2	0	0.0	0	0.0
	Subtotal	165	22.2%	0	0.0%	0	0.0%
EDGE	F-T	95	12.8	0	0.0	0	0.0
	F-B	198	26.7	10	1.0	0	0.0
	R-B	153	20.6	73	7.0	0	0.0
	R-T	55	7.4	54	5.2	0	0.0
	L-B	42	5.7	102	9.8	0	0.0
	L-T	10	1.3	53	5.1	0	0.0
	R-Bk	7	0.9	39	3.7	0	0.0
	R-F	9	1.2	93	8.9	0	0.0
	L-Bk	2	0.3	23	2.2	0	0.0
	L-F	4	0.5	47	4.5	0	0.0
	Bk-B	2	0.3	94	9.0	2	0.3
	Bk-T	0	0.0	52	5.0	5	0.8
	Subtotal	577	77.8%	640	61.2%	7	1.2%
CORNER	L-BK-B	0	0.0	71	6.8	10	1.6
	L-Bk-T	0	0.0	52	5.0	12	2.0
	L-F-B	0	0.0	126	12.1	38	6.3
	L-F-T	0	0.0	44	4.2	26	4.3
	R-Bk-B	0	0.0	78	7.5	74	12.2
	R-Bk-T	0	0.0	0	0.0	0	0.0
	R-F-B	0	0.0	34	3.3	218	35.9
	R-F-T	0	0.0	0	0.0	222	36.6
	Subtotal	0	0.0%	405	38.8%	600	98.8%
	TOTAL	742	100.0%	1045	100.0%	607	100.0%

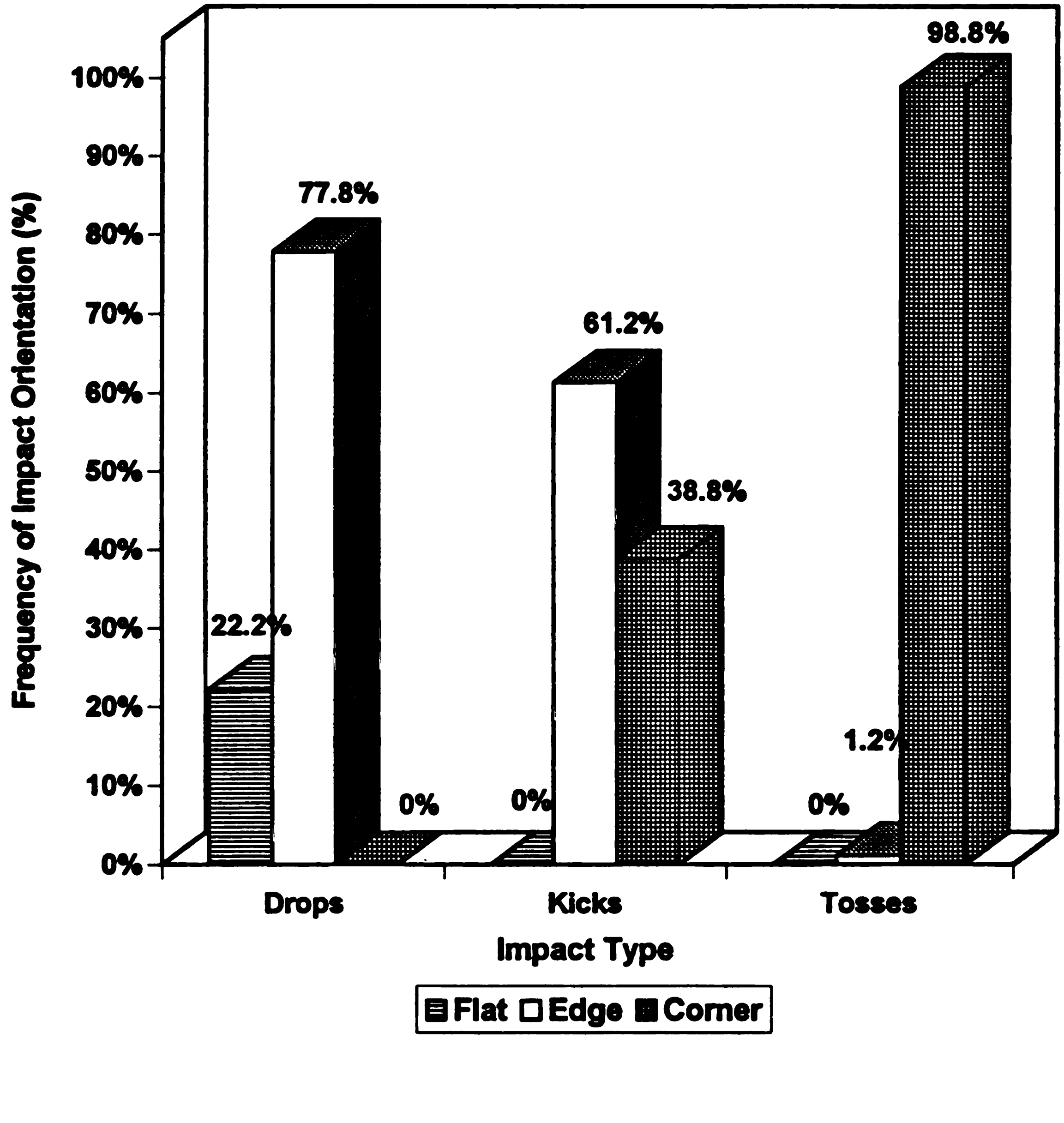

Fig 14. Distribution of Package Orientation as a Function of Impact Type

4.0 CONCLUSIONS

1. Of all the 2394 dynamic events encountered in combined UPS and Federal Express shipments, kicks represent the highest percentage of events (43.65%) followed by drops (30.99%) and tosses (25.36%). The majority of impacts occur during the sorting process which produces lateral impacts due to diverting arms and sliding chutes.

2. Free fall drops occurred from less than 16 inches height in 95% of all cases. The overall maximum drop height was 77.8 inches. On visual observations, most of the manual handling operations during loading and unloading of packages result in small drops and tosses.

3. Tosses were equivalent to less than 10.5 inches of drop height in 95% of all cases. The overall equivalent drop height in a toss was found to be 31.4 inches.

4. Kicks caused less than 135 in./sec of velocity change in 95% of all cases. These are a function of the impacting levels of diverting arms during sorting process. The maximum velocity change recorded was 233 in./sec.

5. The edge orientation received the majority of the impacts, followed by corners and flat faces, respectively. This is mainly due to the fact that most of the impacts are kicks and majority of those kicks occur on edges.

6. All the impacts received by the flat faces were only due to free fall drops. The edge impacts, on the other hand, were mainly due to drops and kicks, but only a fraction of them resulted from tosses. The corner impacts mainly resulted from kicks and tosses, but none of them were drops.

7. Based on the results of this investigation, a test protocol has been developed to test packages for the next day air small parcel environment. The package test sequence has also been defined that should be followed using the appropriate assurance level.

