EUROPEAN EXPRESS SHIPPING DROP / IMPACT STUDY

Paul Russell
Packaging Program Manager
Hewlett-Packard Company

Bill Kipp
Associate Executive Director
International Safe Transit Association

Executive Summary

To design an optimum package, a packaging professional needs a good understanding of the hazards that the packaged product will face as it travels through the distribution system. This understanding comes from analyzing the environment through which it is likely to travel. The packaging professional can then design the package system to withstand the identified hazards.

Past and present environmental data collection techniques and reports, while useful for their own purpose, do not provide enough information to justify existing or to develop new package performance standards. Only by properly collecting (using an agreed-upon guideline), analyzing, and sharing data (in a public form) will there be enough information to fully characterize the distribution environment.

In 1996 a task group called MADE (Measurement and Analysis of the Distribution Environment) under the Institute of Packaging Professionals (IoPP) conducted a study to identify the processes for data collection and analysis, and conducted a pilot run by collecting data in North America. Leveraging from this past work – a new team was formed to examine the distribution environment in Western Europe.

This paper covers the work of that team and the initial finding. In addition, to ensure the reader has the proper context, this paper also briefly covers the methods commonly used to analyze the distribution environment, previous studies, and suggestions for improvement in the data collection and analysis.

A distribution environment can be complex and highly variable, thus making it very difficult to measure. This paper merely attempts to bring to light work done in Western Europe and should serve as a reference to guide any future research studies.

Introduction

The packaging professional faces the challenge of designing a package system that protects the product adequately, yet is also cost-effective and not excessive. An understanding of the environment in which the product was shipped is an essential part of this process. Packages are subject to many hazards while being transported from the manufacturer to the end user. These arise from common and necessary distribution activities–automated and manual handling, transportation, and storage—and can easily damage a product that is not packaged properly. Analysis of the distribution environment allows the packaging professional to design the package system with these hazards in mind.[1]

Packaging professionals work to design and update package systems constantly, yet there is still somewhat limited understanding of the environment through which the packages travel. Many standards and test protocols are based on information gained 20 years ago, from studies done with inaccurate equipment in a completely different environment than the one that exists today. Increased carrier business has led to changing conditions in the shipping environment over the years. This as been recognized by the International Safe Transit Association (ISTA) in the development of their new project 4AB protocol which uses field data to help establish appropriate test sequences and levels.

To ensure the reader has the proper context this paper will briefly summarize past studies and findings that attempted to gain a better understanding of the shipping environment. However the main purpose of this paper is to discuss a particular current study, focused on Western Europe. If the reader is familiar with the past techniques and studies, they can skip directly to the MADE – EMEA Study section.

Four Ways To Define The Distribution Environment

The first step in designing an effective package system is to determine the severity of the shipping environment. Evaluation of the product's distribution method can determine which hazards the product will likely come across, as well as the level of intensity of those hazards. Then the package system can be designed accordingly.

Package handling, transportation, and storage can lead to a variety of hazards within the shipping environment, including, but not limited to, vertical drops, horizontal impacts, vehicle vibration, temperature extremes, and compression loads. The method of distribution greatly influences the presence and severity of these hazards, so understanding the shipping environment is essential to designing a package that will effectively protect its product.

There are four different ways of determining the environment through which a product is shipped:

1. Observation
2. Damage Claims
3. Literature Search
4. Direct Measurement

These techniques can be used individually or in conjunction with each other. The advantages and disadvantages of each is discussed below.

1. Observation

The most informative method of describing the distribution environment would be to actually follow a package as it travels through the shipping environment and watch what happens to it. Through the use of human observation, first-hand knowledge of the environment can be obtained. Cameras can provide documented evidence of the hazards that a package encounters. Of course, following a package through its complete travel route can be very time-consuming and expensive. The information acquired will only be relevant to the time the observation was made and will only provide a glimpse of that environment. In addition, the behavior of the handlers may be affected by the presence of the observers, as it is human nature to try to perform better while being watched.

Unless the observation can take place unnoticed, the results may not give a completely accurate description of the shipping environment. This method may work best for an initial assessment of the environment, which can later be correlated with supporting data gained from other types of measurement. It may also work well for simple and/or controlled environments that only utilize one or two different modes of distribution.

2. Damage Claims

Some hazards in a distribution environment go unnoticed until they cause damage to products with insufficient protection. A review of damage reports, which can be obtained from carrier logs, customer complaints, or shipping department personnel, can provide a better understanding of the hazards encountered in a shipping environment. These reports can be used as documented evidence and can indicate how much money is lost due to damage in transit. It may be possible to characterize the type of damage, as well as the geographical location where the damage took place.

However, damage reports do not always contain specific information on the type or extent of damage that occurred. Sometimes damage is incorrectly blamed on insufficient packaging, when in fact the product itself was defective before shipping or the package was grossly mishandled during shipment. Faulty products are often incorrectly packaged for return, resulting in damage during shipping that is unrelated to the original problem or could even compound it. This often causes damage reports to be misleading. Furthermore, not all damage is reported, since sometimes losses are absorbed rather than claimed, making accurate information hard to obtain.

It can be costly to wait for damage to be reported before trying to determine its cause. This method is most effective when investigating damage that occurs to new products and when trying to improve existing package systems.

3. Literature Search

Perhaps the most widely used approach is to research what others have done. There have been numerous studies performed and an examination of available data can provide a broad understanding of the issues surrounding the measurement of a distribution environment. Research also requires a smaller commitment of time and resources than actually performing the experiments. The difficulty with this approach is that the data can sometimes be outdated and sampling parameters can be unclear or unknown. Conclusions drawn by studies are usually dependent on the author's perspective and selective data may have been used. Also, the data may not be relevant to the shipping environment in question and some variables may not have been fully addressed. In general, however, this approach has provided the guidelines and rules of thumb used in today's package design work.

4. Direct Measurement

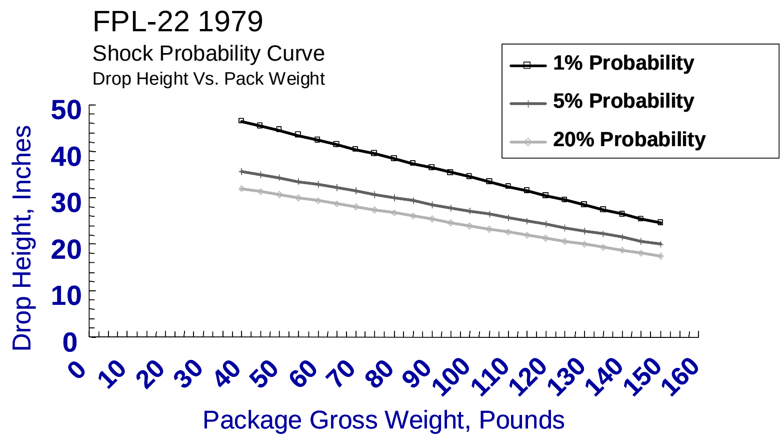
The best substitute for actual observation of the environment a package travels through is the use of a recording device to monitor the package and/or vehicle during shipment. The measurement device can record the events that happen throughout the trip without influencing the package's treatment, since they are usually concealed inside the package. They can be calibrated in the lab before use to test for accuracy, and a correction factor can be established if necessary. Many devices can collect many types of measurements at the same time, thereby utilizing the full capacity of limited resources. Provided the same route is measured enough times (30 trips is recommended[2]) using the same equipment and protocol, some sort of statistically valid information can be obtained to help describe that particular channel of distribution. Specific events will obviously vary from trip to trip but a general idea of what to expect will develop.

The disadvantages of this technique are that the equipment can be expensive and the analysis of the data very time-consuming. The analysis is also subject to the limitations of the recording devices. The accuracy of the equipment determines how well the recorded event correlates to the actual event, and sometimes it can be difficult to compare data. Also, there may be such a great number of variables that only a rough estimate of the environment can be made. Although it is not ideal, for now direct measurement may be the best-suited approach for gaining information about a specific distribution channel.

