1997

A Study of package drops in global distribution environment

Donald Appleton

A STUDY OF PACKAGE DROPS IN A GLOBAL DISTRIBUTION ENVIRONMENT

By

Donald J. Appleton

A Thesis

Submitted to the

Department of Packaging Science

College of Applied Science and Technology

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE

Rochester Institute of Technology

1997

Department of Packaging Science
College of Applied Science and Technology
Rochester Institute of Technology
Rochester, New York

CERTIFICATE OF APPROVAL

M. S. DEGREE THESIS

The M.S. degree thesis of Donald J. Appleton
has been examined and approved
by the thesis committee as satisfactory
for the thesis requirements for the
Master of Science Degree

Thomas L. Howath

Stephen B. Buice

John M. Fin

July 21,1997

COPY RELEASE

A STUDY OF PACKAGE DROPS IN A GLOBAL DISTRIBUTION ENVIRONMENT

I, Donald J. Appleton, hereby grant permission to the Wallace Memorial Library of RIT to reproduce this thesis in whole or in part. Any reproduction will not be for commercial use or profit.

July 21, 1997

ACKNOWLEDGMENTS

First and foremost, I would like to thank Thomas L. Horvath and Stephen R. Pierce MS., from Eastman Kodak Company for their encouragement and support of me throughout this study, as well as the entire graduate program. Steve, through his continued long-term passion for Packaging Science, served to spark my interest in enrollment and completion of the program. Tom has given me unwavering support and worked very hard behind the scenes to enable this opportunity to happen.

I would also like to thank Steve for use of his data recording devices and wealth of knowledge and global contacts, without which this study would not have been possible.

I want to express my gratitude to John Siy for his participation on my committee and his support and encouragement over the years.

I would like to thank Mark E. Brooks from the PEGD test laboratory for his work on test fixture fabrication, test shipment execution, and event sorting.

I want to express my appreciation to Merilee Ritter, MS. from Eastman Kodak Company for her statistical analysis of the data collected.

I also want to thank Melissa Mannion for helping me navigate through Microsoft Word® Version 6.

I would like to thank Dr. Harold J. (Pete) Raphael for his work in establishing the Packaging Science program at RIT. In addition, I would like to thank him for convincing me, in 1980, to pursue a carrier in Packaging Science.

Finally, last but certainly not least, I would like to thank my parents Ralph E. and Jean S. Appleton for a lifetime of love, support and encouragement.

DEDICATION

This thesis is dedicated to my family: Kathy, Teddy, and Kelly Appleton, who have had to put up with numerous sacrifices while I have pursued this goal. Without their love, support, understanding, and compromises, I would not have been able to succeed.

A STUDY OF PACKAGE DROPS IN A GLOBAL DISTRIBUTION ENVIRONMENT

By

Donald J. Appleton

ABSTRACT

The focus of this study was to compile and interpret drop heights and drop frequencies data for small parcel packages moving through the Eastman Kodak Company global distribution network. The need for this study arose from the inclusion of drop height probability curves into Kodak's shipping tests for packaged product weighing less than 100 lb. Kodak packaging engineers suspected the drop heights included in the probability curves were too high in drop height and too many in frequency when compared to the actual distribution environment. The data for this study resulted from dozens of test shipments using dummy-load packages throughout the Kodak global distribution network. The test shipments were conducted in the United States, Europe, and Australia. The test packages were equipped with a drop-height recording device called a SAVER® to record when a drop occurred and from what height the package was dropped. Data from the recorder was downloaded, "real" events were sorted out from events that were not true drops. Once sorting was completed, the "real" data was analyzed utilizing various statistical techniques. The results of the analysis led to the development of data-derived statistical test plans based on the actual field-measured data. The results of this experiment, when compared to the probability curve currently in use, show that the drop heights outlined in the probability curve are too high and too many are called for. This experiment will serve as the basis for new shipping tests based on actual field measurements. The field data indicates that the current test may have led to overtesting and overpackaging of our products. These findings identify an opportunity for waste reduction as well as an overall reduction in expenditure for packaging.

CONTENTS

1.0 INTRODUCTION

BUSINESS CLIMATE

In the business environment of the 90s, pressures on cost control and continuous improvement are greater than ever. These two areas have been identified as fertile ground to improve corporate earnings. Companies must do more with less, and what was "World Class" yesterday is barely acceptable today.

The area of package engineering has not escaped the influx of these new pressures. The optimum package is no longer the lofty goal of a corporation. It is now the demand of every new program. The package has to do all of the traditional functions which packages have always performed (contain, protect, identify, sell), but now it must execute these functions at lower unit costs and with more environmentally-friendly material than ever before.

Package development costs are also under scrutiny. Package development cycle times must be reduced to improve project development costs. Moreover, package development cycles have become compressed to match much shorter product development cycle times. The packaging engineer no longer enjoys the luxury of going through numerous design iterations on the way to an effective packaging solution.

Although not as prevalent as in the early 90s, the packaging professional is still faced with building environmental responsibility into packaging solutions. The gray area between environmental reality and perception rages on. There is, however, little debate that source reduction/waste avoidance is, both in reality and perception, an effective environmental design approach. Representative (not excessive) shipping tests allow the packaging engineer to design a package using the minimum amount of materials.

Reducing the percentage of product delivered damaged has also been identified as an area to improve costs. A continuous balance must be considered between using less packaging (higher risk of damage) and reducing damage rates (higher use/cost of packaging). The ideal package solution employs all of the inherent ruggedness of the product, plus just enough packaging protection to equal the forces and hazards of the distribution environment.

There are obvious, and-not-so obvious, costs of delivering damaged goods to a customer. From the point damage is incurred, all time and money spent on design, development, manufacturing and distribution expenditures for the damaged product are lost. Additional costs are required for distribution (for return shipment) and replacement and/or repair of the damaged product. Some not so obvious costs are customer dissatisfaction, channel partner dissatisfaction, loss of brand equity, and potential loss of future product sales.

SHIPPING TEST PROCEDURE OPTIONS

The packaging professional has an influence on cost reduction and product damage rate by conducting the correct and effective shipping tests on the package design. Typically, package designs must successfully pass a shipping test towards the end of development, which serves as a verification of the package design integrity.

There are several philosophies on what defines a "correct and effective" shipping test. The philosophies can be broken down into three broad categories: Integrity Testing, General Simulation and Focused Simulation[1].

An Integrity Test procedure determines whether or not the product plus package is strong enough to withstand test conditions that are viewed as representative of generic distribution hazards. In an Integrity Test, the packaging engineer needs to know little or nothing about the specific shipping environment the package will travel through. The packaging engineer relies on organizations like International Safe Transit Association (ISTA) to develop a test procedure that effectively challenges the product plus package system to ensure damage-free receipt of the product. These types of tests do not represent

---

[1] **Dennis Young, "Strategic Transport Packaging Performance: Linking Product and Package Evaluation to Corporate Objectives", IOPP Transpack '95.**

real (measured) occurrences derived from field data. Generally, this type of testing is very conservative, leading to low damage rates at the expense of higher packaging costs. This type of test procedure has been used for many years and is generally used by companies which may not have the resources for field data measurement. In addition, it is a good test procedure to use if knowledge is limited as to the particulars of how a company's product gets to its customers.

A General Simulation Test procedure is derived from actual field data, which is sorted and blended to represent the worst combination of conditions. The field data, however, is not necessarily from "your" distribution environment. A vibration spectrum from environment 'A' and shock input from environment 'B' are blended together to create a test procedure, which tends to be on the conservative side. ASTM D-4169 is an example of a General Simulation Test. This test is divided into three assurance levels to give some flexibility to test intensity. Although not as conservative as Integrity Testing, if the correct assurance level is not used, General Simulation may lead to higher than needed packaging costs. Any given company's environment may never be as severe as the "worst of the worst." These types of tests are used by companies which know how their products are shipped, but may not have the time and resources required to conduct a field measurement study.

A Focused Simulation Test procedure is derived from one particular company's actual field data. On-board shock recorders, like the SAVER® from Lansmont Corporation, make it possible for companies to measure their own specific shipping environment(s).

Measuring devices like the SAVER®, weighing in at 2.2 lb. and whose dimensions are 5" x 3" x 2", are capable of recording "on board" measurements of the numerous forces which act upon a package as it passes through the distribution environment. Among the attributes measured are shock, vibration, temperature, and time. Once measured, the data may be used as the basis for a truly representative laboratory shipping test. The theory of utilizing Focused Simulation is that the measured field data will allow packaging engineers to know the shipping environment in great detail. This technique yields quantitative data on the nature of hazards. This "real" data will allow for creation of a representative shipping test for a specific environment, leading to optimum package designs. The downside to Focused Simulation use is the capital and time expenditure required to conduct a study of this type. Among other costs, a data measuring and recording device must be procured, a closed loop for outbound and return trips must be established, and shipping charges must be paid. Another major cost involves downloading, sorting, and interpreting data. Once that is completed statistical analysis of the data must take place. Clearly, Focused Simulation is not for everyone.