TEST PROTOCOL

AVERAGE NUMBER OF IMPACTS PER ROUND TRIP: 48

AVERAGE NUMBER OF IMPACTS PER ONE WAY TRIP: 24

PREDICTED NUMBER OF DROPS PER ONE WAY TRIP: 0.31(24) = 7

PREDICTED NUMBER OF TOSSES PER ONE WAY TRIP: 0.23(24) = 6

PREDICTED NUMBER OF KICKS PER ONE WAY TRIP; 0.46(24) = 11

Using Figures 7, 8, and 9, measure at 99% (Assurance Level I), 95% (Assurance Level II), and 90% (Assurance Level III) to determine severity level for each type of impact.

IMPACT TYPE	ASSURANCE LEVEL I	ASSURANCE LEVEL II	ASSURANCE LEVEL III
Drops	26 inches	17 inches	12 inches
Tosses	17 inches	11 inches	8 inches
Kicks	175 in./sec	140 in./sec	123 in./sec

TEST SEQUENCE

Perform the tests in the following sequence using the appropriate assurance level.

1. Perform 7 drops. The orientation of impact is determined from Figure 14.
   - 2 drops on randomly selected flat faces, preferably bottom and one side face.
   - 5 drops on randomly selected edges, preferably three bottom edges, and two side edges.

2. Perform 6 tosses (drops). The orientation of impact is determined from Figure 14.
   - 8 drops on randomly selected corners.

3. Perform 11 kicks (lateral impacts) required only in case of diverting arms. The orientation of impact is determined from Figure 14.
   - 7 kicks on randomly selected edges.
   - 4 kicks on randomly selected corner.

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LIST OF REFERENCES

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APPENDIX

APPENDIX A

Table A1: Individual Drop Events in Overnight Small Parcel Environment of UPS and Federal Express

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
Monterey, CA	1	1	1.60	4.96
		2	1.80	
		3	3.50	
		4	3.20	
		5	4.60	
		6	8.90	
		7	5.20	
		8	3.80	
		9	1.00	
		10	3.60	
		11	4.50	
		12	4.90	
		13	13.00	
		14	9.30	
		15	6.30	
		16	4.20	
Monterey, CA	2	1	3.00	6.33
		2	6.60	
		3	11.10	
		4	2.90	
		5	2.30	
		6	2.50	
		7	7.60	
		8	6.70	
		9	13.90	
		10	9.30	
		11	6.80	
		12	8.70	
		13	4.60	
		14	6.00	
		15	2.90	
Monterey, CA	3	1	10.80	6.06
		2	15.10	
		3	2.40	
		4	1.80	
		5	2.00	
		6	7.10	
		7	2.30	
		8	7.00	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
Monterey, CA	4	1	5.80	8.84
		2	2.20	
		3	3.70	
		4	16.50	
		5	5.30	
		6	4.60	
		7	9.10	
		8	16.60	
		9	9.20	
		10	20.10	
		11	4.80	
		12	8.20	
Monterey, CA	5	1	2.10	8.14
		2	3.00	
		3	5.30	
		4	18.90	
		5	9.30	
		6	0.70	
		7	25.90	
		8	4.50	
		9	3.80	
		10	9.40	
		11	5.90	
		12	10.00	
		13	16.30	
		14	5.50	
		15	1.50	
Monterey, CA	6	1	4.20	5.85
		2	2.90	
		3	1.30	
		4	3.90	
		5	4.20	
		6	4.50	
		7	1.60	
		8	1.40	
		9	2.00	
		10	18.50	
		11	7.40	
		12	9.70	
		13	14.50	
Monterey, CA	7	1	2.50	5.99
		2	1.30	
		3	2.30	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
		4	7.40	
		5	9.90	
		6	3.80	
		7	2.10	
		8	2.30	
		9	2.50	
		10	2.70	
		11	3.90	
		12	0.80	
		13	8.90	
		14	6.90	
		15	12.00	
		16	13.10	
		17	2.70	
		18	30.40	
		19	8.90	
		20	3.90	
		21	4.70	
		22	5.30	
		23	1.60	
		24	0.70	
		25	9.50	
		26	4.80	
		27	9.30	
		28	3.60	
Monterey, CA	8	1	0.80	5.12
		2	12.10	
		3	2.10	
		4	8.70	
		5	1.40	
		6	2.40	
		7	1.30	
		8	4.60	
		9	18.70	
		10	3.30	
		11	2.60	
		12	2.60	
		13	9.50	
		14	4.60	
		15	2.10	
Monterey, CA	9	1	0.60	10.05
		2	1.70	
		3	2.50	
		4	6.00	
		5	2.60	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
		6	1.90	
		7	2.50	
		8	10.50	
		9	77.80	
		10	3.50	
		11	3.90	
		12	18.00	
		13	35.70	
		14	2.80	
		15	3.60	
		16	5.90	
		17	4.00	
		18	3.10	
		19	9.00	
		20	16.70	
		21	7.60	
		22	8.50	
		23	8.40	
		24	4.50	
Monterey. CA	10	1	3.80	6.35
		2	2.10	
		3	6.70	
		4	11.70	
		5	9.30	
		6	4.30	
		7	4.90	
		8	3.60	
		9	5.20	