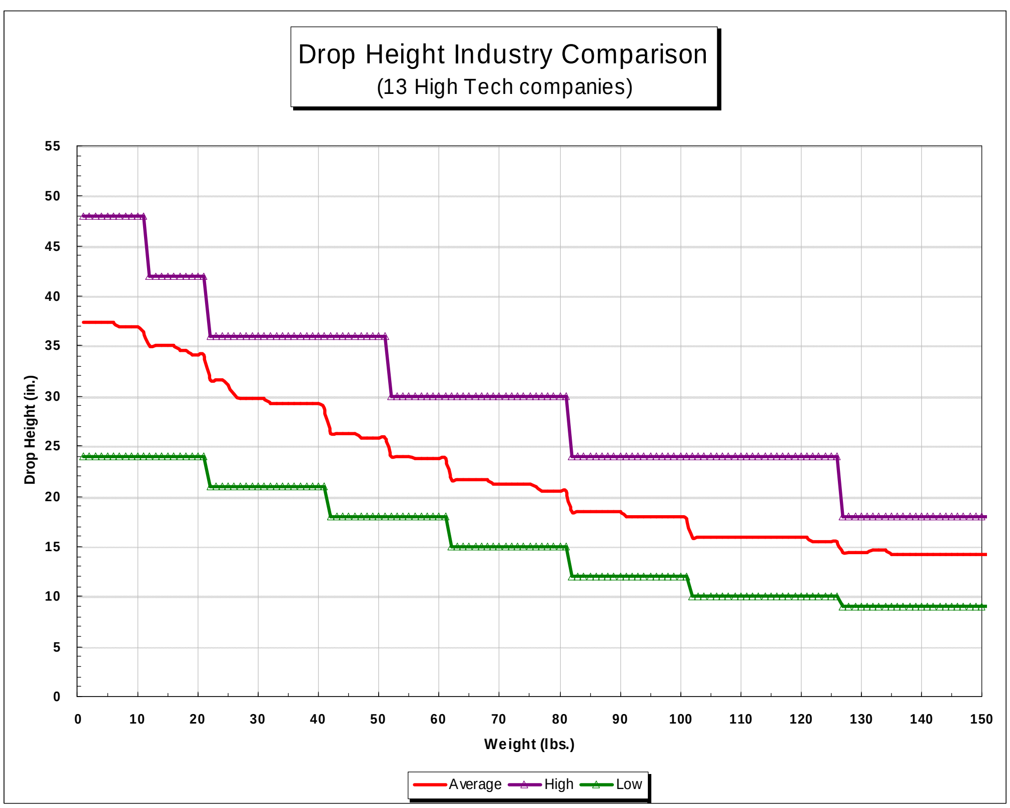
<u>Past Studies</u>

FPL 22

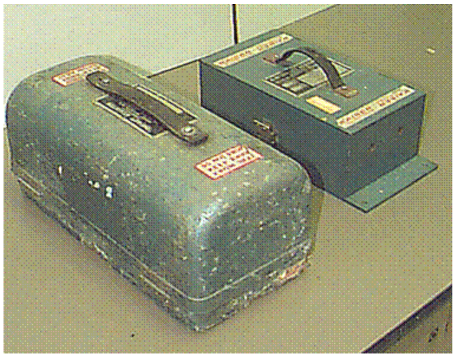
Numerous studies have been conducted attempting to define the distribution environment, but none have had as much impact on the packaging profession as a report written by F. E. Ostrem and W. D. Godshall and published in 1979. The report, called the Forest Products Laboratory General Technical Report FPL 22, An Assessment of the Common Carrier Shipping Environment (commonly referred to as FPL 22), was based on a literature search of information and measurements collected between 1959 and 1977. The information provided by this report was a breakthrough at the time, as it provided packaging professionals with a generalization of the environment, which they could then translate into a basis for laboratory testing and company specification. Below is a shock probability curve from FPL-22.

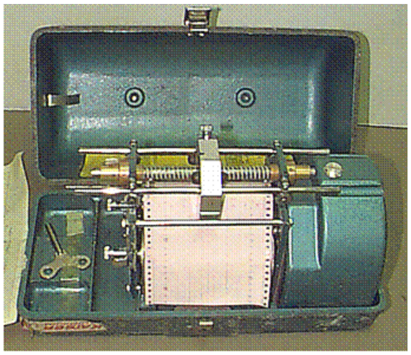


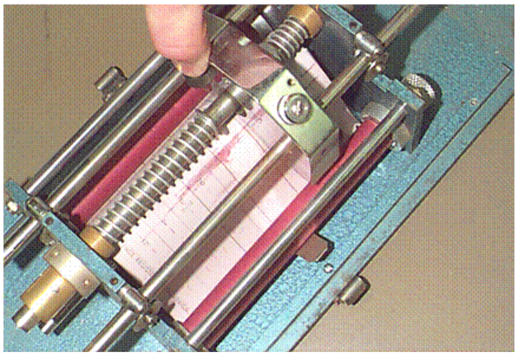
A majority of today's high tech companies' testing requirements have their roots based on this report. Below you can see an example of 13 high tech companies which use drop heights that get smaller as the product weight goes up – similar to FPL-22.



However, the key element that was overlooked by the high tech industry is that the report was based on measurements taken by devices that had a low accuracy and lacked repeatability in the lab. As seen below, these devices used weighted springs with pen attachments to record impacts (X, Y and Z directions) on a moving piece of paper. It was then up to the reviewer to manually measure these “impact” tracings to determine the drop height level. This was difficult to nearly impossible to correlate to lab drop test readings as most drops in the real world are not flat and even include tumbling.







Ostrem and Godshall admit, “the data concerning handling, although not adequate for package design or test purposes, does provide useful information.” An example of this is the drop height portion of the report, which was based on using spring mass recording devices such as Impact-O-Graphs and B & K Bump Recorders, which provide very little data and are often inaccurate (Herb Schueneman, 1996).

IBM Study

On November 7, 1989, Mark T. Kerr of IBM concluded a three-year focused study on drop height measurements. The study consisted of 280 shipments of five different size and weight packages through seven different handling points. A total of 17 data recorders (a combination of both Dallas Instruments DHR-1 and Instrumented Sensor Technology (IST) EDR-1) were used in the study. The recorder's analysis algorithm was based on time and velocity change, which also presents certain technical limitations and issues.

Some interesting findings were that no perfect flat drops occurred (although many drops could be considered flat for package testing purposes) and there was no difference between boxes with high-resolution graphics and those without. In addition, there was no significant difference between boxes with or without hand holes.

The study concluded that package graphics, aesthetics, and design had little influence on the treatment the packages received. Human factors in the line layout of the distribution companies' loading and unloading area actually contributed more to the mishandling and damage. This assumption was later confirmed in another IBM report, "New Approaches to Defining the Distribution Environment," written by Jack N. Daniels and Robert T. Sanders (Distribution Packaging Technology, R. Fiedler, 1995).

The conclusions reached by these studies showed that Medium weight packages defy current logic and design specifications and in the real-world, drop height doesn't necessarily go down as weight goes up (Mark Kerr, 1996).

MSU Consortium

The Consortium of Distribution Packaging is an operational unit within the School of Packaging at Michigan State University. It was established in 1990 to encourage basic and applied research, testing, and service in the area of distribution packaging through the cooperative funding and collective support of industry and academia. Through this joint-action program, research that is beyond the capability and available funding of individual organizations may be undertaken so that techniques and advances thus developed can increase the effectiveness of all member companies. With the participation and support of over ten companies, over 15 studies relating to distribution environment measurement have been completed.

Some of these studies are listed below, and many are published in various journals and conference proceedings. More information on these reports and the Consortium can be obtained by contacting Dr. S. Paul Singh at Michigan State University.

- Analysis Techniques for Package Distribution Environment Data (provided analysis techniques which could be used to develop methods for drop height testing)
- Comparison between Commercial Drop Height Recorders
- Designing Packages for Overnight Parcel Environment
- Drop Heights Encountered in the United Parcel Service Small Parcel Environment in the United States (concluded that the size of the package has no significant effect on drop heights)
- Dynamic Analysis of Less Than Truckload Shipments

- Measurement and Analysis of the Overnight Small Package Shipping Environment for Federal Express and United Parcel Service (explained unit ratio method of classifying shock events)
- Measurement of the UPS Shipping Environment
- Measuring the Truck Shipping Environment
- Monitoring Transient Shocks in Rail and Truck Environments
- Packaging Dynamics in the Overnight Small Parcel Delivery System of Federal Express, United Parcel Service, and United States Postal Service.
- Predicting Temperature Variations in Truck Shipments
- The UPS Shipping Environment

MADE – Alpha

The Measurement and Analysis of the Distribution Environment (MADE) task group was established under P2C2 (Protective Packaging of Computer Components), a subcommittee of the Institute of Packaging Professionals (IoPP), in 1991. However, lack of member activity stalled the group until August 1996, when a new committee was formed. The task group was made up mostly of people from high tech industry that consisted of almost 75 companies and organizations. The group's mission was to obtain a better understanding of the distribution environment and share that knowledge with others. The "alpha" phase objective was in establishing and validating guidelines for data collection and analysis. It was not meant to represent a comprehensive assessment of the environment, but simply to serve as a pilot to demonstrate the process and feasibility of the project. Eight (8) round-trip shipments were measured for impacts and temperature using self-contained data recorders from Instrumented Sensor Technology (IST) and Lansmont. Shipments via United Parcel Service and Federal Express covered distances across the U.S., between companies on the west and the east coasts. Three data recorders - two to measure shock and temperature and one to measure only temperature - were hard mounted on wood blocks and surrounded by foam.

Out of eight round trips, only six round-trip shipments could be used in this phase. Most events observed were not free fall drops. They were impacts, in basically all orientations. The highest drop height found in all six round trips was 38.8 inches. In the majority of cases, the SAVER and EDR3 units measured similar acceleration versus time waveforms, having similar peak Gs, durations, and velocity changes. Resultant drop heights were different because the calculation methods used to get from acceleration versus time to the equivalent drop height appeared to be different. Waveform discrepancies can often be explained by the differences in filter frequencies.

Even taking this into account, there was still some disagreement between the results given by the units. Most of these were found to be caused by the fact that the analysis was being performed in different parts of the same event. This occurred because the “window” or time frame that was recorded did not always agree completely between units. Although the units were triggered by the same event, the recorded waveforms started and ended at slightly different times, sometimes missing important parts of an event. This issue was addressed in phase beta by extending the recording window well beyond the triggering time, as well as by minimizing the dead time, which is the time just after one event when the unit does not record the waveform. This can be an important consideration when multiple events happen in rapid succession, dubbed an “event storm.”

Phase alpha revealed many issues regarding data collection and analysis, which were necessary to address before continuing with the beta phase. The discrepancies between the units were a concern, as was the time needed for data analysis. The question of whether the difference between the units was a performance issue or just a software issue was raised. Also, it was suggested that to prevent the need for event-by-event analysis, new methods of examining the data (such as adapting new software, developing additional routines, or finding different setup parameters) should be investigated.