An experienced packaging engineer may make a reasonable judgment as to field performance when evaluation of packages damaged from the field are compared to similar type packages yielding similar results from the test laboratory. This type of prediction based on an engineer's evaluation does have a certain degree of risk. However, is significantly more cost effective then a full scale field study.

The true measure of how well a shipping test performs is to compare tested package results with "real" field data. Damage is defined as when the stresses of handling exceed the strength of the package plus product. Monitoring the performance of packages in the field is extremely important as no shipping test can absolutely, fully reproduce field conditions. An accurate measure of field damage may require developing a damage reporting process and active monitoring dozens of shipments. Damage rates that are based on a passive process of customer complaints and claims for damage may be very low when compared to the actual damage rate.[2]

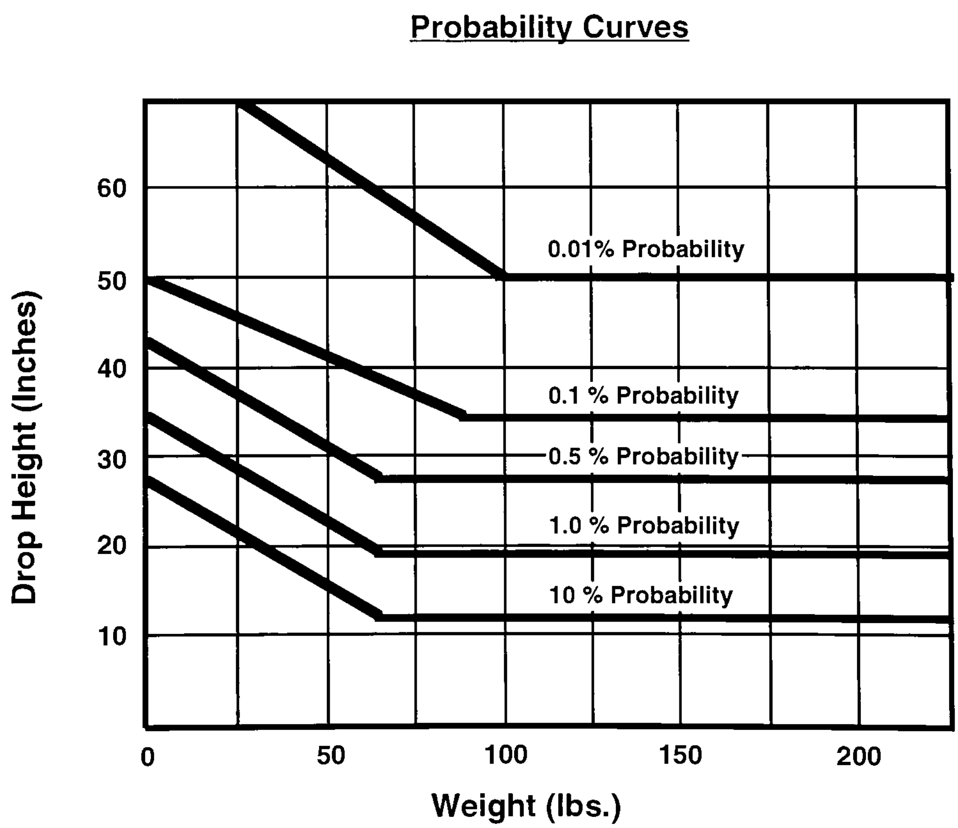
---

[2] **Sheehan, Richard "Predicting Field Performance from Laboratory Testing" Current Trends in Protective Packaging of Computers pp. 43, 44.**

REASON FOR STUDY

Generally, shipping tests are comprised of two major components. Vibration, used to simulate input from transportation hazards (truck, plane, train, ship) and Shock, used to simulate input from handling hazards (drops, kicks, other impacts). The focus of this study is on the shock portion (Drop Test) of the Eastman Kodak Company shipping test for small parcel products shipped in a variety of distribution environments. The shock (drop) measurements will be recorded by a data recording device in the form of equivalent drop heights. This study was selected as a topic because of the introduction of the "Probability Curves for Handling Shocks"[3] (shown below) into the TS 211 shipping test used by Kodak for packaged product under 100 pounds.

probability curves



[3] Richard K. Brandeburg, Ph.D., Julian June-Ling Lee, Ph.D., Fundamentals of Packaging Dynamics p.106 (MTS Systems).

Although the introduction of this curve was done with the best intentions, no data was ever introduced serving as a link between Kodak's distribution environment and the probability curve. Moreover, skepticism increased as efforts directed towards the curves' publisher have failed to yield any hard data used as a basis for the curve. This problem is confounded by the fact that the curve is at least 12 years old and responsible parties have long since moved on. One questions how such a curve could be developed when considering the technology available to measure distribution environments prior to 1985. In fact, the authors state, "Unfortunately, very little is known about the drop heights and shock levels encountered in distribution, except that every distribution system has a unique and complex profile."[4]

This study will serve as a foundation for a truly representative drop test portion of Kodak's small parcel shipping test. The shipping test will be created to reproduce the dynamics which were directly measured in the field. A reality check of a good test procedure is the ability to reproduce damage observed in the field by running a shipping test in the laboratory. If that "reality check" is not met, then the validity of their shipping test must be questioned. Once a good shipping test is created, a connection can be made as to the appropriate type and amount of packaging materials needed to protect the product.[5]

STUDY ASSUMPTIONS:

1) Hypothesis: The "Probability Curves for Handling Shocks" used in the Kodak Shipping Tests are representative of our shipping environment.

2) Measurement of the selected shipping environments will yield data representative of Kodak's global distribution environment.

---

[4] **Richard K. Brandeburg, Ph.D., Julian June-Ling Lee, Ph.D., Fundamentals of Packaging Dynamics (MTS Systems Corporation, 1985), p. 103.**

[5] **Sheehan, Richard "The Connection with Materials and Component Specifications", IOPP Transpack '97.**

3) Future lab and field verification testing and shipments will be required for absolute verification of the data.

STUDY OBJECTIVES:

1) In the context of Focused Simulation, drop heights and drop frequencies that small parcel packages are subjected to in distribution environment of Eastman Kodak Company will be measured and recorded.

2) Through statistical data analysis, regional differences in the distribution environment and/or package weight influence on drop height and frequency will be determined. A determination will be made as to whether these influences are significant enough to justify multiple test procedures.

3) Through statistical data analysis, data will be sorted to offer assurance levels (low, medium, high) which will lend flexibility to the test procedure in matching program/product requirements.

4) Data will be used as verification of the current probability curve or as a foundation for a more representative test procedure utilizing more accurate, data-derived, drop heights and frequencies measured in the field study.

2.0 LITERATURE REVIEW

The concept of conducting drop tests on completed package design is not new and there is considerable literature written about the subject. A literature search reveals some interesting explanations regarding the rationale for shipping tests and correlation to real world events.

DEFINITION OF DISTRIBUTION ENVIRONMENT

It is important to understand that the distribution network is defined from the point the packaged product leaves the manufacturing location to the point at which the customer unpacks the product. Products, which are moved by hand (manually), have the potential to be dropped at any point within the distribution network. Manual handling creates an opportunity for free fall drops from a range of heights and frequencies. Parcel delivery services move and handle very large numbers of packages every day, thus creating the potential for drops that transfer shocks to the package. The shock to the package, caused by a sudden high rate of deceleration, is transferred to the product inside the package. This is when damage to the product may happen.

SIGNIFICANCE OF DROP HEIGHT

Generally, the natural height to carry packaged products as they move through distribution is waist high. Another influence on drop heights are belt systems and conveyors used to move parcel packages quickly throughout the distribution environment. These observations suggest that process, rather than weight, may play a critical roll in influencing from how high a package is dropped.

The shock (drop) aspect of distribution hazards creates the need for the packaging professional to have a representative and repeatable drop test to confirm package/cushion designs and to verify any product and/or package design changes. It is widely believed that the shock input hazard creates the greatest potential for damage to the packaged product.[6]

LINKAGE TO REAL WORLD EVENTS

Observations have lead to the conclusion that packages are almost never dropped in such a way so the package impacts a surface completely flat. This is caused by several reasons, such as center of gravity and the way the package is released or falls. This characteristic becomes very important both from a data interpretation and test development standpoint. A truly flat drop represents a more severe shock to the product than does an edge or corner drop, which are more typical of the real world. Although pure flat drops do not typically take place, due to their reproducibility in a laboratory situation, they serve as a useful element in a shipping test. Moreover, because of their "worst case" nature, they build in a safety factor into shipping tests.