		10	11.90	
Atlanta, GA	1	1	9.80	5.36
		2	4.00	
		3	2.70	
		4	0.50	
		5	1.10	
		6	2.50	
		7	2.20	
		8	9.50	
		9	4.90	
		10	3.80	
		11	8.70	
		12	9.70	
		13	2.50	
		14	11.30	
		15	3.10	
		16	10.30	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
		17	4.90	
		18	4.90	
Atlanta, GA	2	1	16.10	8.90
		2	1.70	
		3	11.30	
		4	6.50	
Atlanta, GA	3	1	4.10	4.37
		2	0.90	
		3	2.20	
		4	0.80	
		5	3.10	
		6	6.20	
		7	5.20	
		8	4.30	
		9	0.70	
		10	4.70	
		11	2.00	
		12	4.50	
		13	2.90	
		14	2.20	
		15	14.90	
		16	2.60	
		17	4.90	
		18	7.40	
		19	7.20	
		20	5.60	
		21	5.40	
Atlanta, GA	4	1	4.90	6.85
		2	4.30	
		3	4.20	
		4	22.20	
		5	10.10	
		6	2.20	
		7	9.90	
		8	11.40	
		9	5.00	
		10	4.50	
		11	14.60	
		12	8.80	
		13	3.90	
		14	1.60	
		15	1.80	
		16	5.60	
		17	1.40	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
Atlanta, GA	5	1	7.70	6.30
		2	0.80	
		3	9.90	
		4	2.20	
		5	3.60	
		6	11.50	
		7	12.10	
		8	1.00	
		9	4.80	
		10	3.20	
		11	5.20	
		12	8.20	
		13	11.80	
		14	1.70	
		15	4.70	
		16	2.50	
		17	22.00	
		18	3.20	
		19	4.10	
		20	3.80	
		21	10.60	
		22	5.30	
		23	2.10	
		24	9.20	
Atlanta, GA	6	1	9.90	7.27
		2	13.30	
		3	7.30	
		4	5.70	
		5	4.70	
		6	1.50	
		7	8.50	
Atlanta, GA	7	1	4.60	7.83
		2	8.20	
		3	19.30	
		4	17.80	
		5	6.90	
		6	3.30	
		7	1.60	
		8	1.40	
		9	7.40	
Atlanta, GA	8	1	3.90	5.31
		2	8.80	
		3	1.50	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
		4	2.70	
		5	6.50	
		6	2.20	
		7	2.30	
		8	1.00	
		9	7.00	
		10	7.60	
		11	6.30	
		12	4.90	
		13	3.40	
		14	16.20	
Atlanta, GA	9	1	5.70	5.29
		2	7.80	
		3	3.70	
		4	3.20	
		5	1.40	
		6	2.00	
		7	9.70	
		8	8.80	
		9	7.00	
		10	2.40	
		11	4.20	
		12	7.60	
Atlanta, GA	10	1	4.00	5.93
		2	2.90	
		3	1.70	
		4	4.80	
		5	6.70	
		6	20.50	
		7	1.90	
		8	2.30	
		9	7.10	
		10	7.70	
		11	2.30	
		12	0.50	
		13	1.90	
		14	5.40	
		15	16.50	
		16	8.60	
Rochester, NY	1	1	18.00	8.47
		2	4.90	
		3	3.40	
		4	1.20	
		5	11.40	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
		6	11.90	
Rochester, NY	2	1	3.10	5.00
		2	0.90	
		3	0.70	
		4	2.90	
		5	5.10	
		6	13.80	
		7	2.30	
		8	1.70	
		9	1.80	
		10	7.30	
		11	3.70	
		12	16.70	
Rochester, NY	3	1	3.40	4.62
		2	3.70	
		3	3.30	
		4	5.10	
		5	2.70	
		6	3.60	
		7	0.90	
		8	1.60	
		9	6.90	
		10	3.50	
		11	11.10	
		12	1.10	
		13	13.20	
Rochester, NY	4	1	2.80	4.19
		2	3.90	
		3	3.20	
		4	3.00	
		5	4.80	
		6	1.40	
		7	0.80	
		8	3.30	
		9	3.90	
		10	1.70	
		11	4.50	
		12	5.70	
		13	2.90	
		14	8.20	
		15	15.30	
		16	4.50	
		17	1.30	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
Rochester, NY	5	1	3.60	5.17
		2	4.50	
		3	2.50	
		4	2.70	
		5	6.00	
		6	1.90	
		7	7.80	
		8	3.00	
		9	0.60	
		10	7.60	
		11	5.40	
		12	5.00	
		13	19.40	
		14	1.80	
		15	3.20	
		16	3.70	
		17	11.10	
		18	3.30	
Rochester, NY	6	1	8.70	5.15
		2	3.60	
		3	4.00	
		4	1.40	
		5	6.10	
		6	1.50	
		7	2.00	
		8	5.60	
		9	5.30	
		10	5.70	
		11	13.60	
		12	5.20	
		13	4.30	
Rochester, NY	7	1	5.80	5.66
		2	4.00	
		3	8.70	
		4	3.50	
		5	3.80	
		6	2.60	
		7	1.40	
		8	1.30	
		9	12.50	
		10	13.80	
		11	4.60	
		12	8.30	
		13	2.40	
		14	2.10	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
		15	8.00	
		16	3.20	
		17	1.80	
		18	6.10	
		19	5.80	
		20	8.30	
		21	10.80	
Rochester, NY	8	1	2.30	7.69
		2	3.70	
		3	4.70	
		4	33.60	
		5	8.80	
		6	4.20	
		7	3.90	
		8	0.60	
		9	7.30	
		10	0.40	
		11	1.90	
		12	26.10	
		13	9.00	
		14	1.20	
Rochester, NY	9	1	2.40	5.38
		2	4.20	
		3	5.00	
		4	7.00	
		5	2.90	
		6	3.30	
		7	5.20	
		8	2.00	
		9	2.90	
		10	6.60	
		11	3.10	
		12	2.70	
		13	3.10	
		14	19.00	
		15	3.90	
		16	5.80	
		17	6.50	
		18	2.60	
		19	4.20	
		20	1.40	
		21	12.90	
		22	11.60	
Rochester, NY	10	1	0.60	5.62