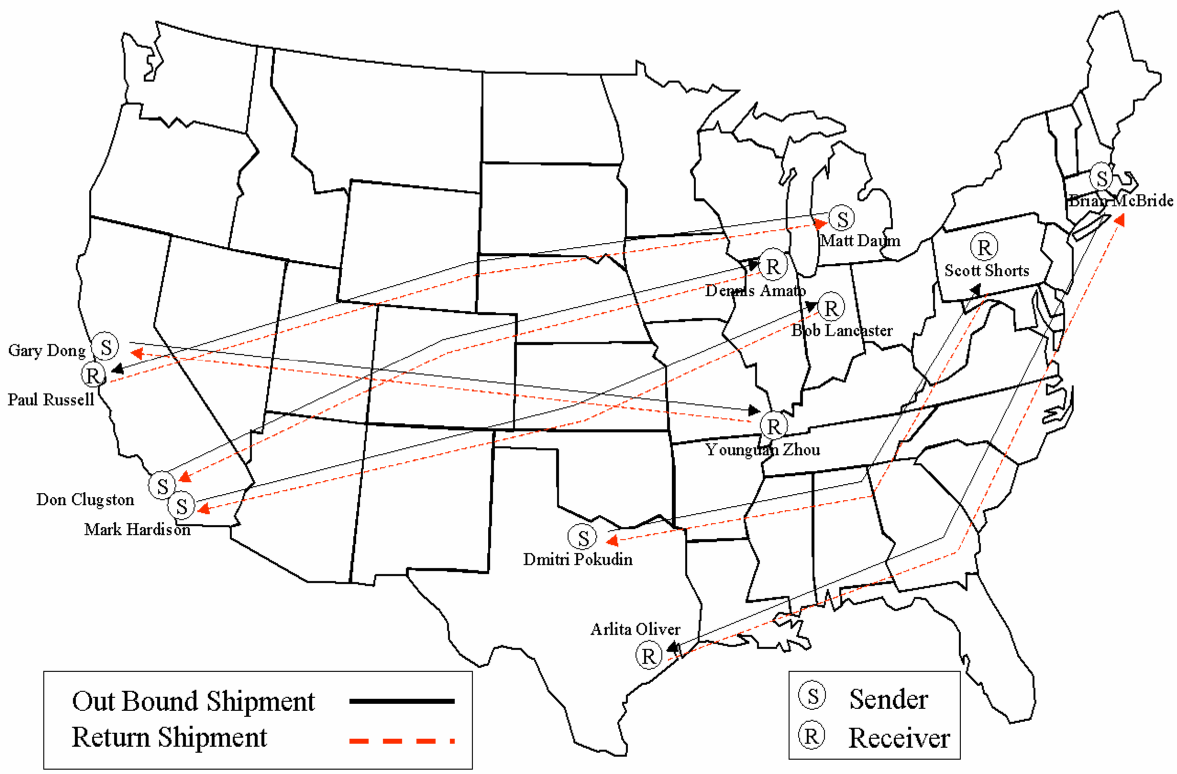
Some modifications, dealing with data format and presentation, were recommended. Some were minor, such as changing the term “shipper” to “sender” on the trip documentation form and including the date and time of turnaround. A more major decision involved the recording unit’s orientation. Units should be positioned in the package according to their designated orientation, no matter what orientation the axes are (the software is set to report impact direction as per the unit’s designated orientation). This was an issue in phase alpha because the units were side by side, but was not a problem for phase beta.

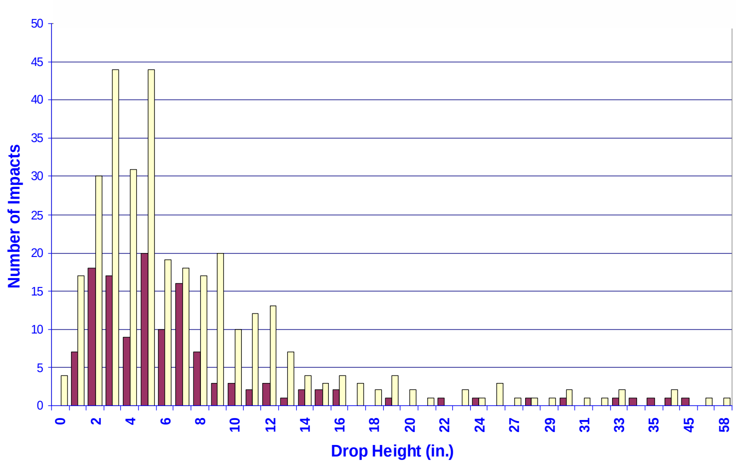
Decisions about the manner in which to present the results were also made. If a large number of replications of the same trip, package size, etc. are to be conducted, then it was deemed better to present results in a statistical distribution format. If conditions change from trip to trip, it was more appropriate to present actual results (example, events higher than 10 inches, 5 largest drops, etc.). This allows the user to determine what statistical analysis is most appropriate depending on the applications.

MADE – Beta

Whereas phase alpha evaluated existing instrumentation and methods of collecting data, the focus of the beta phase was to actually collect some data, while still refining the collection and analysis process, and develop data archiving and results presentation techniques. Six instrumented boxes were shipped via UPS and FedEx second-day delivery, three round trips for each carrier, on five different routes.

MADE Beta Shipper / Receiver Map





24 Round Trip shipment files

Drop height (inches)	Avg drops per shipment	Max number per shipment
below 18	119	165
18 to 24	5	10
24 to 30	2	5
30 to 36	1	5
36 or higher	1	3

Due to limited resources and time the Beta study was concluded. Due to limited sample size per route, no definite conclusions about the environment where reached but recommendations and best practice processes were established.

However, approaching the data from a high level perspective (not by route but by region) some conclusions can be drawn.

- Most drops happen below 14 inches
- Few drops happen at higher heights

MADE – EMEA

Scope

The concept was to ship instrumented packages via express carriers from various origins to various destinations in Europe. Acceleration, temperature, and humidity were recorded and used to calculate/interpret velocity change, drop height, impact orientation, and atmospheric conditions. One size and weight dummy package was shipped, and recorders (SAVER™ 3X90™) from Lansmont were used as the instrumentation.

A test plan was developed to measure the small parcel, second-day shipping environment. This test plan focused on defining the process for data collection and analysis. The information gathered during this phase is being shared with ISTA for their project 4AB. The findings from this study are not intended to be a comprehensive assessment of the second-day shipping environment in Europe, but an initial pilot program to collect distribution data that can be used to better define test specifications for the European region.

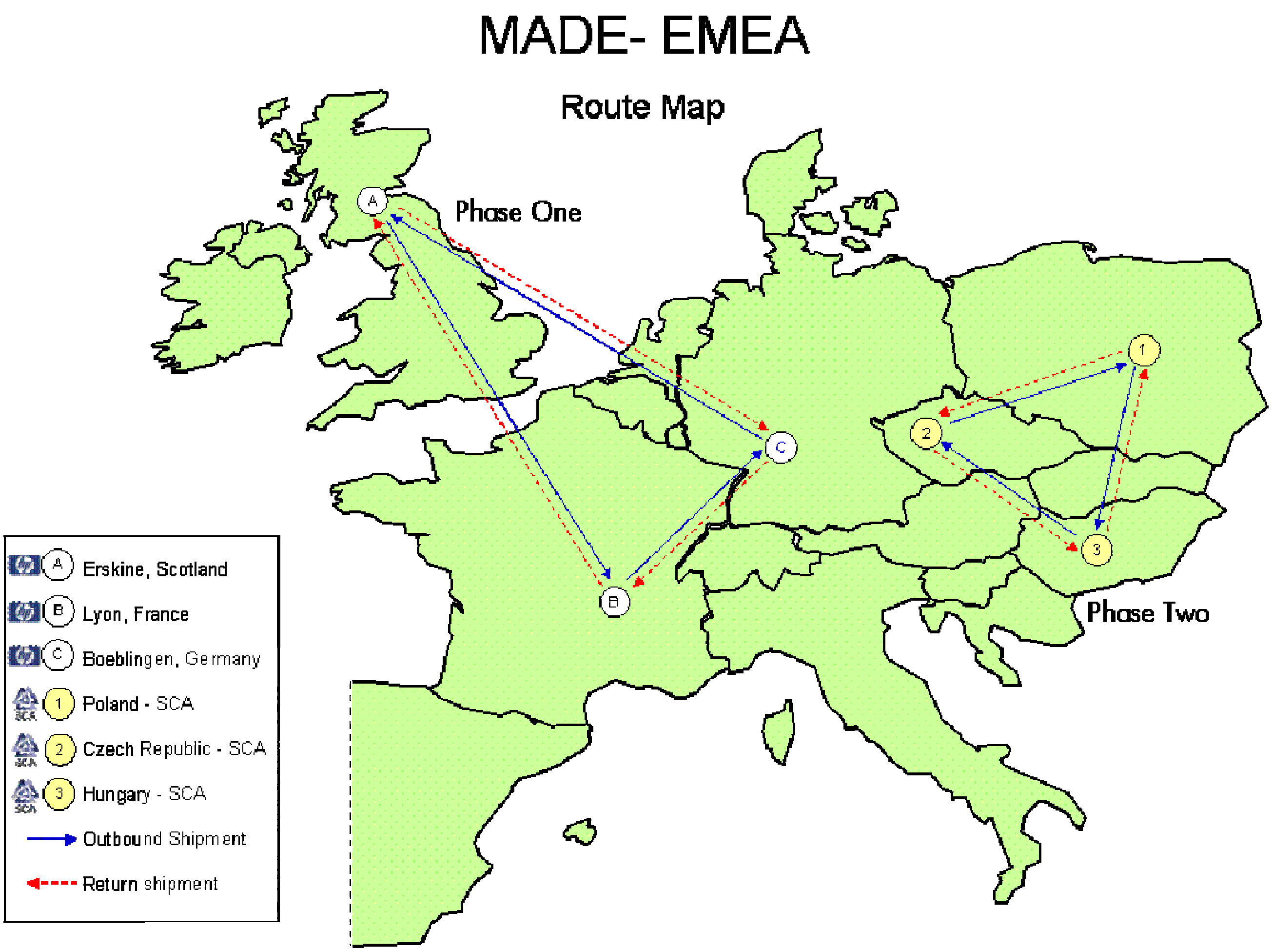
The following is the Project Outline detailing the destinations, what we're monitoring (shipment types, types of data, packaging configuration, data recorder set up, data collection process, re-packaging and return shipments, download sites, download timeline).