"Real world" drops are typically random in nature, dictating that the product must be protected equally on all faces, as well as comers and edges. "Real world" drops may also occur onto a variety of different types of surfaces. These not only include typical floors and truck beds, but also other packages for example, which may greatly influence the rate of deceleration and velocity change values. Again, it is important to remember these two characteristics are the components of product damage. The peak acceleration (G level) is not the only element of damage. The shape of the shock pulse (trapezoidal, sinusoidal, etc.) and the shock duration are important elements of product damage. A trapezoidal pulse is more severe than a sinusoidal pulse given the same peak G level and duration. This is due to an increased "area under the curve" or velocity change.

From a practical standpoint (with some exceptions e.g. military packaging) the packaging system cannot be expected to protect the product against disastrous, extremely

[6] **Hewlett Packard Homepage: http://www.corp.hp.com/publish/talkpkg/testing/section3.htm.**

rare events. Designing to such a high level of protection would certainly lead to excessive costs and packaging materials used.[7]

---

[7] **Hewlett Packard Homepage.**

3.0 TEST MATERIALS AND METHODS

MATERIALS

Measuring Device

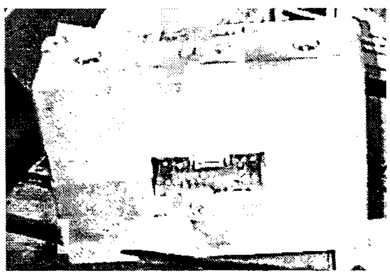
An electronic data measuring and recording device is often used to gather information about shock, vibration, humidity and other factors in the distribution environment. For this study, the SAVER® by Lansmont Corporation was utilized as the in-package measuring device. Several data recorders were used during the course of the study. All devices were calibrated at the start of the study and checked at the beginning and end of each trip to confirm. The SAVER® was utilized for the study not only for its small size (5" x 3" x 2") and weight (2.2 lb.), which minimizes detection in the test packages, but also because of its ability to measure and record a significant amount of data (several megabytes) over a long period of time (or several weeks).

Each recorder used for this study contains a tri-axial accelerometer, which enables it to measure amplitude and direction of an event. In addition, it is able to measure when a zero-G condition occurs, which is a characteristic of a drop. Once events are determined to be "real," the software bundled with the SAVER® has the ability to determine the release height of the package as well as impact velocity.

Test Packages

The test packages containing "dummy loads" were intended to and designed to look like ordinary product. The reasoning behind this was so that the packages would move through the distribution stream as normally as possible, therefore receiving more representative treatment and recording more representative data.

One package weighed 10 lb and had dimensions of approximately 12" x 6" x 10". This size and weight is typical of a number of Kodak packages, both for chemical products and small equipment products.



The package did not contain product, containing instead an appropriately-sized wooden block with a hollowed out center section in which data recorder was placed. The wooden block was sized such that several inches of foam could be placed around the wooden block to protect the data recorder from excessive shock, which may have cause damage to the data recorder. The foam does not affect the ability of the data recorder to accurately record drop heights. This was confirmed in the laboratory prior to any of the study shipments.

A second package weighed 55 lb and measured 10" x 10" x 10", representative of photochemical product.

The final package weighed 35 lb and had dimensions of approximately 12" x 12" x 16", representative of a case of Kodak Ektacolor Royal paper.

As with the other test packages, this test package did not contain product. It also contained an appropriately sized wooden block with a hollowed out center section in which a data recorder was placed. The wooden block and data recorder were placed into a corrugated carton complete with Kodak Ektacolor Royal paper trade dress.

METHODS

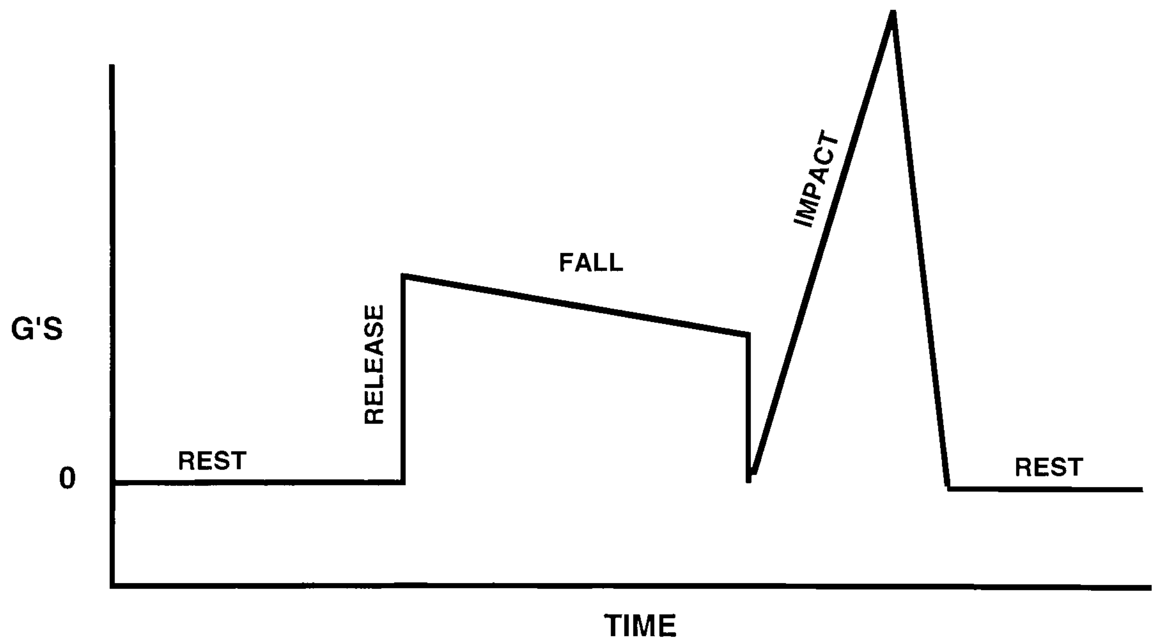
Data Collection

All of the test units were calibrated by the manufacturer at the beginning of this experiment. The calibrations were confirmed in our laboratory as a safeguard check, and were periodically checked throughout the course of this experiment. If discrepancies in calibration were discovered, the data recorder in question was taken out of service and sent to back to the manufacturer for repair and/or re-calibration.

At the start of every trip, the battery in each data recorder was fully charged, the unit turned on, and carefully placed into the dummy load package. Each test package, was subjected to a flat bottom "check drop" from a known height at the beginning of its journey. Upon arrival at its destination, the package was once again subjected to a flat bottom check drop, from the same height as the first drop, before the package was turned around to begin a return trip. Upon arrival back at the lab, the test package was subjected to the final flat bottom drop, again at the same height as the initial "check drop", before the data recorder was downloaded and the unit shut off.

The check drops were easy to recognize because of their well-formed drop signature and common drop height (Figure 1).

Figure 1



The check drops served several very important functions during our study:

• The check drops served as markers that defined each trip. A trip was defined as *either* an outbound or return leg of a round trip.

• The check drops served as confirmation that the recorder was working throughout the trip. Unfortunately, on several trips, the recorders were not functioning continuously. This problem was identified quickly through use of the check drop process.

• The check drops served as confirmation that the recorders were in correct calibration both at the beginning and the end of each trip.

Routes Measured

Our customer base is becoming more global all the time, so it was decided the data collection method should be planned to reflect this characteristic. For this study, the Kodak distribution network was divided up into three major regions: the United States, Europe, and Australia. These regions were chosen because they represent the areas where the majority of our products are distributed and effective contacts in those areas helped manage test package receipt and shipment.

The mode of transportation measured within this study was truck transportation.

The United States was subdivided into Less-than-Truckload (LTL) and small parcel categories to more accurately reflect the way our products are shipped. The domestic small parcel data was gathered from shipments that all began in Rochester, NY and were shipped to various locations throughout the United States. The LTL shipments within the United States began in Rochester, NY and were shipped to Dallas, TX and Whitier, CA.

The European data was collected from shipments between Central Distribution Centers (CDCs) in the European region. The CDCs are located in Chalon, France; Harrow, England; and Stuttgart, Germany.

The Australian data was collected from shipments made between Melbourne and Sydney via LTL. In addition, local deliveries within metropolitan Melboume were also included in the data collected.[8]

The data was downloaded using the SAVER® software upon return to Kodak's Package Engineering and Graphic Design (PEDG) test lab at Kodak Rochester, NY. Once downloaded, the data was sorted to determine which events were real and which were not. Using the signature check drop pulse (Figure 1) as a guide, a PEGD technician was trained

---

[8] **Stephen R. Pierce, MS., personal communications.**

on what to look for to determine whether or not the event was caused by a real drop or not. Typically, for a variety of reasons, the majority of events measured were determined to be caused by something other than a drop and therefore, not included. For consistency of interpretation, the same technician was used to sort the data from all of the trips.