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
		2	1.70	
		3	1.40	
		4	6.90	
		5	3.80	
		6	7.80	
		7	5.10	
		8	4.80	
		9	3.90	
		10	8.60	
		11	18.10	
		12	4.70	
Portland, OR	1	1	4.20	5.65
		2	7.20	
		3	13.80	
		4	2.80	
		5	5.60	
		6	2.40	
		7	0.60	
		8	4.60	
		9	4.70	
		10	3.30	
		11	7.90	
		12	3.90	
		13	2.90	
		14	5.30	
		15	4.80	
		16	16.80	
		17	5.40	
		18	7.30	
		19	6.60	
		20	3.20	
		21	6.50	
		22	4.50	
Portland, OR	2	1	4.90	7.61
		2	12.90	
		3	18.50	
		4	9.30	
		5	1.50	
		6	6.10	
		7	6.30	
		8	12.70	
		9	8.50	
		10	7.50	
		11	3.60	
		12	5.10	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
		13	2.00	
Portland, OR	3	1	0.40	4.34
		2	1.30	
		3	1.40	
		4	1.40	
		5	2.20	
		6	1.50	
		7	0.90	
		8	3.00	
		9	0.60	
		10	19.30	
		11	3.30	
		12	5.00	
		13	6.30	
		14	14.20	
Portland, OR	4	1	4.40	6.07
		2	4.70	
		3	2.90	
		4	3.00	
		5	7.30	
		6	8.80	
		7	7.30	
		8	9.30	
		9	12.20	
		10	2.20	
		11	4.10	
		12	1.10	
		13	5.80	
		14	11.90	
Portland, OR	5	1	4.10	4.62
		2	2.60	
		3	13.00	
		4	0.60	
		5	0.60	
		6	6.10	
		7	5.40	
		8	3.60	
		9	3.60	
		10	3.70	
		11	1.50	
		12	2.20	
		13	5.10	
		14	0.60	
		15	20.50	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
		16	5.70	
		17	1.90	
		18	8.20	
		19	0.90	
		20	3.90	
		21	5.10	
		22	2.80	
Portland, OR	6	1	5.30	10.60
		2	4.80	
		3	3.10	
		4	4.50	
		5	5.40	
		6	14.00	
		7	7.60	
		8	9.30	
		9	22.70	
		10	7.30	
		11	3.80	
		12	3.40	
		13	2.50	
		14	51.40	
		15	24.60	
		16	7.00	
		17	3.50	
Portland, OR	7	1	4.60	3.47
		2	4.80	
		3	1.30	
		4	3.20	
		5	3.30	
		6	0.60	
		7	5.00	
		8	5.40	
		9	2.10	
		10	1.00	
		11	7.40	
		12	2.10	
		13	3.90	
		14	3.70	
		15	1.30	
		16	1.40	
		17	2.30	
		18	1.30	
		19	2.10	
		20	1.60	
		21	5.60	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
		22	1.90	
		23	2.20	
		24	7.60	
		25	9.40	
		26	0.20	
		27	4.00	
		28	8.50	
		29	4.20	
		30	2.30	
		31	2.60	
		32	6.10	
		33	2.50	
		34	2.40	
Portland, OR	8	1	1.70	2.76
		2	0.40	
		3	2.70	
		4	3.20	
		5	4.60	
		6	5.00	
		7	2.20	
		8	2.30	
		9	2.70	
Portland, OR	9	1	2.20	3.21
		2	3.30	
		3	3.30	
		4	1.90	
		5	3.60	
		6	5.30	
		7	0.90	
		8	3.10	
		9	4.80	
		10	2.90	
		11	9.60	
		12	1.00	
		13	4.50	
		14	0.30	
		15	3.40	
		16	3.10	
		17	3.50	
		18	4.00	
		19	2.60	
		20	0.80	
Portland, OR	10	1	1.30	5.12
		2	5.60	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
		3	6.20	
		4	6.50	
		5	1.20	
		6	6.30	
		7	7.30	
		8	7.00	
		9	5.30	
		10	4.50	
Memphis, TN	1	1	3.20	6.46
		2	5.20	
		3	2.60	
		4	10.20	
		5	11.10	
		6	13.00	
		7	9.80	
		8	1.70	
		9	1.30	
Memphis, TN	2	1	5.20	5.10
		2	5.10	
		3	2.20	
		4	9.90	
		5	3.10	
Memphis, TN	3	1	2.40	5.29
		2	4.60	
		3	5.30	
		4	2.70	
		5	2.90	
		6	17.30	
		7	4.90	
		8	11.50	
		9	0.90	
		10	3.00	
		11	2.90	
		12	3.50	
		13	8.70	
		14	6.20	
		15	3.10	
		16	6.80	
		17	3.30	
Memphis, TN	4	1	1.70	6.33
		2	2.30	
		3	11.10	
		4	1.00	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
		5	2.60	
		6	9.70	
		7	15.90	
Memphis, TN	5	1	0.80	4.78
		2	3.70	
		3	2.40	
		4	11.70	
		5	0.40	
		6	2.10	
		7	5.30	
		8	3.20	
		9	2.10	
		10	5.40	
		11	13.70	
		12	3.30	
		13	1.50	
		14	11.20	
		15	6.60	
		16	0.30	
		17	2.90	
		18	11.90	
		19	2.80	
		20	4.20	
Memphis, TN	6	1	3.00	4.13
		2	3.20	
		3	9.30	
		4	2.90	
		5	3.10	
		6	3.30	
Memphis, TN	7	1	1.10	7.45
		2	3.20	
		3	0.20	
		4	0.60	
		5	0.60	
		6	4.90	
		7	5.40	
		8	7.30	
		9	36.50	
		10	0.70	
		11	21.30	
		12	4.10	
		13	4.50	
		14	7.50	
		15	12.00	