Destinations

Each test packaged system was intended to be shipped 30 times (15 round trips) via an express carrier. The actual number of shipments was 17 shipments for Route A, 22 shipments for Route B, and 18 shipments for Route C. There were 3 participating sites acting as shippers and receivers. The packaged system was shipped through the normal express carrier process (i.e. pickup, sortation hubs, routing, delivery, etc) and then was rerouted back to the original shipper. This boomerang shipment was equivalent to a round trip, but was divided into two one way trips.

See the following Table and Figure for details.

	Shipper				Receiver			
Route	First Name	Last Name	City	Country	First Name	Last Name	City	Country
A	Bryan	Love	Erskine	United Kingdom	Frederic	Lombard	Vaulx-Milieu Villefontaine	France
B	Frederic	Lombard	Vaulx-Milieu Villefontaine	France	Holger	Henkes	Boeblingen	Germany
C	Holger	Henkes	Boeblingen	Germany	Byran	Love	Erskine	United Kingdom



Statistical Significance

- The test plan used one size container, one specific weight, and the same data recorder set up parameters.
- Fifty-seven (57) one-way shipments were made.
- 3 ship to and receiving locations were chosen to represent Europe (Erskine, Scotland; Lyon, France, and Boeblingen, Germany).

Shipment Service Level and Service Providers

All shipments were 2nd day express. It was understood that some of these shipments might actually be traveling by ground. This is still considered part of the 2nd Day system. Carriers utilized were UPS and DHL.

Fixture Design and Packaging Configuration

A wooden mockup represented a dummy product and was designed such that one Lansmont portable field recording device could be mounted rigidly. The portable field recording device was orientated similar to the shipping container to record top, bottom, front, back, right side, and left side.

Outside dimensions of dummy product 17" X 15" x 8" (43.2cm x 38.1cm x 20.3cm).

The dummy products were made from common materials that could be obtained anywhere in the world. A detailed drawing was created so that duplicate samples could be produced consistently.

The weight of the dummy product was 22.5 lb. (10.21 Kg) without the recorders. The gross weight with portable field recording device (1 lb (0.45 Kg)) was 23.5 lb (10.66 Kg). Total weight of shipment (including packaging materials) was 27.5 lb (12.47 Kg).

The portable field recording devices were packaged into the shipping container so the corner of the dummy product was towards the manufacturer's joint. The shipping container was taped closed using a minimum 2 inch wide clear box sealing tape in an H pattern on both the top and bottom flaps.

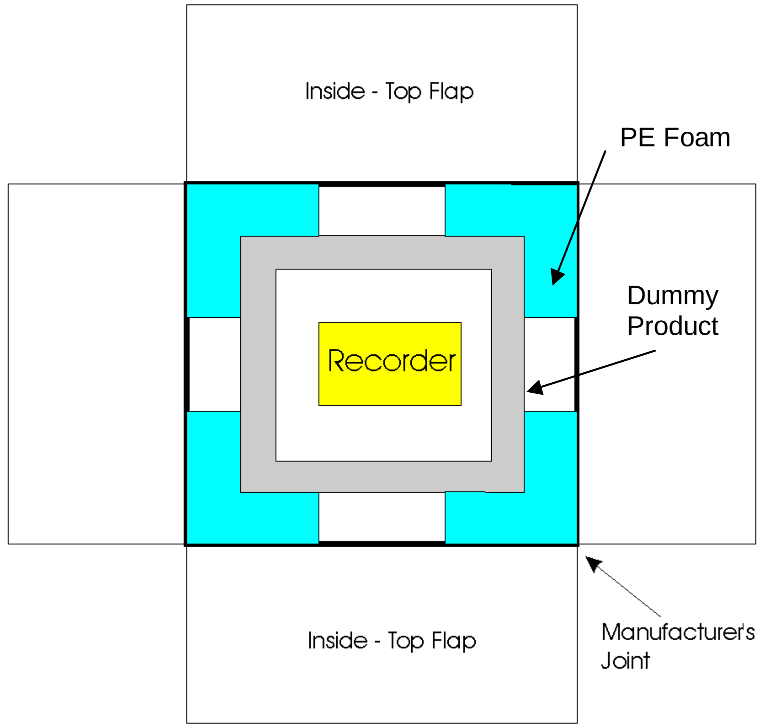
The cushioning, a total of eight 2" (5.08 cm) thick polyethylene laminate corner blocks of 2.2 pound/cu ft. (35.2 gm/liter) density, was designed to protect the dummy product and recorder to a maximum acceleration level of 50 G's when dropped from a height of 60 inches (1.5 m). The cushion material selected needed to be obtainable anywhere in Europe and the United States and have uniform density.

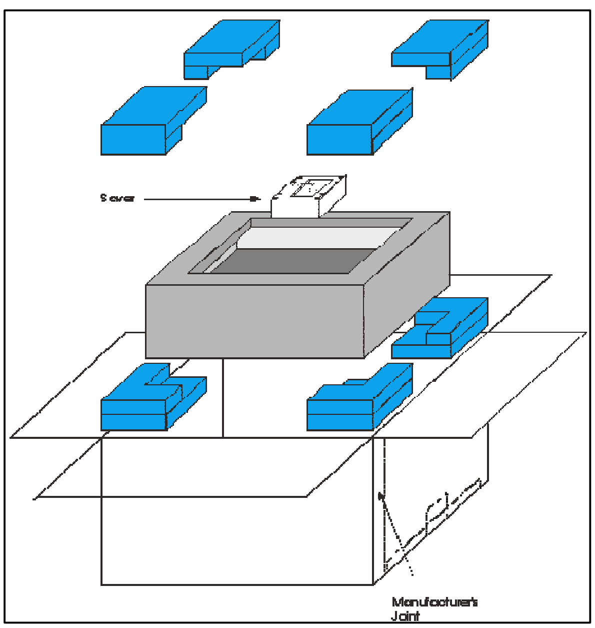
The shipping container had inside dimensions of 21" x 19" x 12" (53.34cm x 48.26cm x 30.48cm). This shipping container was made of doublewall (B/C) corrugated with a minimum bursting strength of 275 psi with a liner/medium makeup of 42#L-26#M-33#L-26#M-42#L and was kraft in color. The manufacturer's joint was glued.

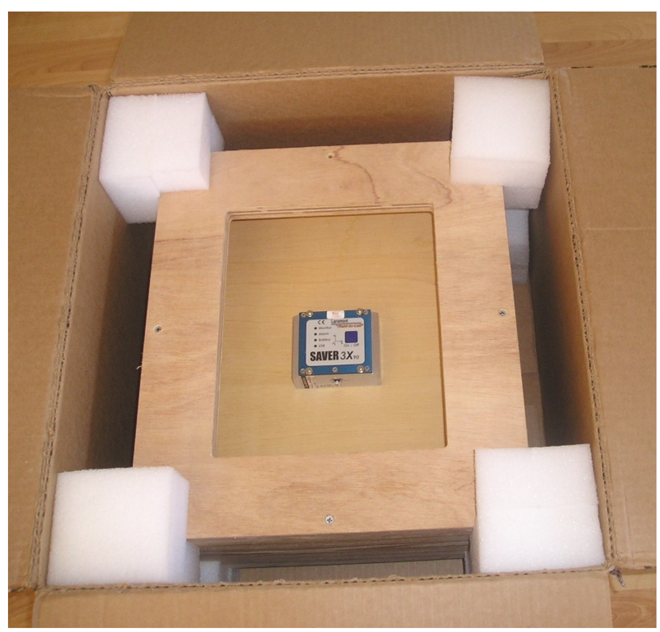
The weight of the foam and corrugated packaging is estimated to be 5.68 lb. (2.58 Kg).

The shipping label was oriented on the top flaps with respect to the manufacturer's joint.

See figures and photographs on the following page.