4.0 RESULTS AND DISCUSSION

An Analysis of Variance (ANOVA) was used throughout this study to identify and isolate characteristics affecting drop height and frequency. For the three different package weights included in our study, there was no evidence to substantiate package weight having a strong correlation with drop height. The data derived from the different package weights, up to 55 lb., appeared to be from the same data population.

It was determined using ANOVA however, that each sub environment or "process" had a strong influence on both drop height and drop frequency. The term "process" means the method by which the packages were handled. This finding is logical due to the fact that each sub-environment utilized different tools to distribute and move packages. Tools such as trucks, belt/conveyer belt heights, loading techniques, and level of personnel training vary significantly from one sub-environment to the next.[9] These conditions have a major affect on identifying data populations.

For this reason, the data for this study is divided into four categories: Domestic (USA) Parcel, LTL (USA), Australia, and Europe. The method of transportation in both Australia and Europe was LTL. For simplicity, the headings for Australia and Europe data will not reflect this, however.

What follows on the next several pages is a compilation, summary, and statistical summary of all of the data measured in our experiment.

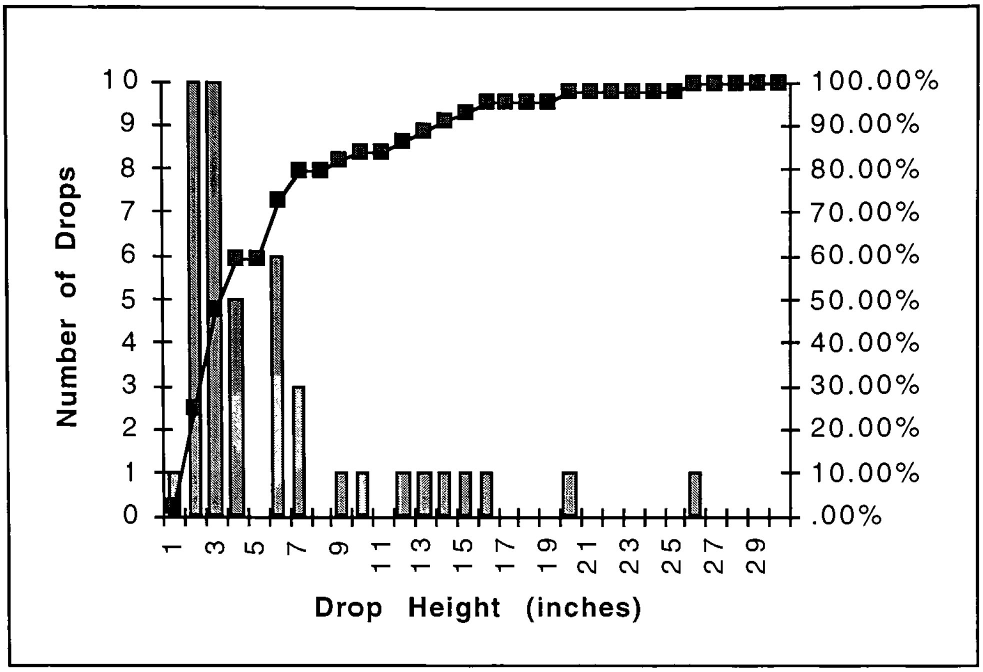
[9] **Merrilee Ritter, MS., personal communications.**

EUROPEAN DROP HEIGHT DATA SUMMARY, HISTOGRAM, STATISTICS

The following is the summary of the European drop height data:

Drop Height (inches)	Frequency (drops)	Cumulative %
1	1	2.27%
2	10	25.00%
3	10	47.73%
4	5	59.09%
5	0	59.09%
6	6	72.73%
7	3	79.55%
8	0	79.55%
9	1	81.82%
10	1	84.09%
11	0	84.09%
12	1	86.36%
13	1	88.64%
14	1	90.91%
15	1	93.18%
16	1	95.45%
17	0	95.45%
18	0	95.45%
19	0	95.45%
20	1	97.73%
21	0	97.73%
22	0	97.73%
23	0	97.73%
24	0	97.73%
25	0	97.73%
26	1	100.00%
27	0	100.00%
28	0	100.00%
29	0	100.00%
More	0	100.00%

The following is a Histogram of the European Drop Heights:



The following is a statistical summary of the European drop heights:

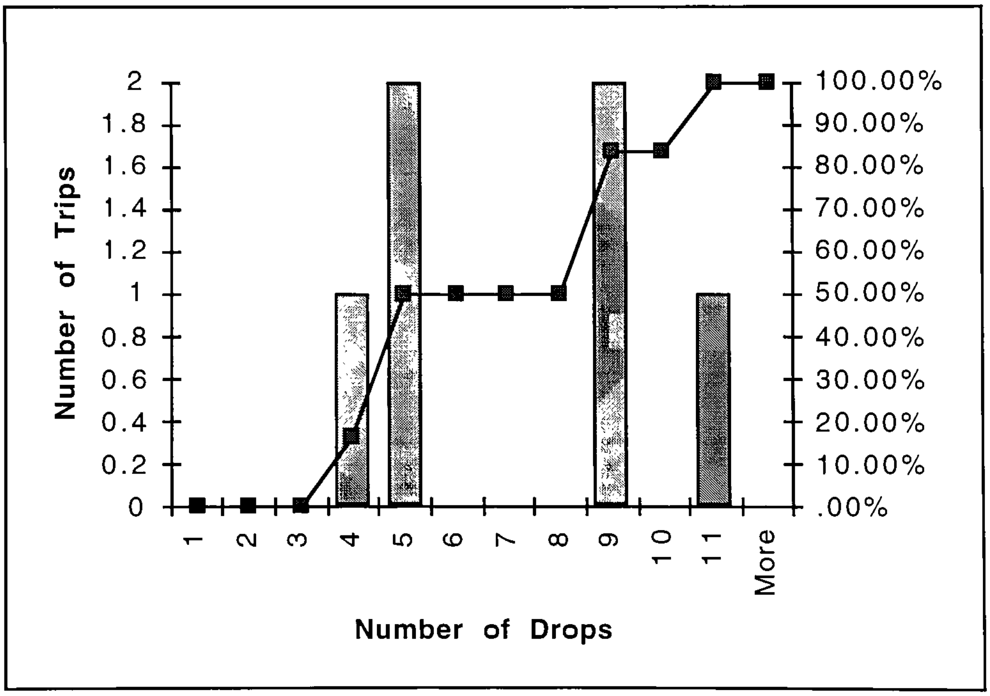
Mean (inches)	5.448864
Median (inches)	3.28
Mode (inches)	2.51
Standard Deviation (inches)	5.420728
Range (inches)	24.41
Minimum (inches)	0.77
Maximum (inches)	25.18
Count (drops)	44

EUROPEAN DROPS PER TRIP DATA SUMMARY, HISTOGRAM AND STATISTICS

The following is the summary of the European Drop per trip data:

Drops/Trip	Frequency (trips)	Cumulative %
1	0	0.00%
2	0	0.00%
3	0	0.00%
4	1	16.67%
5	2	50.00%
6	0	50.00%
7	0	50.00%
8	0	50.00%
9	2	83.33%
10	0	83.33%
11	1	100.00%
More	0	100.00%

The following is a Histogram of the European Drops per trip:



The following is a statistical summary of the European drops per trip:

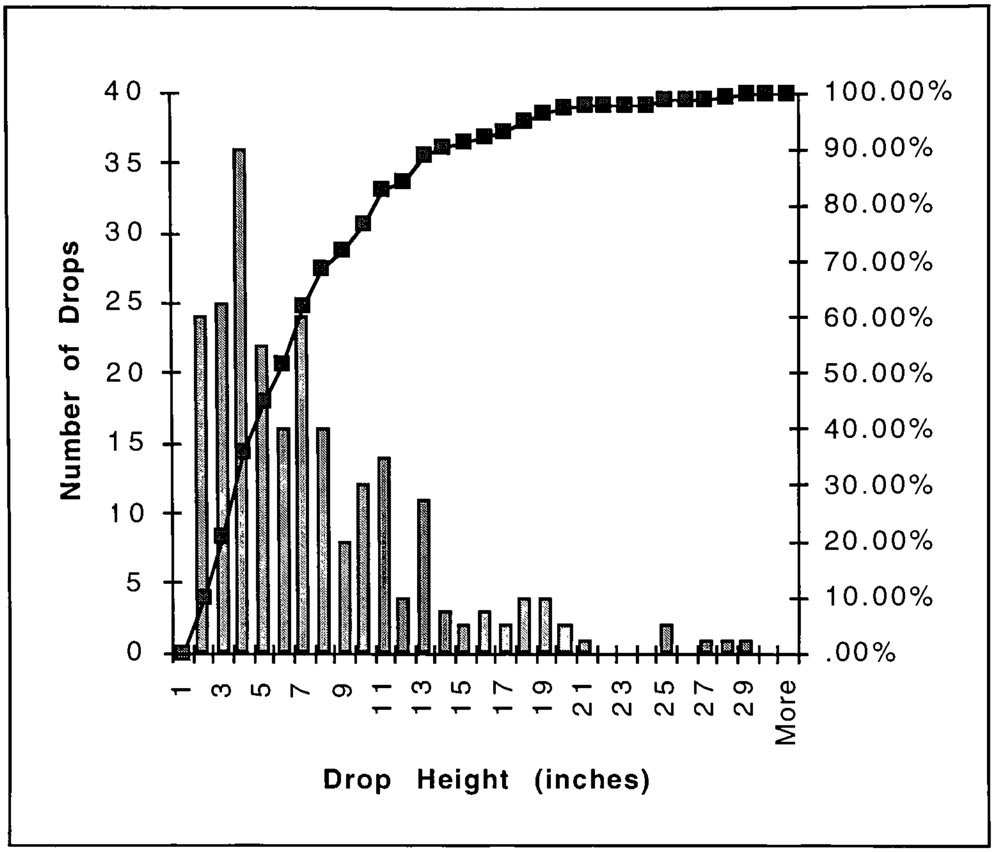
Mean (drops/trip)	7.166666667
Median (drops/trip)	7
Mode (drops/trip)	9
Standard Deviation (drops/trip)	2.857738033
Range (drops/trip)	7
Minimum (drops/trip)	4
Maximum (drops/trip)	11
Count (trips)	6

AUSTRALIAN DROP HEIGHT DATA SUMMARY, HISTOGRAM, STATISTICS

The following is the summary of the Australian Drop height data:

Drop Height (inches)	Frequency (drops)	Cumulative %
1	0	0.00%
2	24	10.08%
3	25	20.59%
4	36	35.71%
5	22	44.96%
6	16	51.68%
7	24	61.76%
8	16	68.49%
9	8	71.85%
10	12	76.89%
11	14	82.77%
12	4	84.45%
13	11	89.08%
14	3	90.34%
15	2	91.18%
16	3	92.44%
17	2	93.28%
18	4	94.96%
19	4	96.64%
20	2	97.48%
21	1	97.90%
22	0	97.90%
23	0	97.90%
24	0	97.90%
25	2	98.74%
26	0	98.74%
27	1	99.16%
28	1	99.58%
29	1	100.00%
30	0	100.00%
More	0	100.00%

The following is a Histogram of the Australian Drop Heights:



The following is a statistical summary of the Australian drop heights:

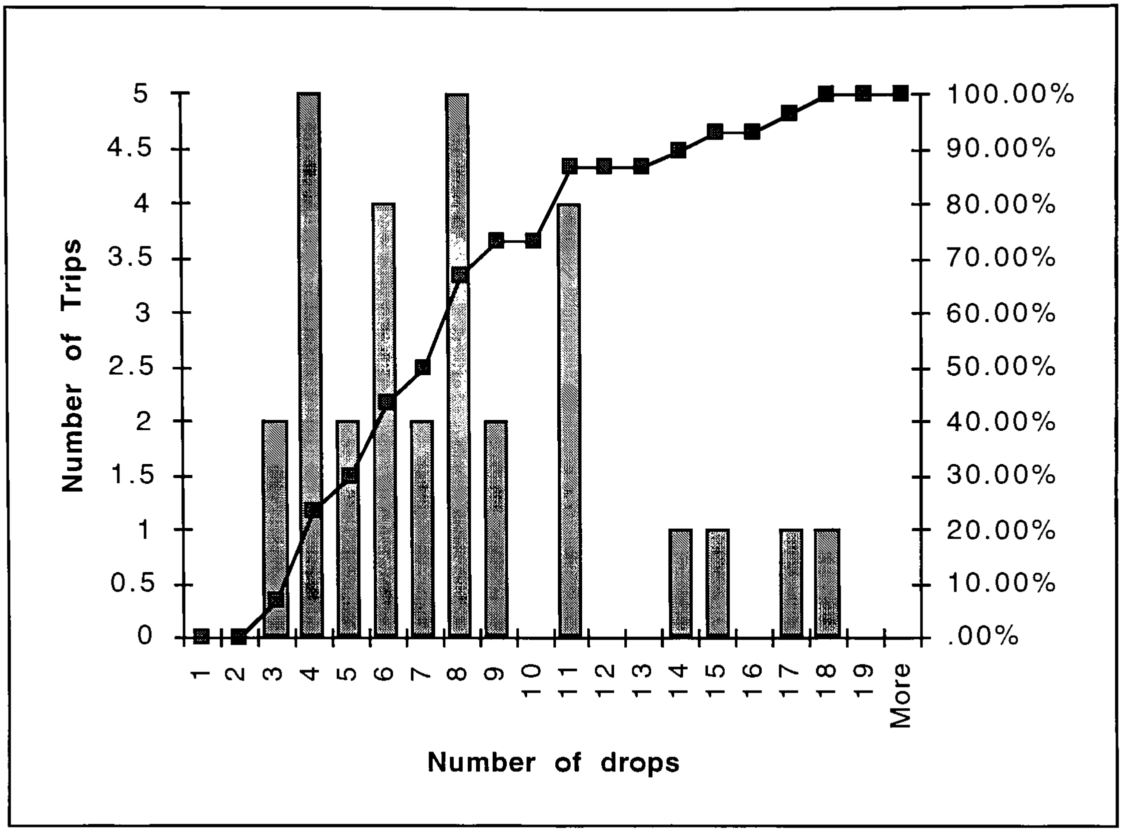
Mean (inches)	7.041806723
Median (inches)	5.685
Mode (inches)	6.05
Standard Deviation (inches)	5.24326875
Range (inches)	27.16
Minimum (inches)	1.03
Maximum (inches)	28.19
Count (drops)	238

AUSTRALIAN DROPS PER TRIP DATA SUMMARY, HISTOGRAM, AND STATISTICS

The following is the summary of the Australian Drop per trip data:

Drops/Trip	Frequency (trips)	Cumulative %
1	0	0.00%
2	0	0.00%
3	2	6.67%
4	5	23.33%
5	2	30.00%
6	4	43.33%
7	2	50.00%
8	5	66.67%
9	2	73.33%
10	0	73.33%
11	4	86.67%
12	0	86.67%
13	0	86.67%
14	1	90.00%
15	1	93.33%
16	0	93.33%
17	1	96.67%
18	1	100.00%
19	0	100.00%
More	0	100.00%

The following is a Histogram of the Australian drops per trip:



The following is a statistical summary of the Australian drops per trip:

Mean (drops per trip)	8
Median (drops per trip)	7.5
Mode (drops per trip)	8
Standard Deviation (drops per trip)	4.025778999
Range	15
Minimum (drops per trip)	3
Maximum (drops per trip)	18
Count (trips)	30

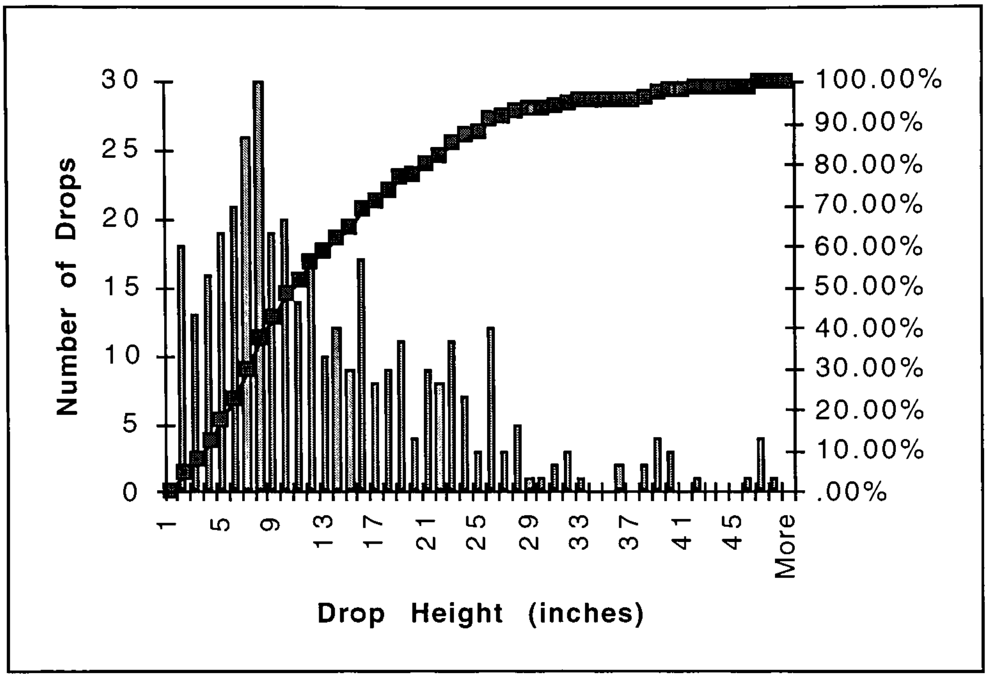
LESS THAN TRUCK LOAD (LTL) DROP HEIGHT DATA SUMMARY, HISTOGRAM, STATISTICS

The following is the summary of the Domestic (USA) Less Than Truckload (LTL) Drop height data:

Drop Height (inches)	Frequency (drops)	Cumulative %
1	0	0.00%
2	18	4.77%
3	13	8.22%
4	16	12.47%
5	19	17.51%
6	21	23.08%
7	26	29.97%
8	30	37.93%
9	19	42.97%
10	20	48.28%
11	14	51.99%
12	17	56.50%
13	10	59.15%
14	12	62.33%
15	9	64.72%
16	17	69.23%
17	8	71.35%
18	9	73.74%
19	11	76.66%
20	4	77.72%
21	9	80.11%
22	8	82.23%
23	11	85.15%
24	7	87.00%
25	3	87.80%
26	12	90.98%
27	3	91.78%
28	5	93.10%
29	1	93.37%
30	1	93.63%
31	2	94.16%
32	3	94.96%
33	1	95.23%
34	0	95.23%
35	0	95.23%
36	2	95.76%
37	0	95.76%
38	2	96.29%
39	4	97.35%
40	3	98.14%
41	0	98.14%
42	1	98.41%
43	0	98.41%
44	0	98.41%

45	0	98.41%
46	1	98.67%
47	4	99.73%
48	1	100.00%
More	0	100.00%

The following is a Histogram of the Less Than Truckload (LTL) Drop Heights:



The following is a statistical summary of the Less Than Truckload (LTL) drop heights:

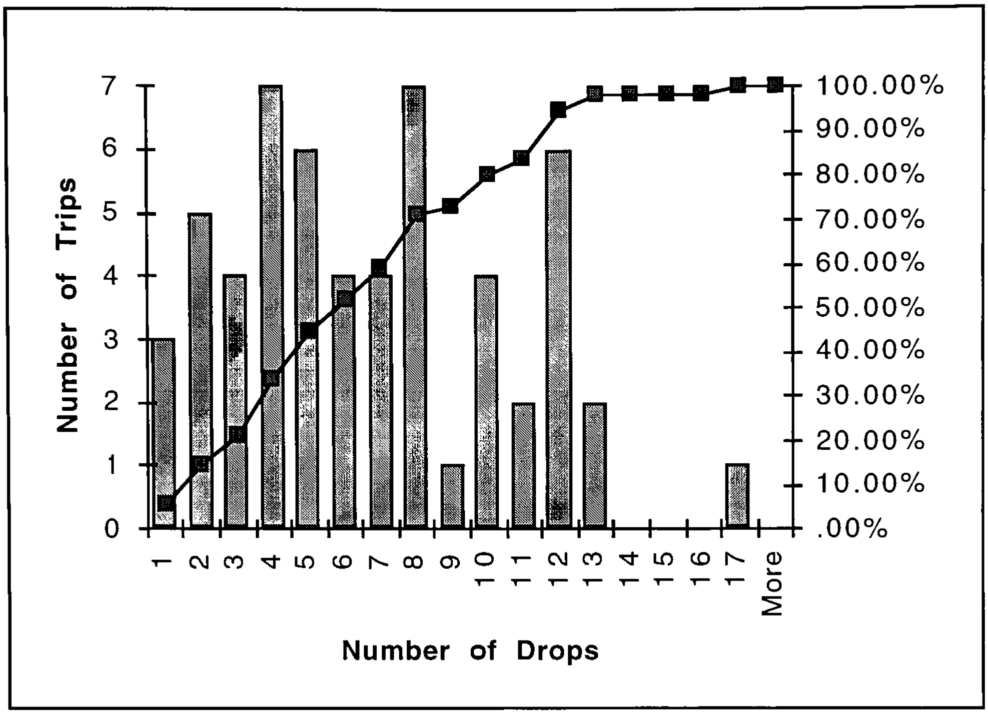
Mean (inches)	13.77984085
Median (inches)	11
Mode (inches)	8
Standard Deviation (inches)	9.6723898
Range (inches)	46
Minimum (inches)	2
Maximum (inches)	48
Count (drops)	377

LESS THAN TRUCKLOAD (LTL) DROPS PER TRIP DATA SUMMARY, HISTOGRAM, AND STATISTICS

The following is the summary of the Less Than Truckload (LTL) drops per trip data:

Drops/Trip	Frequency (trips)	Cumulative %
1	3	5.36%
2	5	14.29%
3	4	21.43%
4	7	33.93%
5	6	44.64%
6	4	51.79%
7	4	58.93%
8	7	71.43%
9	1	73.21%
10	4	80.36%
11	2	83.93%
12	6	94.64%
13	2	98.21%
14	0	98.21%
15	0	98.21%
16	0	98.21%
17	1	100.00%
More	0	100.00%

The following is a Histogram of the Less Than Truckload (LTL) drops per trip:



The following is a statistical summary of the Less Than Truckload (LTL) drops per trip:

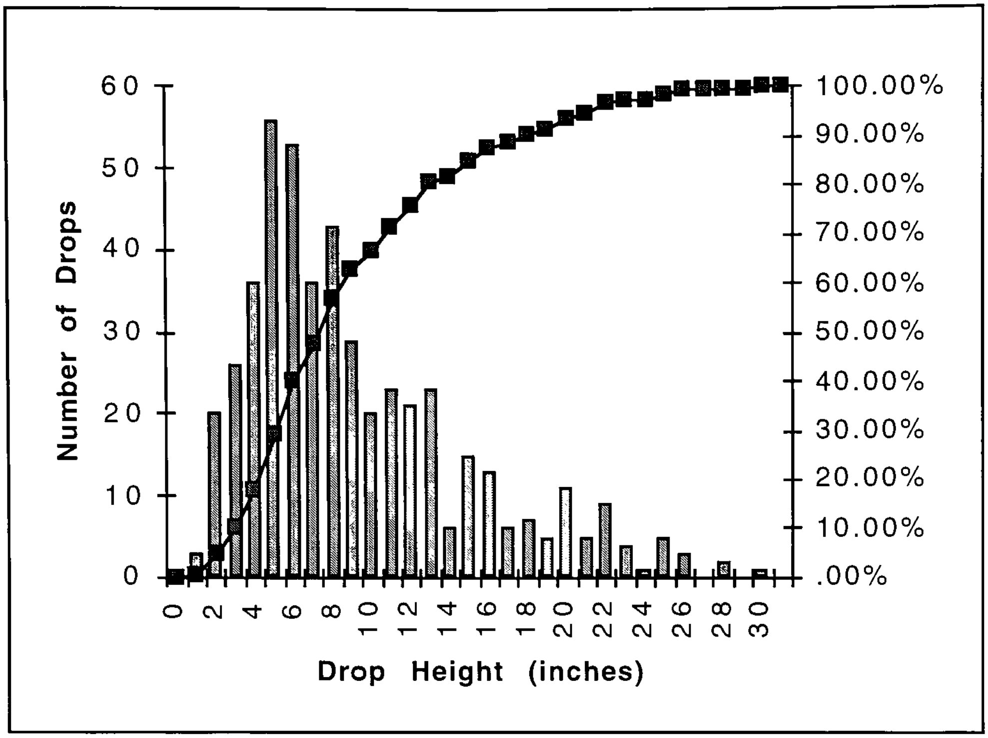
Mean (drops/trip)	6.732142857
Median (drops/trip)	6
Mode (drops/trip)	8
Standard Deviation (drops/trip)	3.777883349
Range (drops/trip)	16
Minimum (drops/trip)	1
Maximum (drops/trip)	17
Count (trips)	56

DOMESTIC PARCEL DROP HEIGHT DATA SUMMARY, HISTOGRAM, STATISTICS

The following is the summary of the domestic parcel drop height data:

Drop Height (inches)	Frequency (drops)	Cumulative %
0	0	0.00%
1	3	0.62%
2	20	4.77%
3	26	10.17%
4	36	17.63%
5	56	29.25%
6	53	40.25%
7	36	47.72%
8	43	56.64%
9	29	62.66%
10	20	66.80%
11	23	71.58%
12	21	75.93%
13	23	80.71%
14	6	81.95%
15	15	85.06%
16	13	87.76%
17	6	89.00%
18	7	90.46%
19	5	91.49%
20	11	93.78%
21	5	94.81%
22	9	96.68%
23	4	97.51%
24	1	97.72%
25	5	98.76%
26	3	99.38%
27	0	99.38%
28	2	99.79%
29	0	99.79%
30	1	100.00%
More	0	100.00%

The following is a Histogram of the domestic parcel drop height data:



The following is a statistical summary of the domestic parcel drop heights:

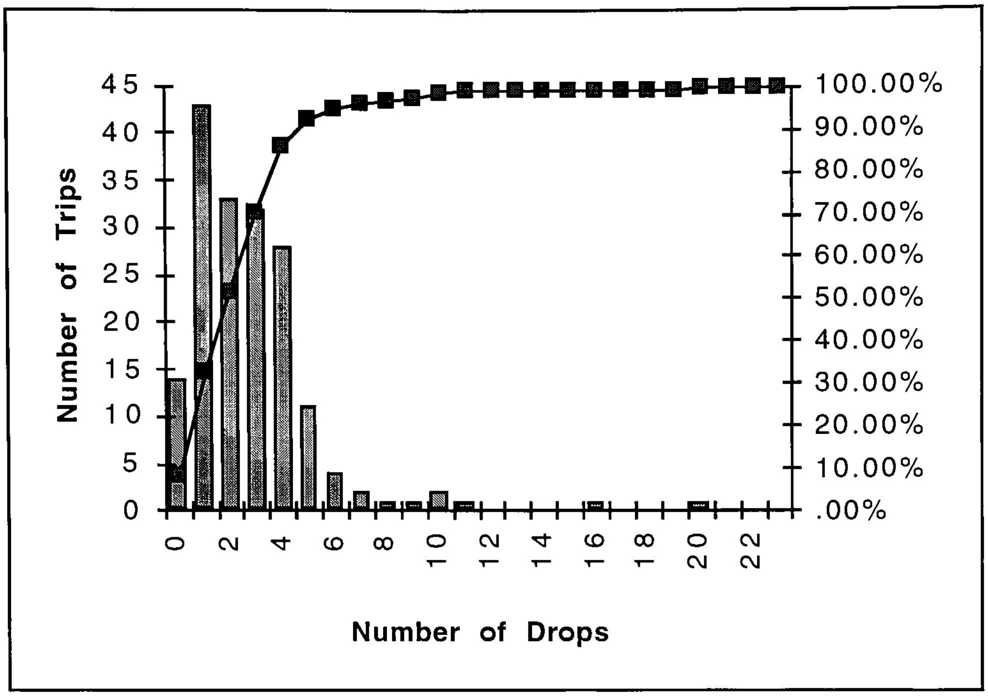
Mean (inches)	9.319502075
Median (inches)	8
Mode (inches)	5
Standard Deviation (inches)	5.741629844
Range (inches)	29
Minimum (inches)	1
Maximum (inches)	30
Count (drops)	482

DOMESTIC PARCEL DROPS PER TRIP DATA SUMMARY, HISTOGRAM, AND STATISTICS

The following is the summary of the domestic parcel drops per trip data:

Drops/Trip	Frequency (trips)	Cumulative %
0	14	8.05%
1	43	32.76%
2	33	51.72%
3	32	70.11%
4	28	86.21%
5	11	92.53%
6	4	94.83%
7	2	95.98%
8	1	96.55%
9	1	97.13%
10	2	98.28%
11	1	98.85%
12	0	98.85%
13	0	98.85%
14	0	98.85%
15	0	98.85%
16	1	99.43%
17	0	99.43%
18	0	99.43%
19	0	99.43%
20	1	100.00%
21	0	100.00%
22	0	100.00%
More	0	100.00%

The following is a Histogram of the domestic parcel drops per trip:



The following is a statistical summary of the domestic parcel drops per trip:

Mean (drops/trip)	2.83908046
Median (drops/trip)	2
Mode (drops/trip)	1
Standard Deviation (drops/trip)	2.575444575
Range (drops/trip)	20
Minimum (drops/trip)	0
Maximum (drops/trip)	20
Count (trips)	174

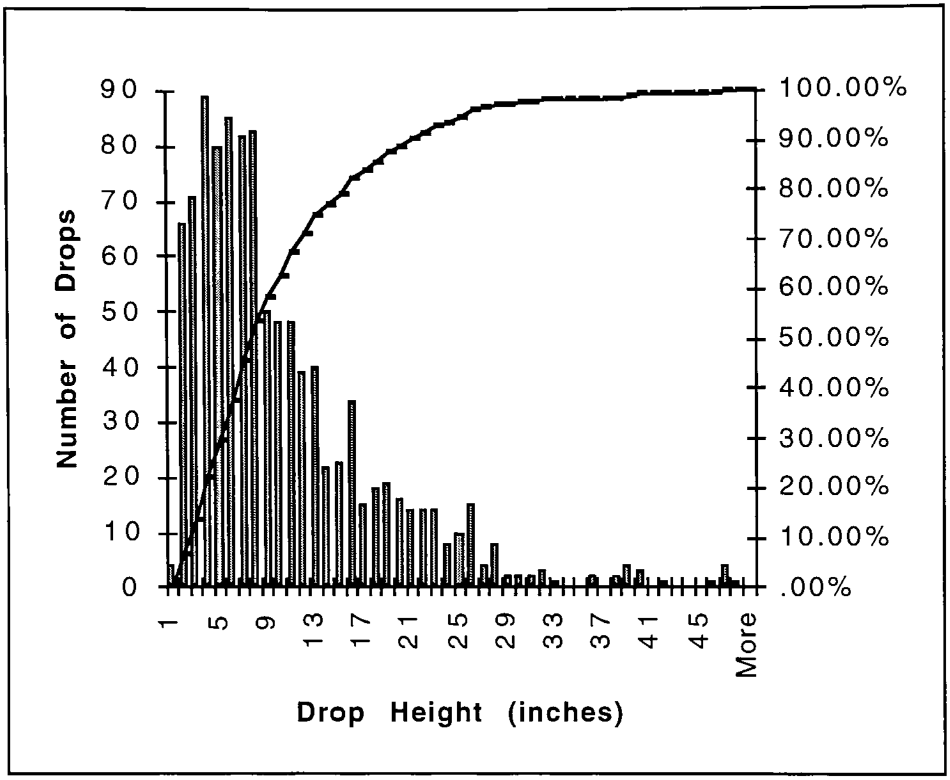
ALL DROP HEIGHT DATA SUMMARY, HISTOGRAM, STATISTICS

The following is the summary of all of the drop height data compiled from the four segments of the distribution environment:

Drop Height (inches)	Frequency (drops)	Cumulative %
1	4	0.38%
2	66	6.69%
3	71	13.47%
4	89	21.97%
5	80	29.61%
6	85	37.73%
7	82	45.56%
8	83	53.49%
9	50	58.26%
10	48	62.85%
11	48	67.43%
12	39	71.16%
13	40	74.98%
14	22	77.08%
15	23	79.27%
16	34	82.52%
17	15	83.95%
18	18	85.67%
19	19	87.49%
20	16	89.02%
21	14	90.35%
22	14	91.69%
23	14	93.03%
24	8	93.79%
25	10	94.75%
26	15	96.18%
27	4	96.56%
28	8	97.33%
29	2	97.52%
30	2	97.71%
31	2	97.90%
32	3	98.19%
33	1	98.28%
34	0	98.28%
35	0	98.28%
36	2	98.47%
37	0	98.47%
38	2	98.66%
39	4	99.04%
40	3	99.33%
41	0	99.33%
42	1	99.43%
43	0	99.43%
44	0	99.43%
45	0	99.43%
46	1	99.52%

47	4	99.90%
48	1	100.00%
More	0	100.00%

The following Histogram below summarizes all drop height data:



The following is a statistical summary of the "All Drop Height" data:

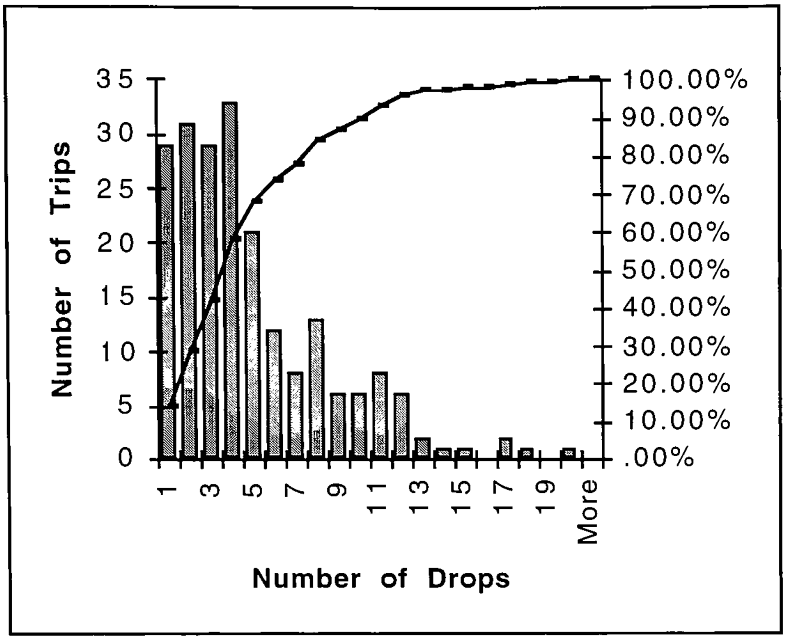
Mean (inches)	10.26809933
Median (inches)	8
Mode (inches)	8
Standard Deviation (inches)	7.844748503
Range (inches)	47.23
Minimum (inches)	0.77
Maximum (inches)	48
Count (drops)	1047

ALL DROPS PER TRIP DATA SUMMARY, HISTOGRAM, STATISTICS

The following is the summary of all of the drops per trip data compiled from the four segments of this Kodak distribution environment measured in this study:

Drops/Trip	Frequency (trips)	Cumulative %
1	29	13.81%
2	31	28.57%
3	29	42.38%
4	33	58.10%
5	21	68.10%
6	12	73.81%
7	8	77.62%
8	13	83.81%
9	6	86.67%
10	6	89.52%
11	8	93.33%
12	6	96.19%
13	2	97.14%
14	1	97.62%
15	1	98.10%
16	0	98.10%
17	2	99.05%
18	1	99.52%
19	0	99.52%
20	1	100.00%
More	0	100.00%

The following Histogram summarizes all the data compiled from the four segments of this Kodak distribution environment measured in this study:



The following is a statistical summary of the "all drops per trip" data compiled from the four segments of the Kodak distribution environment measured in this study:

Mean (drops/trip)	4.990476
Median (drops/trip)	4
Mode (drops/trip)	4
Standard Deviation (drops/trip)	3.706957
Range (drops/trip)	19
Minimum (drops/trip)	1
Maximum (drops/trip)	20
Count (trips)	210

TEST PLANS

Two test plans have been derived from this study. The first test plan is derived from data looking at each distribution sub-environment independently. Examination of the data sets has revealed that the data populations are dependent upon process.

Again, the statistical analysis of the data reveals the process has a much greater affect on handling than does the weight of the package, at least pertaining to the weight range we have examined in this study.[10]

The following test plans are based on a raw, real data model as opposed to a descriptive theoretical statistical model approach. The large data sample size within this study allows for sound test plans to be derived using this approach. This approach will lead to a test plan yielding true and real life estimations.

Test Plan 1

This test plan was derived from analysis of each shipping environment (process) independently of each other. This plan would be used only if the destination on the product shipments are known to be confined to one region of the world. This test plan gives the packaging engineer and quality assurance the flexibility of testing to a specific environment. It should only be used when the product team has a very high degree of certainty that their product region will not change.

This test plan also reveals the most severe handling environment (LTL). This procedure may be used by programs, which due to product value, quantity, etc., feel more comfortable subjecting their packages to a more severe (conservative) test.

---

[10] **Merrilee Ritter, MS., personal communications.**

Assurance Level	Environment	Environment	Environment	Environment
low (50%)	Domestic Parcel	LTL	Australia	Europe
number of drops	4	7	8	8
drop distribution	one at 8" one at 13" one at 16" one at 30"	three at 8" one at 10" one at 16" one at 26:" one at 48"	three at 4" two at 7" one at 11" one at 13" one at 28"	four at 3" three at 6" one at 25"
medium (84%)				
number of drops	7	11	12	10
drop distribution	three at 6" two at 8" one at 13" one at 30"	three at 5" three at 7" two at 10" one at 16" one at 26" one at 48"	three at 4" three at 6" two at 8" two at 11" one at 17" one at 28"	three at 2" three at 3" one at 4" one at 6" one at 7" one at 25"
high (99%)				
number of drops	9	15	16	13
drop distribution	two at 5" two at 6" two at 8" one at 13" one at 16" one at 30"	three at 5" three at 7" three at 8" two at 10" two at 16" one at 26" one at 48"	four at 4" three at 6" four at 8" three at 11" one at 17" one at 28"	three at 2" three at 3" two at 4" two at 6" one at 7" one at 25"
Statistical for above test				
average # of	3.3	6.7	8	7.2
standard deviation	2.8	3.8	4	2.9
median # of drops	3	6	7.5	7
average drop	9.4	13.8	7	5.4
standard deviation	5.8	9.7	5.2	5.4
median drop	8	11	5.7	3.3
maximum drop	30	48	28	25

The second test plan is the result of a complete compilation and statistical analysis of all drop frequency and all drop heights from US small parcel, European, Australian, and LTL data pooled together. This test plan would be used when the destination of the package is not specific to one region of the world.

Test Plan 2

Assurance (approximate probability)	Environment
low (50%)	All carriers
number of drops	5
drop distribution	one at 4" one at 8" one at 13" one at 26" one at 39"
medium (84%)	
number of drops	9
drop distribution	two at 4" two at 6" two at 8" one at 13" one at 26" one at 39"
high (99%)	
number of drops	13
drop distribution drops	two at 4" two at 6" two at 8" two at 10" one at 13" one at 16" one at 26" one at 39" one at 48"

The previous test plans are based on the following descriptive statistics:

average # of drops	4.99
standard deviation of number of drops	3.7
median # of drops	4
average drop height (inches)	10.27
standard deviation of drop height	7.8
median drop height (inches)	8
maximum drop height (inches)	48

5.0 CONCLUSIONS AND RECOMMENDATIONS

The events measured and the data produced during this study (for packages weighing 55 lb and under) disprove the null hypothesis which states the drop height probability curves are representative of the Kodak distribution environment. The highest drop height measured in this study, which consisted of over 1000 measured drops, was 48 inches. The 48" drop only occurred on one out of the 210 trips measured for this study. By way of comparison, at the 0.01% level on the probability curve, a packaged product weighing 25 lb or less must be dropped from 70" ten times. This clearly points to a high potential for over packaging.

This study also demonstrates, for the package weights (10 lb.-55 lb.) researched in this study, distribution process has a greater affect on drop height than package weight does. This is very much contrary to traditional thinking around package weight and drop height. Traditionally, the heavier the package, the lower the drop height.

The probability curves may be of use to others who are not able to gather real field data, but they are clearly too severe to represent the Kodak distribution environment measured in this study.

The findings are significant because they suggest the overpackaging of Kodak products in order to successfully pass the test drop heights required by the probability curves. Moreover, the overpackaging may have led to more iterations and costs during the package development process as well, and to more waste for our customers to manage. The findings identify an opportunity for package waste reduction as well as an overall reduction in expenditure on packaging by the company.

The next step is to put this study and test plans to good use as the basis of a new drop test Standard Operating Procedure in the form of a corporate test procedure and standard.

RECOMMENDATIONS FOR FUTURE AREAS OF STUDY

Possible areas for future work within the scope of this study include:

1) Confirmation of the drop test effectiveness through field shipment studies.

2) Further study of packages closer to the 100 lb range as less manual handling takes place during movements of such larger packages.

3) Further study of orientation and which surface of the package is most likely to be subjected to a drop impact. It may also be useful to measure how different package design features affect orientation (e.g. label placement etc.).

4) Measurement of environments in emerging markets such as the Far East, India and the former Soviet Union.

6.0 REFERENCES

Richard K. Brandeburg, Ph.D., Julian June-Ling Lee, Ph.D., Fundamentals of Packaging Dynamics (MTS Systems Corporation, 1985).

Dennis Young, "Strategic Transport Packaging Performance: Linking Product and Package Evaluation to Corporate Objectives", IOPP Transpack '95.

Hewlett Packard Homepage: http://www.corp.hp.com/publish/talkpkg/testing/section3.htm.

Richard Sheehan, "Predicting Field Performance from Laboratory Testing" Current Trends in Protective Packaging of Computers.

Richard Sheehan, "The Connection with Materials and Component Specifications", IOPP Transpack '97.

Merrilee Ritter, MS., Quality Assurance Statistician, personal communications.

Stephen R. Pierce, MS., Senior Packaging Engineer, Certified Packaging Professional, personal communications.