Table A1: (Continued)

Destination	Trip #	Drop Event #	Drop Height (inches)	Average (inches)
		16	9.30	
Memphis, TN	8	1	3.00	6.41
		2	6.50	
		3	7.70	
		4	1.40	
		5	2.90	
		6	4.60	
		7	9.10	
		8	18.90	
		9	12.00	
		10	2.50	
		11	1.60	
		12	7.70	
		13	8.30	
		14	3.50	
Memphis, TN	9	1	5.30	9.04
		2	3.30	
		3	3.60	
		4	3.90	
		5	8.90	
		6	21.70	
		7	14.40	
		8	5.40	
		9	3.40	
		10	10.60	
		11	2.60	
		12	4.60	
		13	10.40	
		14	21.50	
		15	16.00	
Memphis, TN	10	1	16.50	7.19
		2	0.50	
		3	10.10	
		4	2.00	
		5	3.20	
		6	20.50	
		7	5.20	
		8	0.70	
		9	11.80	
		10	8.90	
		11	3.90	
		12	3.00	

APPENDIX A

Table A2: Individual Kick Events in Overnight Small Parcel Environment of UPS and Federal Express

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
Monterey, CA	1	1	32	66.75
		2	75	
		3	58	
		4	69	
		5	70	
		6	36	
		7	30	
		8	51	
		9	59	
		10	96	
		11	127	
		12	98	
Monterey, CA	2	1	48	78.58
		2	88	
		3	114	
		4	61	
		5	47	
		6	71	
		7	139	
		8	63	
		9	39	
		10	114	
		11	92	
		12	67	
Monterey, CA	3	1	57	76.74
		2	59	
		3	87	
		4	64	
		5	57	
		6	48	
		7	85	
		8	96	
		9	127	
		10	122	
		11	180	
		12	113	
		13	32	
		14	35	
		15	30	
		16	38	
		17	75	
		18	85	
		19	106	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		20	38	
		21	79	
		22	67	
		23	85	
Monterey, CA	4	1	61	74.33
		2	90	
		3	35	
		4	108	
		5	113	
		6	45	
		7	99	
		8	110	
		9	46	
		10	65	
		11	85	
		12	46	
		13	70	
		14	41	
		15	101	
Monterey, CA	5	1	70	70.16
		2	74	
		3	47	
		4	62	
		5	61	
		6	66	
		7	62	
		8	110	
		9	114	
		10	142	
		11	43	
		12	73	
		13	50	
		14	50	
		15	88	
		16	46	
		17	53	
		18	73	
		19	65	
		20	72	
		21	74	
		22	44	
		23	73	
		24	81	
		25	61	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
Monterey, CA	6	1	94	86.13
		2	130	
		3	66	
		4	61	
		5	74	
		6	62	
		7	73	
		8	120	
		9	135	
		10	108	
		11	96	
		12	104	
		13	55	
		14	115	
		15	69	
		16	91	
		17	69	
		18	100	
		19	68	
		20	89	
		21	60	
		22	116	
		23	63	
		24	49	
Monterey, CA	7	1	49	74.07
		2	58	
		3	39	
		4	40	
		5	105	
		6	61	
		7	72	
		8	59	
		9	83	
		10	107	
		11	54	
		12	86	
		13	79	
		14	126	
		15	88	
		16	85	
		17	80	
		18	93	
		19	76	
		20	48	
		21	92	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		22	49	
		23	57	
		24	101	
		25	72	
		26	61	
		27	71	
		28	48	
		29	114	
		30	69	
Monterey, CA	8	1	98	92.78
		2	84	
		3	56	
		4	147	
		5	143	
		6	135	
		7	97	
		8	53	
		9	117	
		10	82	
		11	58	
		12	58	
		13	75	
		14	59	
		15	77	
		16	42	
		17	155	
		18	134	
Monterey, CA	9	1	67	79.63
		2	109	
		3	49	
		4	94	
		5	45	
		6	32	
		7	116	
		8	71	
		9	71	
		10	60	
		11	49	
		12	125	
		13	65	
		14	89	
		15	146	
		16	86	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
Monterey, CA	10	1	67	80.76
		2	89	
		3	116	
		4	47	
		5	82	
		6	73	
		7	40	
		8	97	
		9	71	
		10	98	
		11	153	
		12	91	
		13	74	
		14	59	
		15	43	
		16	134	
		17	39	
Atlanta, GA	1	1	81	82.80
		2	67	
		3	138	
		4	81	
		5	71	
		6	90	
		7	115	
		8	101	
		9	77	
		10	79	
		11	86	
		12	30	
		13	100	
		14	79	
		15	62	
		16	73	
		17	74	
		18	65	
		19	69	
		20	118	
Atlanta, GA	2	1	42	82.71
		2	61	
		3	66	
		4	113	
		5	121	
		6	128	
		7	48	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
Atlanta, GA	3	1	103	117.93
		2	136	
		3	164	
		4	70	
		5	105	
		6	111	
		7	93	
		8	206	
		9	145	
		10	94	
		11	165	
		12	101	
		13	117	
		14	41	
Atlanta, GA	4	1	60	80.50
		2	88	
		3	73	
		4	57	
		5	60	
		6	59	
		7	103	
		8	76	
		9	74	
		10	179	
		11	71	
		12	136	
		13	40	
		14	64	
		15	59	
		16	44	
		17	51	
		18	67	
		19	57	
		20	53	
		21	82	
		22	92	
		23	121	
		24	93	
		25	162	
		26	72	
Atlanta, GA	5	1	87	79.05
		2	63	
		3	55	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		4	133	
		5	60	
		6	77	
		7	80	
		8	46	
		9	64	
		10	61	
		11	133	
		12	51	
		13	123	
		14	100	
		15	97	
		16	75	
		17	42	
		18	96	
		19	59	
Atlanta, GA	6	1	96	106.64
		2	36	
		3	110	
		4	107	
		5	211	
		6	69	
		7	158	
		8	60	
		9	141	
		10	108	
		11	77	
Atlanta, GA	7	1	70	83.70
		2	64	
		3	107	
		4	63	
		5	67	
		6	132	
		7	88	
		8	63	
		9	81	
		10	160	
		11	85	
		12	50	
		13	80	
		14	172	
		15	52	
		16	72	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		17	87	
		18	63	
		19	41	
		20	77	
Atlanta, GA	8	1	134	104.24
		2	73	
		3	73	
		4	65	
		5	95	
		6	180	
		7	112	
		8	57	
		9	108	
		10	127	
		11	73	
		12	159	
		13	109	
		14	126	
		15	52	
		16	157	
		17	72	
Atlanta, GA	9	1	88	84.70
		2	54	
		3	72	
		4	63	
		5	130	
		6	61	
		7	87	
		8	146	
		9	93	
		10	53	
		11	177	
		12	10	
		13	98	
		14	41	
		15	64	
		16	59	
		17	54	
		18	113	
		19	106	
		20	125	
Atlanta, GA	10	1	103	94.68
		2	52	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		3	130	
		4	99	
		5	105	
		6	90	
		7	90	
		8	71	
		9	167	
		10	105	
		11	69	
		12	113	
		13	194	
		14	90	
		15	86	
		16	80	
		17	44	
		18	139	
		19	64	
		20	57	
		21	82	
		22	128	
		23	50	
		24	52	
		25	107	
Rochester, NY	1	1	71	78.81
		2	77	
		3	53	
		4	72	
		5	33	
		6	89	
		7	60	
		8	133	
		9	63	
		10	46	
		11	97	
		12	62	
		13	86	
		14	44	
		15	155	
		16	120	
Rochester, NY	2	1	114	70.23
		2	51	
		3	39	
		4	55	
		5	43	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		6	97	
		7	46	
		8	96	
		9	123	
		10	58	
		11	67	
		12	59	
		13	90	
		14	62	
		15	69	
		16	69	
		17	149	
		18	63	
		19	59	
		20	48	
		21	33	
		22	55	
Rochester, NY	3	1	91	74.65
		2	90	
		3	112	
		4	62	
		5	71	
		6	71	
		7	87	
		8	51	
		9	72	
		10	94	
		11	55	
		12	84	
		13	62	
		14	42	
		15	67	
		16	93	
		17	65	
Rochester, NY	4	1	18	80.95
		2	136	
		3	108	
		4	134	
		5	70	
		6	49	
		7	74	
		8	58	
		9	85	
		10	82	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		11	84	
		12	52	
		13	67	
		14	64	
		15	125	
		16	42	
		17	107	
		18	85	
		19	98	
Rochester, NY	5	1	53	68.16
		2	69	
		3	52	
		4	44	
		5	42	
		6	73	
		7	121	
		8	67	
		9	54	
		10	49	
		11	32	
		12	30	
		13	70	
		14	97	
		15	78	
		16	76	
		17	125	
		18	92	
		19	69	
		20	31	
		21	53	