Inside - Top Flap
PE Foam
Dummy Product
Recorder
Inside - Top Flap
Manufacturer's Joint


Saver
Manufacturer's Joint


SAVER 3X

Data Collection Process

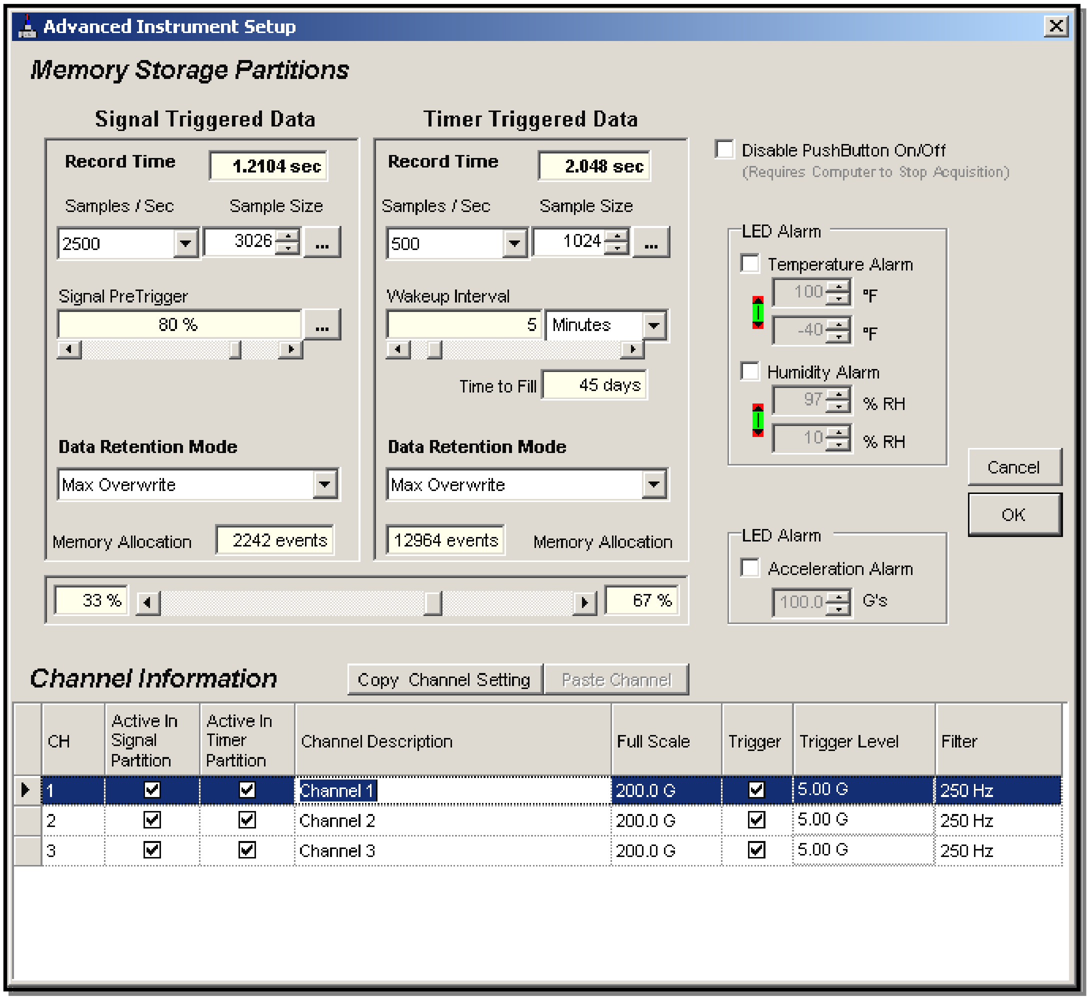
The data from each recorder was retrieved at the end of each one-way trip and the instrument was re-set. Data and tracking information was sent to the HP eRoom location for storage and analysis.

The plan was to create a total of 90 analysis files, 30 files for each shipment route, according to the following table. In fact, due to scheduling and other issues, only 57 files were recorded: 17 for Route A, 22 for Route B, and 18 for Route C. The table below shows the planned shipment and routes.

Route A		Route B		Route C	
Shipper:	Bryan Love	Shipper:	Frederic Lombard	Shipper:	Holger Henkes
Origin City	Erskine	Origin City	Vaulx-Milieu Ville Fontaine	Origin City	Boeblingen
Origin Country	Scotland	Origin Country	France	Origin Country	Germany
Receiver:	Frederic Lombard	Receiver:	Holger Henkes	Receiver:	Bryan Love
Destination City	Vaulx-Milieu Ville Fontaine	Destination City	Boeblingen	Destination City	Erskine
Destination Country	France	Destination Country	Germany	Destination Country	Scotland
Description - owner for file down loading	File Name	Description - owner for file down loading	File Name	Description - owner for file down loading	File Name
Outbound - Receiver	A01.SXd	Outbound - Receiver	B01.SXd	Outbound - Receiver	C01.SXd
Return - Shipper	A02.SXd	Return - Shipper	B02.SXd	Return - Shipper	C02.SXd
Outbound - Receiver	A03.SXd	Outbound - Receiver	B03.SXd	Outbound - Receiver	C03.SXd
Return - Shipper	A04.SXd	Return - Shipper	B04.SXd	Return - Shipper	C04.SXd
Outbound - Receiver	A05.SXd	Outbound - Receiver	B05.SXd	Outbound - Receiver	C05.SXd
Return - Shipper	A06.SXd	Return - Shipper	B06.SXd	Return - Shipper	C06.SXd
Outbound - Receiver	A07.SXd	Outbound - Receiver	B07.SXd	Outbound - Receiver	C07.SXd
Return - Shipper	A08.SXd	Return - Shipper	B08.SXd	Return - Shipper	C08.SXd
Outbound - Receiver	A09.SXd	Outbound - Receiver	B09.SXd	Outbound - Receiver	C09.SXd
Return - Shipper	A10.SXd	Return - Shipper	B10.SXd	Return - Shipper	C10.SXd
Outbound - Receiver	A11.SXd	Outbound - Receiver	B11.SXd	Outbound - Receiver	C11.SXd
Return - Shipper	A12.SXd	Return - Shipper	B12.SXd	Return - Shipper	C12.SXd
Outbound - Receiver	A13.SXd	Outbound - Receiver	B13.SXd	Outbound - Receiver	C13.SXd
Return - Shipper	A14.SXd	Return - Shipper	B14.SXd	Return - Shipper	C14.SXd
Outbound - Receiver	A15.SXd	Outbound - Receiver	B15.SXd	Outbound - Receiver	C15.SXd
Return - Shipper	A16.SXd	Return - Shipper	B16.SXd	Return - Shipper	C16.SXd
Outbound - Receiver	A17.SXd	Outbound - Receiver	B17.SXd	Outbound - Receiver	C17.SXd
Return - Shipper	A18.SXd	Return - Shipper	B18.SXd	Return - Shipper	C18.SXd
Outbound - Receiver	A19.SXd	Outbound - Receiver	B19.SXd	Outbound - Receiver	C19.SXd
Return - Shipper	A20.SXd	Return - Shipper	B20.SXd	Return - Shipper	C20.SXd
Outbound - Receiver	A21.SXd	Outbound - Receiver	B21.SXd	Outbound - Receiver	C21.SXd
Return - Shipper	A22.SXd	Return - Shipper	B22.SXd	Return - Shipper	C22.SXd
Outbound - Receiver	A23.SXd	Outbound - Receiver	B23.SXd	Outbound - Receiver	C23.SXd
Return - Shipper	A24.SXd	Return - Shipper	B24.SXd	Return - Shipper	C24.SXd
Outbound - Receiver	A25.SXd	Outbound - Receiver	B25.SXd	Outbound - Receiver	C25.SXd
Return - Shipper	A26.SXd	Return - Shipper	B26.SXd	Return - Shipper	C26.SXd
Outbound - Receiver	A27.SXd	Outbound - Receiver	B27.SXd	Outbound - Receiver	C27.SXd
Return - Shipper	A28.SXd	Return - Shipper	B28.SXd	Return - Shipper	C28.SXd
Outbound - Receiver	A29.SXd	Outbound - Receiver	B29.SXd	Outbound - Receiver	C29.SXd
Return - Shipper	A30.SXd	Return - Shipper	B30.SXd	Return - Shipper	C30.SXd

Data Recorder Setup Parameters

This was conducted based on manufacturer's guidelines. Each SAVER™ 3X90 was programmed with the following recording parameters. A setup file was created *MADE EMEA.sxs) and saved in the HP eRoom location.



Screenshot of “Setup Detail” from SaverXware

Shipping and Receiving Instructions

1st Original Shipping Entity Outbound Instructions

- Procedures used for SAVER™ 3X90 preparation for shipment
    1. Make sure computer date and time are current
    2. Start SAVER™ 3X90 software
    3. Connect cable between unit and computer, using the USB port
    4. Click on “Utilities”, then “Restart with Onboard Setup”
    5. Select “Automatic Start” then click “OK”

6. Disconnect cable from unit
7. Repackage as necessary
8. Send shipment to appropriate location
9. Email tracking # to package recipient

§ A shipping log documented each shipment with the following data elements:

1. Trip Shipment
2. Date shipped
3. Outbound Carrier (if known)
4. Outbound Tracking Number

Receiving Entity Instructions

§ Using a receiving log form - all shipment tracking information (for EVERY shipment) was documented/captured and collected for use by the analysis team. Data elements captured were:

1. Trip Shipment
2. Date received
3. Inbound Carrier
4. Inbound Tracking Number
5. Date shipped back
6. Outbound Carrier (if known)
7. Outbound Tracking Number

§ For each trip shipment, the box was opened and the data download from the recorder using the naming system described in the Route table, and the data file was sent to the HP eRoom.

1. Procedure used for SAVER™ 3X90™ data download
    1. Start SaverXware software
    2. Connect cable between unit and computer, using the USB port
    3. Click on "talk to instrument"
    4. Click on "read back data"; wait until reading is finished.
    5. Save as "C:SaverXware/datastore/filename.sxd"; Exit
    6. Send the SAVER™ 3X90 data file to the appropriate eRoom location.
    7. Follow the Procedure for SAVER™ 3X90 preparation like the 1st outbound shipment for the remaining trips

Original Shipping Entity - Receiving Instructions

§ When the test packaged system was received, inspect the packaging and replace as necessary. This includes the protective foam blocks, the corrugated container or any other medium needing replacement. It was advised that the packaging be changed out on the 5th round trip or earlier if necessary.

§ Using the shipping log, document each shipment with the following data elements:
  1. Date received back
  2. Inbound Carrier
  3. Inbound Tracking Number
  4. Date shipped back
  5. Outbound Carrier (if known)
  6. Outbound Tracking Number

§ At each trip shipment, the box was opened and the data downloaded from the recorder, using the naming system described in the Route table, and the data file was sent to the HP eRoom.
  - o Procedure used for SAVER™ 3X90™ data download
    1. Start SaverXware software
    2. Connect cable between unit and computer, using the USB port
    3. Click on “talk to instrument”
    4. Click on “read back data”; wait until reading is finished.
    5. Save as “C:SaverXware/datastore/filename.sxd”; Exit
    6. Send the SAVER™ 3X90 data file to the appropriate eRoom location.
    7. Follow the Procedure for SAVER™ 3X90 preparation like the 1st shipment for the remaining trips.

Tracking Information

Tracking information reports were obtained from the carrier’s web site and saved as PDF files (using the tracking number) and stored in the on-line e-room. Because of challenges in coordinating the tracking information with the data (synchronizing the UTC time base of the recorders with local times), location statistics are not included with this report. All data is in the e-room, however, and may be analyzed at a later date.

UPS Package Tracking	http://www.ups.com/tracking/tracking.html
DHL	http://www.dhl.com/splash.html

The MADE-EMEA Data

Equivalent Free-Fall Drop Heights

In the express shipping environment, shocks are not caused exclusively by free-fall drops. As a matter of fact, “pure” free-fall drops are relatively rare. Potentially damaging shocks are far more likely to be caused by slides, conveyor operations, diverter strikes, package-to-package impacts, manual sortation, and a variety of other situations. A very typical scenario in this environment is that the package is *moving* prior to impact, but not free-falling. However, since in the laboratory we often simulate *all* of these types of impact events with free-fall drop testing, it is most meaningful and useful to analyze the field data in terms of *equivalent free-fall drop heights (**EFFDH**)*. This requires package calibration and special analysis techniques as described in the following sections.

EFFDH, Velocity Change, Impact Velocity, and Coefficient of Restitution

The SAVER™ 3X90 and its companion software, SaverXware, incorporates an algorithm using "zero g time"®, a form of signature analysis, and related information to determine drop height. This approach works remarkably well for analyzing drops when a package is "cleanly" dropped and free-falls, and in certain other well-defined situations. However, when the shock event is a typical field impact other than from a drop, alternative analysis methods must be used to extract EFFDH. The instrument's three-channel recorded shock pulses can yield this information with reasonable accuracy if interpreted properly.

The area under an acceleration-vs.-time shock pulse is proportional to the total velocity change, which is the sum of the impact and rebound velocities which caused the shock. However, it is only the *impact* velocity which is related to EFFDH. Therefore the *rebound* velocity must be removed from the total velocity change before EFFDH can be calculated. Since rebound velocity is equal to impact velocity times ***e*** (the coefficient of restitution), the key to calculating EFFDH from shock pulses is knowing the package ***e*** associated with each event.

Package Calibration

Prior to beginning the study shipments, the packages were taken to Lansmont's Sunnyvale, CA lab for calibration. This consisted of dropping each of the three packages on faces, edges, and corners from heights of 40 and 75 cm. The data was examined and coefficients of restitution (***e***'s) were calculated. As is typical of packages with strong outer boxes and symmetrically placed, soft, resilient cushions, the ***e*** was relatively consistent regardless of drop height or impact orientation. The range of values was from 0.37 to 0.50, but the data was tightly grouped with a mean of 0.43 and a standard deviation of only .04. Therefore an ***e*** of 0.43 (corresponding to a rebound height of approximately 13.5 cm from a 75 cm drop (5.5 inches from 30 inches)) was used in subsequent EFFDH calculations. Of course this ***e*** only applies to impacts with hard surfaces (the calibration impacts were against a steel plate on a concrete foundation). It was arbitrarily assumed that impacts with moderately-soft surfaces would have an ***e*** of 0.3 (corresponding to a rebound height of approximately 6.75 cm from a 75 cm drop (2.7 inches from 30 inches)) and that impacts with very soft surfaces would have an ***e*** of 0.2 (corresponding to a rebound height of approximately 3 cm from a 75 cm drop (1.2 inches from 30 inches)).

Analysis of EFFDH from Velocity Change

So the procedure for calculating EFFDH from impact shock pulses was as follows:

- If the impact appeared to be with a hard surface (as evidenced by the peak accelerations of the three-axis shock pulses) an ***e*** of 0.43 was used
- If the impact appeared to be with a moderately-soft surface (lower peak accelerations) an ***e*** of 0.3 was used
- If the impact appeared to be with a soft surface (low accelerations) an ***e*** of 0.2 was used.

Overall Determination of EFFDH

Each event (there were a total of 1995 events recorded) was examined in detail. Of these, 556 were deemed to be "significant" (over 6 inches (15 cm) EFFDH). These 556 events fell into 3 broad categories and were treated as follows:

- "Pure" free-fall drops. If the "zero g" data reasonably matched the signature of a free-fall drop, the software's analysis was taken directly and entered as the EFFDH.
- Impacts not associated with free-fall drops. If the impact was significant but the "zero-g" signature was not recognizable as a drop, EFFDH was calculated from velocity change data as outlined above.
- Impacts with pre-motion. Many events appeared to be neither "pure" drops nor impacts without drops, but something in-between. In these cases a best effort at interpreting the "zero-g" data was made *and* drop height was calculated based on velocity change, then the two results were averaged. Admittedly this can be a somewhat subjective process, but we feel that if there is sufficient data in terms of number of recorded events, a subsequent statistical analysis will lead to valid conclusions.

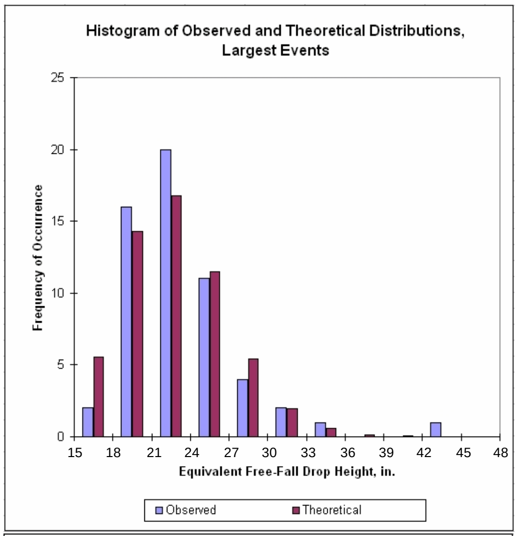
Statistical Analysis

The study obviously created a large amount of information. So what are we to do with it? The goal is most often to translate such data into a meaningful laboratory test which will provide a valid simulation of the environment measured. In our opinion, the best way to do this is through use of what we are calling the "Sheehan Method" – put forward by Richard L. Sheehan of 3M Packaging Systems in his Dimensions.01 presentation[3]. This is a "must-read" for anyone undertaking a drop height study with the intent of using it to configure laboratory tests. In summary, the method consists of first identifying the highest, second-highest, third-highest, etc. drop from *each individual shipment*, fitting each of these data sub-sets to an appropriate statistical distribution, then analyzing the *distributions* (not the data itself) to construct a laboratory drop test protocol. This will be demonstrated in the following sections.

The spreadsheet on the next page represents a summary of data to which the "Sheehan Method" of analysis was applied (all readings and subsequent analyses are in inches).

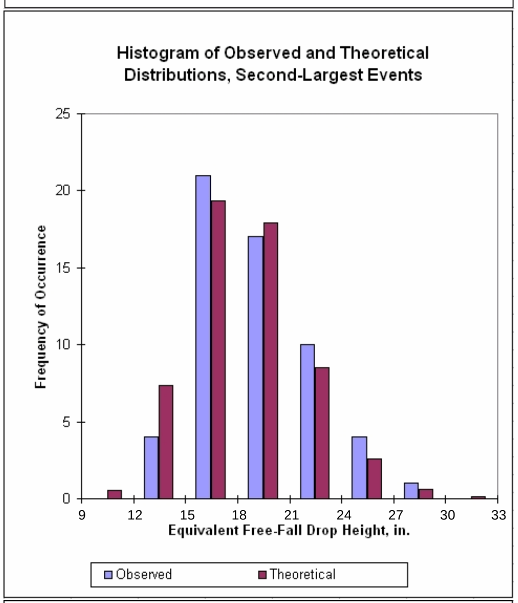
File	Total No. of Recorded Events	No. of Drops/Impacts at or Above 6"	Highest Drop/Impact from Ea. Trip	2nd Highest Drop/Impact from Ea. Trip	3rd Highest Drop/Impact from Ea. Trip	4th Highest Drop/Impact from Ea. Trip
A0X1	18	9	25	24	16	15
A0X	30	5	21	19	15	9
Paul2Bryan	39	9	25	24	21	18
A01b	30	9	21	16	14	14
A02	25	7	20	13	11	11
A04	47	12	19	15	13	13
A05	43	11	31	18	18	12
A06	38	10	21	21	21	17
A07	43	12	18	16	16	13
A08	37	13	20	17	15	14
A09	39	11	23	16	16	15
A10	38	19	27	20	18	15
A11	41	13	24	22	17	14
A12	42	15	24	15	15	15
A13	28	11	22	19	18	14
A14	70	21	42	22	21	15
A15	31	12	33	22	19	18
B0X G-S	34	9	19	17	16	16
B0X S-G	41	10	28	24	18	15
B01	22	8	25	21	19	14
B02	57	14	24	24	23	20
B03	39	9	28	21	12	11
B04	31	7	19	18	17	13
B05	28	9	32	29	23	21
B06	27	11	25	21	20	19
B07	27	8	26	19	18	17
B08	32	12	23	18	16	14
B09	32	13	22	18	14	13
B10	32	8	20	15	13	12
B11	38	7	22	18	14	13
B12	38	10	21	16	16	15
B13	41	13	26	23	20	20
B14	26	10	19	16	14	11
B15	28	5	21	13	10	9
B16	25	2	23	14	0	0
B17	24	5	19	19	17	13
B18	31	9	20	18	16	14
B19	22	7	23	12	11	10
B20	32	10	18	16	11	10
C0X-FS	32	13	17	17	16	16
C0X-F	32	7	21	15	9	9
C01	32	12	23	16	15	14
C02	35	12	24	23	21	20
C03	15	4	21	20	15	14
C04	27	7	18	17	16	13
C05	24	6	20	20	19	19
C06	55	9	20	19	18	16
C07	47	11	16	15	11	10
C08	37	8	23	17	17	12
C09	43	10	21	19	18	13
C10	20	5	24	19	15	15
C11	57	16	28	21	15	15
C12	46	14	21	20	18	17
C13	38	8	18	17	11	11
C14	35	8	21	15	15	12
C15	35	7	19	17	14	14
C16	39	4	22	16	10	10