		22	130	
		23	79	
		24	46	
		25	72	
Rochester, NY	6	1	94	68.23
		2	89	
		3	67	
		4	76	
		5	63	
		6	106	
		7	70	
		8	59	
		9	37	
		10	70	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		11	58	
		12	69	
		13	50	
		14	19	
		15	56	
		16	28	
		17	33	
		18	57	
		19	62	
		20	69	
		21	116	
		22	124	
		23	46	
		24	52	
		25	153	
		26	51	
Rochester, NY	7	1	120	67.68
		2	40	
		3	74	
		4	47	
		5	58	
		6	43	
		7	72	
		8	94	
		9	116	
		10	44	
		11	34	
		12	72	
		13	76	
		14	46	
		15	38	
		16	87	
		17	74	
		18	87	
		19	35	
		20	62	
		21	123	
		22	128	
		23	41	
		24	80	
		25	56	
		26	55	
		27	59	
		28	34	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
Rochester, NY	8	1	94	64.20
		2	71	
		3	98	
		4	45	
		5	82	
		6	39	
		7	67	
		8	79	
		9	48	
		10	109	
		11	97	
		12	62	
		13	69	
		14	14	
		15	49	
		16	49	
		17	72	
		18	55	
		19	59	
		20	42	
		21	51	
		22	50	
		23	45	
		24	50	
		25	109	
Rochester, NY	9	1	41	75.29
		2	90	
		3	114	
		4	64	
		5	86	
		6	56	
		7	71	
		8	94	
		9	60	
		10	64	
		11	62	
		12	79	
		13	116	
		14	103	
		15	94	
		16	141	
		17	16	
		18	74	
		19	56	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		20	38	
		21	64	
		22	63	
		23	127	
		24	34	
Rochester, NY	10	1	89	71.36
		2	101	
		3	73	
		4	93	
		5	64	
		6	42	
		7	53	
		8	75	
		9	72	
		10	56	
		11	125	
		12	62	
		13	111	
		14	110	
		15	67	
		16	101	
		17	59	
		18	71	
		19	47	
		20	48	
		21	41	
		22	81	
		23	24	
		24	92	
		25	27	
Portland, OR	1	1	70	85.76
		2	75	
		3	79	
		4	86	
		5	81	
		6	69	
		7	62	
		8	89	
		9	44	
		10	65	
		11	62	
		12	80	
		13	44	
		14	80	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		15	100	
		16	81	
		17	93	
		18	128	
		19	119	
		20	129	
		21	82	
		22	74	
		23	64	
		24	105	
		25	70	
		26	120	
		27	114	
		28	80	
		29	142	
Portland, OR	2	1	56	79.17
		2	138	
		3	74	
		4	47	
		5	70	
		6	61	
		7	62	
		8	90	
		9	102	
		10	83	
		11	16	
		12	85	
		13	71	
		14	121	
		15	46	
		16	86	
		17	78	
		18	139	
Portland, OR	3	1	66	71.95
		2	46	
		3	72	
		4	76	
		5	37	
		6	38	
		7	44	
		8	41	
		9	77	
		10	100	
		11	121	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		12	62	
		13	52	
		14	72	
		15	79	
		16	81	
		17	108	
		18	50	
		19	83	
		20	119	
		21	87	
Portland, OR	4	1	93	81.25
		2	122	
		3	34	
		4	81	
		5	81	
		6	78	
		7	65	
		8	64	
		9	116	
		10	97	
		11	64	
		12	51	
		13	108	
		14	115	
		15	59	
		16	70	
		17	109	
		18	81	
		19	54	
		20	83	
Portland, OR	5	1	52	79.59
		2	70	
		3	40	
		4	92	
		5	88	
		6	47	
		7	74	
		8	80	
		9	108	
		10	79	
		11	90	
		12	32	
		13	40	
		14	44	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		15	119	
		16	68	
		17	106	
		18	38	
		19	65	
		20	87	
		21	90	
		22	116	
		23	86	
		24	126	
		25	106	
		26	85	
		27	121	
Portland, OR	6	1	143	63.95
		2	17	
		3	64	
		4	77	
		5	123	
		6	56	
		7	46	
		8	62	
		9	26	
		10	34	
		11	44	
		12	63	
		13	52	
		14	58	
		15	86	
		16	36	
		17	45	
		18	108	
		19	57	
		20	65	
		21	81	
Portland, OR	7	1	53	68.09
		2	43	
		3	61	
		4	83	
		5	70	
		6	63	
		7	42	
		8	90	
		9	45	
		10	61	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		11	52	
		12	45	
		13	45	
		14	36	
		15	122	
		16	99	
		17	141	
		18	58	
		19	62	
		20	115	
		21	64	
		22	48	
Portland, OR	8	1	52	82.52
		2	125	
		3	42	
		4	90	
		5	42	
		6	77	
		7	224	
		8	52	
		9	71	
		10	67	
		11	53	
		12	60	
		13	48	
		14	61	
		15	69	
		16	159	
		17	53	
		18	110	
		19	70	
		20	84	
		21	73	
		22	48	
		23	69	
		24	74	
		25	95	
		26	90	
		27	198	
		28	65	
		29	71	
		30	50	
		31	116	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
Portland, OR	9	1	72	76.91
		2	117	
		3	122	
		4	43	
		5	53	
		6	91	
		7	33	
		8	97	
		9	78	
		10	217	
		11	77	
		12	31	
		13	52	
		14	39	
		15	77	
		16	81	
		17	60	
		18	36	
		19	73	
		20	42	
		21	108	
		22	76	
		23	57	
		24	111	
		25	90	
		26	49	
		27	77	
		28	91	
		29	47	
		30	157	
		31	44	
		32	63	
Portland, OR	10	1	33	68.32
		2	133	
		3	62	
		4	85	
		5	47	
		6	49	
		7	50	
		8	62	
		9	57	
		10	112	
		11	23	
		12	88	
		13	57	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		14	114	
		15	47	
		16	106	
		17	52	
		18	54	
		19	67	
Memphis, TN	1	1	59	87.42
		2	8	
		3	56	
		4	144	
		5	31	
		6	79	
		7	114	
		8	73	
		9	94	
		10	72	
		11	101	
		12	59	
		13	137	
		14	63	
		15	22	
		16	140	
		17	68	
		18	153	
		19	127	
		20	92	
		21	77	
		22	108	
		23	120	
		24	101	
Memphis, TN	2	1	69	65.90
		2	36	
		3	71	
		4	40	
		5	71	
		6	45	
		7	65	
		8	51	
		9	138	
		10	73	
Memphis, TN	3	1	46	72.95
		2	58	
		3	46	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		4	30	
		5	64	
		6	117	
		7	34	
		8	45	
		9	67	
		10	58	
		11	95	
		12	71	
		13	69	
		14	71	
		15	53	
		16	56	
		17	58	
		18	146	
		19	87	
		20	142	
		21	126	
		22	66	
Memphis, TN	4	1	89	73.75
		2	88	
		3	58	
		4	12	
		5	142	
		6	73	
		7	98	
		8	50	
		9	73	
		10	98	
		11	45	
		12	59	
Memphis, TN	5	1	52	67.68
		2	49	
		3	47	
		4	90	
		5	87	
		6	81	
		7	65	
		8	45	
		9	70	
		10	55	
		11	38	
		12	131	
		13	28	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		14	50	
		15	59	
		16	42	
		17	57	
		18	90	
		19	92	
		20	71	
		21	85	
		22	105	
Memphis, TN	6	1	72	108.42
		2	57	
		3	114	
		4	110	
		5	140	
		6	132	
		7	111	
		8	43	
		9	59	
		10	106	
		11	124	
		12	233	
Memphis, TN	7	1	40	67.37
		2	99	
		3	29	
		4	79	
		5	65	
		6	58	
		7	58	
		8	72	
		9	53	
		10	38	
		11	55	
		12	54	
		13	70	
		14	67	
		15	109	
		16	46	
		17	38	
		18	54	
		19	104	
		20	55	
		21	77	
		22	87	
		23	68	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		24	91	
		25	107	
		26	54	
		27	75	
		28	57	
		29	68	
		30	94	
Memphis, TN	8	1	84	71.76
		2	67	
		3	28	
		4	53	
		5	54	
		6	50	
		7	52	
		8	65	
		9	78	
		10	80	
		11	44	
		12	120	
		13	49	
		14	117	
		15	34	
		16	94	
		17	52	
		18	67	
		19	59	
		20	33	
		21	58	
		22	162	
		23	163	
		24	62	
		25	69	
Memphis, TN	9	1	33	85.70
		2	54	
		3	34	
		4	95	
		5	46	
		6	64	
		7	116	
		8	128	
		9	55	
		10	151	
		11	139	
		12	92	