Analysis of the Four Highest Drop Heights



Highest EFFDH

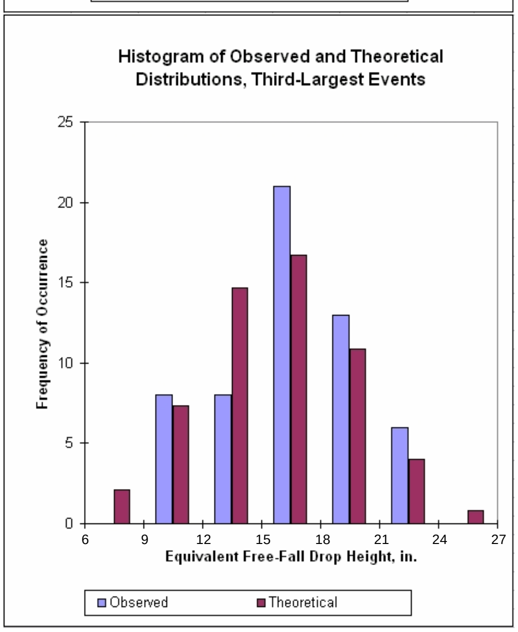
The highest drops/impacts from each shipment were found to fit a log-normal distribution as shown here.[4] The mean is 3.108 and the standard deviation is 0.176 expressed in ln inches. EFFDH for the 90th, 95th, and 99th percentiles are 29.9, 31.6, and 35.2 inches respectively. The 95th percentile is ordinarily recommended by Sheehan. However, notice the 42 inch drop from file A14. This point cannot be discounted, and might lead one to consider making the highest test drop(s) at the 99th percentile level, 35.2 inches.



Second-Highest EFFDH

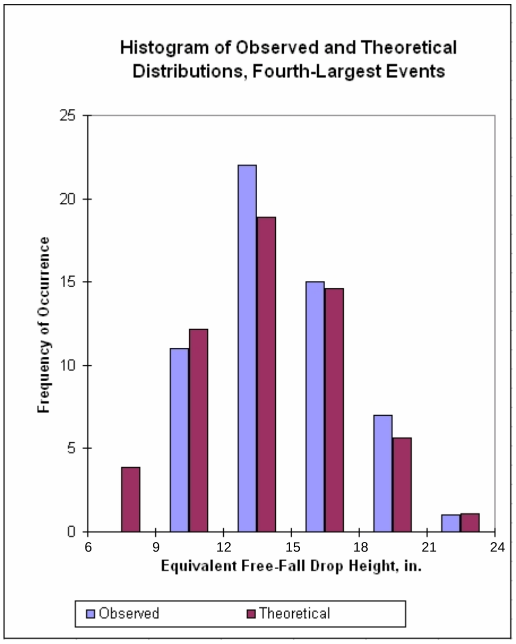
The second-highest drops/impacts from each shipment were also found to fit a log-normal distribution as shown here. The mean is 2.9 and the standard deviation is 0.176 expressed in ln inches. EFFDH for the 90th, 95th, and 99th percentiles are 24.3, 25.7, and 28.6 inches respectively.

Notice that this data fits the distribution very well, and that there are no obvious outliers.



Third-Highest EFFDH

The third-highest drops/impacts from each shipment were found to fit a normal (not log-normal) distribution as shown here. [The important attribute is the fit, not necessarily the type of distribution.] The mean is 15.7 inches and the standard deviation is 3.9 inches. EFFDH for the 90th, 95th, and 99th percentiles are 22.1, 23.4, and 25.8 inches respectively.

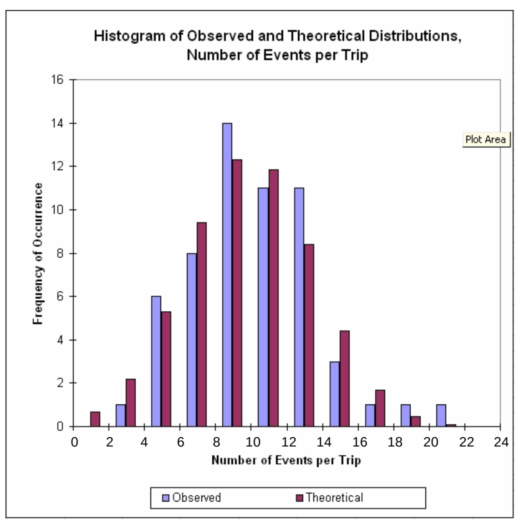


Fourth-Highest EFFDH

The fourth-highest drops/impacts from each shipment were also found to fit a normal distribution as shown here. The mean is 13.9 inches and the standard deviation is 3.5 inches. EFFDH for the 90^{th}, 95^{th}, and 99^{th} percentiles are 19.6, 20.7, and 22.9 inches respectively.

Number of Drops/Impacts Per Shipment

The "Number of Drops/Impacts at or Above 6 in." data from the summary spreadsheet was fit to a normal distribution as shown below. The mean of this data is 9.75 inches with a standard deviation of 3.57 inches. The 90^{th}, 95^{th}, and 99^{th} percentiles of numbers of drops/impacts per shipment are therefore 15.6, 16.8, and 18.9 respectively.



Impact Orientations

The instruments record impact orientations along with the acceleration data for each event. An analysis of these orientations for the 4 highest drops/impacts from each trip yielded the following:

- Flat-face impacts accounted for 21% of the total
- Edge impacts were 51%
- Corner impacts were 28%.

Further,

- Impacts on and around the bottom of the package (bottom face, bottom edges and corners) accounted for 52% of the total
- Impacts on and around the top of the package (top face, top edges and corners) accounted for 22%
- Flat vertical-face impacts were 12%
- Vertical edge impacts were 14%.

Creation of a Drop Test Protocol

As stated in the MADE-EMEA Scope section, these findings are not comprehensive enough in terms of shipment origins and destinations, package size and weight and configuration, carriers, routes, and other aspects to define a generally applicable drop testing protocol. In addition, creation of a laboratory test element must take into account the flow and sequences of the overall simulation Procedure, test equipment characteristics, efficient laboratory operations, etc. The following table presents possible numerical guidelines based only on this data and the above analyses of EFFDH, numbers of drops, and impact orientations.

	90th Percentile	**95th Percentile**	**99th Percentile**
Number of Drops	16	17	19
Highest EFFDH	30	32	35
2nd Highest EFFDH	24	26	29
3RD Highest EFFDH	22	23	26
4th Highest EFFDH	20	21	23

Since the 2nd-4th EFFDH are so closely spaced, one might consider condensing those into a single drop height, and therefore creating a protocol incorporating a small number of drops at the highest EFFDH, and a larger number of drops at a single height representative of the others. In recognition of the 42 inch drop from file A14, one might also consider performing the higher drops at the 99th percentile level, but performing the lower drops at lower percentile levels.

The determination of impact orientations, while somewhat subjective, should follow the data as closely as possible. From the results of this study, a reasonable approach might be as shown below (compare percentages to those given in the "Impact Orientations" section above). Certainly there could be other good arrangements.