Table A2: (Continued)

Destination	Trip No.	Kick Event No.	Vel. Change (in./sec)	Average (in./sec)
		13	46	
		14	133	
		15	63	
		16	79	
		17	63	
		18	127	
		19	43	
		20	164	
		21	70	
		22	92	
		23	84	
Memphis, TN	10	1	52	70.78
		2	86	
		3	107	
		4	48	
		5	75	
		6	104	
		7	61	
		8	70	
		9	64	
		10	94	
		11	32	
		12	63	
		13	30	
		14	57	
		15	28	
		16	184	
		17	13	
		18	44	
		19	50	
		20	71	
		21	35	
		22	83	
		23	87	
		24	93	
		25	93	
		26	106	
		27	81	

APPENDIX A

Table A3: Individual Toss Events in Overnight Small Parcel Environment of UPS and Federal Express

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
Monterey, CA	1	1	1.7	4.95
		2	1.8	
		3	2.4	
		4	2.7	
		5	4.1	
		6	4.3	
		7	7	
		8	15.6	
Monterey, CA	2	1	1.6	3.38
		2	2	
		3	2.8	
		4	4.1	
		5	6.4	
Monterey, CA	3	1	0.5	4.02
		2	1	
		3	1.9	
		4	2.3	
		5	2.4	
		6	2.9	
		7	3	
		8	3.5	
		9	4.3	
		10	4.8	
		11	5.3	
		12	5.9	
		13	7.5	
		14	11	
Monterey, CA	4	1	1.5	3.58
		2	1.6	
		3	2.2	
		4	2.2	
		5	3.3	
		6	3.4	
		7	3.9	
		8	4.1	
		9	4.5	
		10	4.6	
		11	5.2	
		12	6.5	

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
Monterey, CA	5	1	1.2	5.72
		2	2.9	
		3	3	
		4	3.2	
		5	3.3	
		6	4.5	
		7	5.2	
		8	6.9	
		9	7.4	
		10	9.8	
		11	10	
		12	11.2	
Monterey, CA	6	1	1.1	2.61
		2	1.2	
		3	1.4	
		4	1.5	
		5	1.7	
		6	1.8	
		7	2.1	
		8	3.6	
		9	4.3	
		10	4.4	
		11	5.6	
Monterey, CA	7	1	0.6	4.32
		2	0.9	
		3	1	
		4	1.5	
		5	1.6	
		6	1.6	
		7	1.7	
		8	3.4	
		9	3.9	
		10	4.4	
		11	4.8	
		12	5.2	
		13	6.6	
		14	8.9	
		15	9.4	
		16	13.6	
Monterey, CA	8	1	0.8	2.90
		2	1.2	
		3	1.9	
		4	2.4	
		5	2.9	

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
		6	3.8	
		7	4.5	
		8	5.7	
Monterey, CA	9	1	1	3.89
		2	1.2	
		3	1.3	
		4	1.5	
		5	1.6	
		6	1.6	
		7	1.7	
		8	2.2	
		9	2.6	
		10	2.8	
		11	3.1	
		12	3.5	
		13	4.3	
		14	8.2	
		15	8.8	
		16	16.8	
Monterey, CA	10	1	1.4	4.63
		2	1.7	
		3	1.8	
		4	2	
		5	2.4	
		6	3.1	
		7	3.2	
		8	3.3	
		9	4.1	
		10	4.3	
		11	13	
		12	15.2	
Atlanta, GA	1	1	3	5.33
		2	3.2	
		3	4.7	
		4	6.4	
		5	7	
		6	7.7	
Atlanta, GA	2	1	0.5	4.10
		2	4	
		3	7.8	
Atlanta, GA	3	1	0.9	3.79
		2	1.5	

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
		3	1.7	
		4	1.8	
		5	1.8	
		6	2.2	
		7	2.2	
		8	2.3	
		9	2.7	
		10	2.7	
		11	2.8	
		12	2.9	
		13	3	
		14	3.5	
		15	3.6	
		16	3.7	
		17	3.7	
		18	6.2	
		19	7.1	
		20	19.5	
Atlanta, GA	4	1	0.9	3.11
		2	1.2	
		3	1.4	
		4	1.4	
		5	1.5	
		6	1.9	
		7	2	
		8	2.1	
		9	2.8	
		10	3	
		11	6.5	
		12	7.5	
		13	8.2	
Atlanta, GA	5	1	1	3.77
		2	1.1	
		3	2	
		4	2	
		5	2.2	
		6	2.6	
		7	3	
		8	3.1	
		9	3.7	
		10	5.2	
		11	5.7	
		12	6.1	
		13	6.1	
		14	6.2	

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
		15	6.5	
Atlanta, GA	6	1	0.7	3.11
		2	1.7	
		3	1.8	
		4	2.3	
		5	3	
		6	3.6	
		7	8.7	
		8	11.6	
Atlanta, GA	7	1	1.4	5.06
		2	1.4	
		3	1.9	
		4	1.9	
		5	2.2	
		6	3.3	
		7	3.6	
		8	3.7	
		9	4.6	
		10	4.8	
		11	5.2	
		12	5.4	
		13	5.6	
		14	8.4	
		15	9.2	
		16	18.4	
Atlanta, GA	8	1	0.9	5.24
		2	1.5	
		3	1.8	
		4	2.1	
		5	2.2	
		6	2.6	
		7	2.8	
		8	3.4	
		9	3.4	
		10	4.2	
		11	5.8	
		12	5.9	
		13	6.6	
		14	13.1	
		15	13.6	
		16	14	
Atlanta, GA	9	1	1.4	4.99

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
		2	2.2	
		3	2.2	
		4	2.6	
		5	2.6	
		6	3.4	
		7	4.5	
		8	4.8	
		9	5	
		10	5.2	
		11	7.1	
		12	8.2	
		13	9.1	
		14	11.6	
Atlanta, GA	10	1	0.1	4.54
		2	0.5	
		3	1.5	
		4	1.7	
		5	1.8	
		6	1.9	
		7	2.8	
		8	3	
		9	3.2	
		10	3.9	
		11	4.1	
		12	4.8	
		13	5.7	
		14	7.2	
		15	7.4	
		16	23	
Rochester, NY	1	1	0.6	5.89
		2	2.3	
		3	2.5	
		4	2.6	
		5	2.6	
		6	3.6	
		7	3.8	
		8	4.1	
		9	4.5	
		10	5.6	
		11	6.1	
		12	16.7	
		13	21.6	

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
Rochester, NY	2	1	1.3	3.12
		2	1.9	
		3	2.3	
		4	2.3	
		5	2.6	
		6	2.7	
		7	2.8	
		8	3.4	
		9	4.4	
		10	7.5	
Rochester, NY	3	1	0.1	5.41
		2	0.6	
		3	1.1	
		4	1.3	
		5	1.7	
		6	2.8	
		7	3.4	
		8	3.5	
		9	3.9	
		10	5.5	
		11	6.5	
		12	11	
		13	11.3	
		14	13.9	
		15	14.6	
Rochester, NY	4	1	1	2.01
		2	1.3	
		3	1.7	
		4	1.7	
		5	1.8	
		6	2	
		7	2.1	
		8	4.5	
Rochester, NY	5	1	1	4.21
		2	2.3	
		3	3	
		4	3.2	
		5	4.6	
		6	4.7	
		7	10.7	
Rochester, NY	6	1	1	3.35
		2	1.3	
		3	2	