	90th Percentile	**95th Percentile**	**99th Percentile**
Number of Drops	16	17	19
Possible Impacts and Orientations	2 flat base 4 base edges 2 base corners 1 top corner 2 top edges 1 flat top 2 flat vertical faces 2 vertical edges	2 flat base 4 base edges 2 base corners 2 top corners 2 top edges 1 flat top 2 flat vertical faces 2 vertical edges	3 flat base 4 base edges 3 base corners 2 top corners 2 top edges 1 flat top 2 flat vertical faces 2 vertical edges

We are reluctant to unconditionally specify a laboratory drop test protocol based on this data. However, based strictly on this data, and as an example for illustration only, consider these guidelines as a reasonable representation of the findings of this study:

- Total number of drops: Approximately 17
- Highest drops: One or two drops, on the base, from approximately 35 inches
- Lower drops: Remaining drops from approximately 24 inches (since the 2nd- through 4th-highest EFFDHs were all so closely spaced, it may make sense to consolidate them at a single drop height)
- Impact orientation of lower drops to approximately correspond to percentages given above.
- Example implementation:

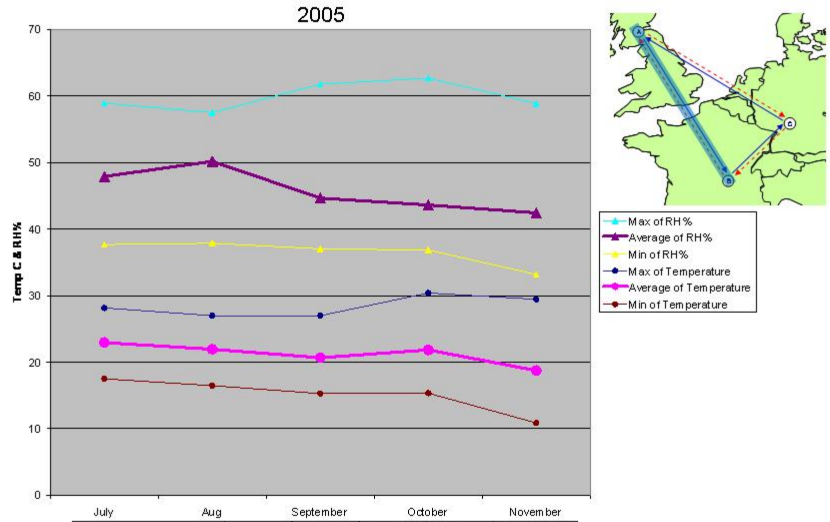
Drop Height	**Impact Orientation**
24 inches	Base corner
24 inches	Base edge
24 inches	Adjacent base edge
24 inches	Top corner
24 inches	Top edge
24 inches	Flat side
24 inches	Vertical edge
35 inches	Flat base
24 inches	Diagonally opposite base corner from previously tested
24 inches	Base edge previously untested
24 inches	Adjacent base edge previously untested
24 inches	Diagonally opposite vertical edge from previously tested
24 inches	Opposite flat side from previously tested
24 inches	Flat top
24 inches	Diagonally opposite top corner from previously tested
24 inches	Adjacent top edge previously untested
35 inches	Flat base

Temperature and Humidity Data

The focus of this study was the determination of drop heights, but the recorders easily measure temperature and humidity, so that data was taken as well. Below are summaries, detailed information is available for each individual shipment.

In box Temperature and Humidity - Route A

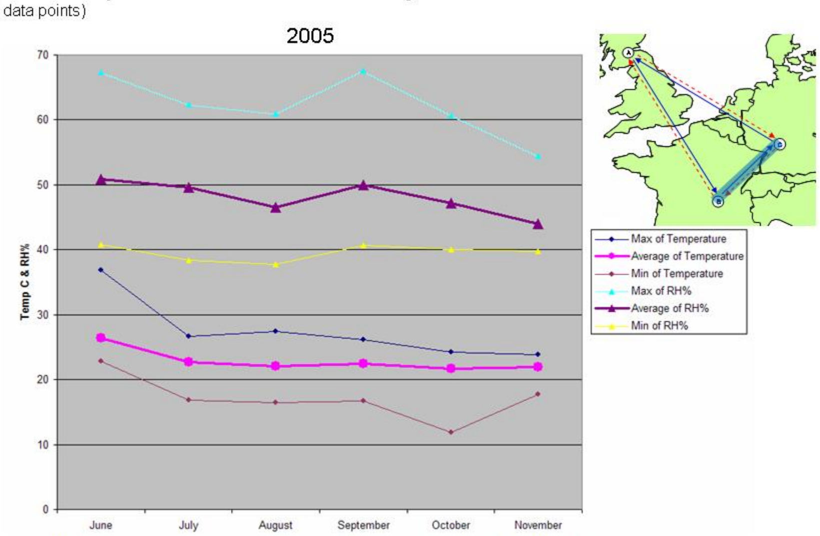
(84,767 data points)



Data	July	Aug	September	October	November
Max of RH%	58.90	57.50	61.77	62.68	58.87
Average of RH%	47.90	50.17	44.65	43.62	42.42
Min of RH%	37.66	37.86	37.04	36.84	33.18
Max of Temperature	28.15	26.99	26.99	30.39	29.43
Average of Temperature	22.93	21.93	20.67	21.83	18.74
Min of Temperature	17.51	16.47	15.27	15.35	10.87

In box Temperature and Humidity - Route B

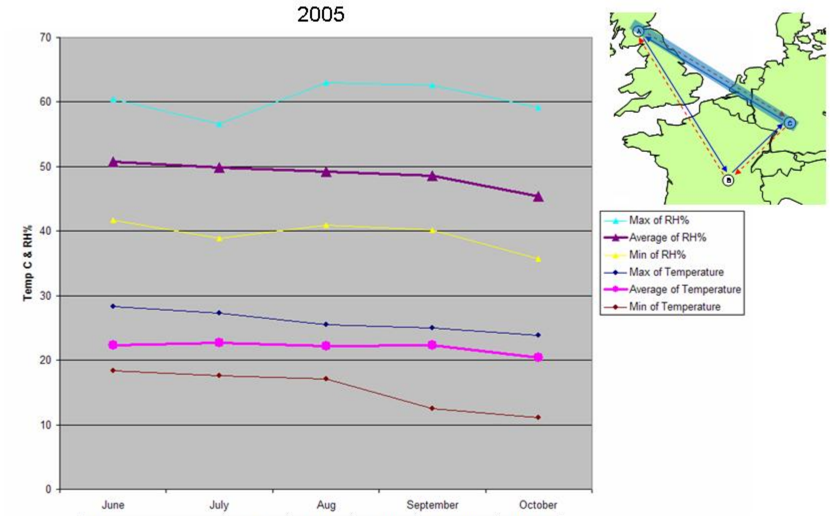
(18,668 data points)



Data	Aug	June	July	September	October	November
Max of RH	60.99	67.29	62.32	67.54	60.66	54.50
Average of RH	46.54	50.90	49.62	50.03	47.14	44.05
Min of RH	37.77	40.82	38.32	40.62	40.01	39.76
Max of Temperature	27.39	36.86	26.67	26.19	24.27	23.91
Average of Temperature	22.09	26.41	22.72	22.48	21.65	21.89
Min of Temperature	16.47	22.79	16.79	16.71	11.83	17.67

In box Temperature and Humidity - Route C

(18,237 data points)



Data	June	July	Aug	September	October
Max of RH%	60.41	56.65	63.03	62.66	59.14
Average of RH%	50.79	49.87	49.27	48.58	45.36
Min of RH%	41.68	38.92	40.98	40.16	35.68
Max of Temperature	28.35	27.31	25.55	25.03	23.87
Average of Temperature	22.33	22.67	22.19	22.27	20.45
Min of Temperature	18.35	17.55	17.11	12.47	11.03

Conclusions

The results of this study of Western Europe showed reasonable correlation with similar credible studies which have been done in the U.S. Perhaps we are getting to the point where the express carrier environment in many parts of the world is becoming reasonably well-defined. It is particularly interesting to compare drop test protocols which might be created from this data with the drop sequences in ISTA 3A (the Parcel Delivery System Shipment simulation test).

The MADE-EMEA study is being continued by SCA Packaging R&D in Central Europe, and already some 20 recorded shipments have been made between locations in Hungary, Poland, and the Czech Republic. Perhaps this will be the subject of a future report and presentation.

As might be imagined, these studies involve a considerable amount of time, effort, and expense. There is procurement of the recorders (our thanks again to Lansmont Corporation for providing the instruments), fabrication and calibration of the packages, logistics arrangements, the actual shipments, data management, and data analysis (our experience suggests that approximately one hour per file is required to properly analyze EFFDH data). On the other hand, the various steps are by now well defined, and it is hoped that this paper can serve as a guide for future studies involving different package configurations, modes, regions, routes, etc.

Much more information could be obtained from this data than what is presented here. Potentially, it might be possible to differentiate between carriers, routes, and locations, and (using the tracking files collected) correlate specific events with specific sites. We only performed a few of these types of analyses but due to time constraints forgo any further investigation. However, the data is there for others to use if desired.

Finally, it is hoped that this paper will serve as a tutorial on how to analyze drop/impact data. In our opinion, *detailed*, (and in many cases *manual*) examination and analysis of *each* significant event is required to ensure results integrity. We think the approach for arriving at drop heights as outlined in the "Overall Determination of EFFDH" section is both reasonable and workable. And emphatically, we are convinced that the "Sheehan Method" of translating study data into laboratory testing protocols should become a standard procedure for anyone doing this type of work.

References and Footnotes

[1] Gilmore, Evelyn, 1999, "Measurement and Analysis of the Distribution Environment", presented at TransPack 2000 Symposium, Austin TX & 2000 ISTACON conference, Orlando, FL. Available at: http://packaging.hp.com/misc/Presentation.

[2] Sheehan, Richard L., 1999, Section 3.3.1 Data Collection contribution to "Measurement and Analysis of the Distribution Environment", Available at: http://packaging.hp.com/made/FinalReport/made_study.htm.

[3] Sheehan, Richard L., 2001, Dimensions.01 presentation "Analysis of Drop Height Data".

[4] All distribution fitting was within 95% confidence intervals. All statistical analysis was performed with XLSTAT-Pro version 7.5.3, available from Addinsoft, http://www.xlstat.com.