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
		4	2.4	
		5	2.6	
		6	2.9	
		7	3.7	
		8	4.1	
		9	6.6	
		10	6.9	
Rochester, NY	7	1	0.6	3.39
		2	0.8	
		3	1.1	
		4	1.5	
		5	1.5	
		6	1.7	
		7	2.2	
		8	2.7	
		9	2.8	
		10	3.5	
		11	3.6	
		12	3.8	
		13	6	
		14	15.6	
Rochester, NY	8	1	1.1	3.97
		2	1.5	
		3	1.6	
		4	1.9	
		5	2.6	
		6	2.9	
		7	3	
		8	3.2	
		9	3.8	
		10	4.6	
		11	4.8	
		12	9.7	
		13	10.9	
Rochester, NY	9	1	0.4	3.39
		2	1.1	
		3	1.5	
		4	1.6	
		5	1.6	
		6	1.7	
		7	1.7	
		8	1.8	
		9	3.1	

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
		10	3.3	
		11	3.6	
		12	4.4	
		13	4.9	
		14	6.1	
		15	14	
Rochester, NY	10	1	0.9	3.36
		2	2	
		3	2.7	
		4	3.8	
		5	3.9	
		6	4	
		7	4.7	
		8	4.9	
Portland, OR	1	1	1.7	4.24
		2	2.2	
		3	2.9	
		4	7.1	
		5	7.3	
Portland, OR	2	1	0.2	5.40
		2	2.4	
		3	4	
		4	4.5	
		5	6.3	
		6	7	
		7	7.3	
		8	7.7	
		9	9.2	
Portland, OR	3	1	0.9	3.07
		2	0.9	
		3	0.9	
		4	1.3	
		5	1.5	
		6	1.5	
		7	1.6	
		8	1.7	
		9	1.9	
		10	1.9	
		11	2.0	
		12	2.1	
		13	2.4	
		14	2.8	
		15	3.0	

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
		16	3.1	
		17	3.1	
		18	5.0	
		19	6.0	
		20	17.8	
Portland, OR	4	1	1.3	3.93
		2	1.7	
		3	1.7	
		4	1.9	
		5	2	
		6	2.2	
		7	3.4	
		8	3.5	
		9	5.1	
		10	5.6	
		11	5.8	
		12	8.3	
		13	11.9	
		14	0.6	
Portland, OR	5	1	0.7	3.39
		2	0.8	
		3	0.9	
		4	1.0	
		5	1.5	
		6	1.7	
		7	1.8	
		8	2.5	
		9	4.1	
		10	6.1	
		11	6.6	
		12	7.2	
		13	9.2	
Portland, OR	6	1	1.7	4.95
		2	2.2	
		3	2.5	
		4	4	
		5	4.1	
		6	4.5	
		7	9.9	
		8	10.7	
Portland, OR	7	1	0.4	3.58
		2	0.7	
		3	0.7	

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
		4	0.9	
		5	1.2	
		6	2.0	
		7	2.1	
		8	2.5	
		9	3.1	
		10	3.4	
		11	3.5	
		12	4.6	
		13	4.7	
		14	5.1	
		15	6.1	
		16	9.3	
		17	10.5	
Portland, OR	8	1	1.8	4.77
		2	2	
		3	2.3	
		4	4.3	
		5	4.7	
		6	5	
		7	5.1	
		8	8.1	
		9	9.6	
Portland, OR	9	1	0.2	1.86
		2	0.7	
		3	0.7	
		4	1.1	
		5	1.3	
		6	1.4	
		7	1.4	
		8	1.6	
		9	1.9	
		10	2.2	
		11	2.5	
		12	2.9	
		13	3.0	
		14	5.2	
Portland, OR	10	1	0.8	4.41
		2	1.6	
		3	1.7	
		4	2.1	
		5	2.1	
		6	2.6	
		7	3.5	

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
		8	3.6	
		9	4.5	
		10	4.9	
		11	6.2	
		12	10.1	
		13	13.6	
Memphis, TN	1	1	1.2	5.87
		2	1.4	
		3	1.7	
		4	1.7	
		5	2.1	
		6	2.1	
		7	2.2	
		8	2.5	
		9	3	
		10	3.9	
		11	7.7	
		12	11.9	
		13	13.4	
		14	16.1	
		15	17.1	
Memphis, TN	2	1	2.4	4.90
		2	4.8	
		3	7.5	
Memphis, TN	3	1	0.3	3.26
		2	0.7	
		3	1	
		4	1.1	
		5	1.3	
		6	1.3	
		7	1.6	
		8	1.7	
		9	2.1	
		10	2.2	
		11	2.5	
		12	2.6	
		13	2.7	
		14	2.8	
		15	3	
		16	3	
		17	4.9	
		18	7.9	
		19	10.9	
		20	11.6	

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
Memphis, TN	4	1	0.7	2.90
		2	1.3	
		3	1.4	
		4	1.9	
		5	1.9	
		6	2.2	
		7	2.6	
		8	6.8	
		9	7.3	
Memphis, TN	5	1	0.6	1.85
		2	0.6	
		3	1	
		4	1.1	
		5	1.1	
		6	1.2	
		7	1.3	
		8	1.3	
		9	1.4	
		10	1.5	
		11	1.6	
		12	2	
		13	2.2	
		14	2.7	
		15	2.9	
		16	3.3	
		17	5.7	
Memphis, TN	6	1	1.3	4.57
		2	1.5	
		3	1.9	
		4	3.7	
		5	5.1	
		6	9.2	
		7	9.3	
Memphis, TN	7	1	0.3	3.52
		2	0.5	
		3	1	
		4	1.5	
		5	1.6	
		6	1.7	
		7	2	
		8	2	
		9	2.7	
		10	2.8	

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
		11	3.3	
		12	4.3	
		13	4.3	
		14	5	
		15	5.5	
		16	5.7	
		17	15.7	
Memphis, TN	8	1	1.1	3.33
		2	1.2	
		3	1.2	
		4	1.4	
		5	1.5	
		6	1.6	
		7	1.9	
		8	2.7	
		9	3.1	
		10	3.2	
		11	3.5	
		12	4	
		13	5	
		14	7.8	
		15	10.8	
Memphis, TN	9	1	0.8	2.01
		2	0.8	
		3	1.3	
		4	1.4	
		5	1.6	
		6	1.7	
		7	2.2	
		8	2.5	
		9	2.9	
		10	3.3	
		11	3.6	
Memphis, TN	10	1	1.1	3.90
		2	1.6	
		3	2	
		4	2.4	
		5	2.5	
		6	2.8	
		7	3.1	
		8	3.3	
		9	3.3	
		10	3.7	
		11	4.2	

Table A3: (Continued)

Destination	Trip No.	Toss Event No.	Eq. Drop Height (in.)	Average (in.)
		12	4.7	
		13	4.7	
		14	5.2	
		15	5.8	
		16	7	
		17	8.9	