EXPRESS SHIPPING DROP / IMPACT STUDY IN CENTRAL AND EASTERN EUROPE

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Background

Through the supply chain, goods are subjected to forces from acceleration and vibration together with environmental conditions such as temperature and humidity. In order to ensure that the goods are not coming to harm, the right specification of packages needs to be addressed. The package has to be designed to give the proper protection while using the right amount of material, i.e. over packing is not accepted nor is under packing. It is important to have reliable data for the validation of packages, and in order to design a proper package the distribution environment is one of the most important factors. Today the knowledge about the distribution environment is increasing but still it is often quite difficult to get reliable data.

Packaging suppliers have different systems to take care of the design and the development of new packages, all from collecting the right input data to estimating the final physical performance of a package. As an example, SCA Packaging works with a design process in four steps at its Innovation Centre and through its network of Design Centres across Europe when a new or an optimization is made of an existing package. In the beginning of a project, in what is called the Research phase, information from the distribution environment is collected into the project. In this work it is important to have knowledge and correct information about the supply chain conditions. The experience is that this information is usually not easy to get and the customer and the user of the package does not always have enough information or maybe limited insight in the supply chain.

A number of projects with the aim to map the distribution environment at different locations have been performed during the past years, e.g. the MADE (Measurement and Analysis of the Distribution Environment) [1], EMEA-MADE (European Express Shipping Drop/Impact Study) [2] and SRETS (Source Reduction by European Testing Schedules) [3] studies. The objective of the studies is to build or to develop existing standards for packaging and transportation testing. The information received from these studies is for example the distribution of drop heights depending on package weight and the influence of time to rupture for a package depending on the peak acceleration and where in the supply chain different peak accelerations occurs, Figure 1.

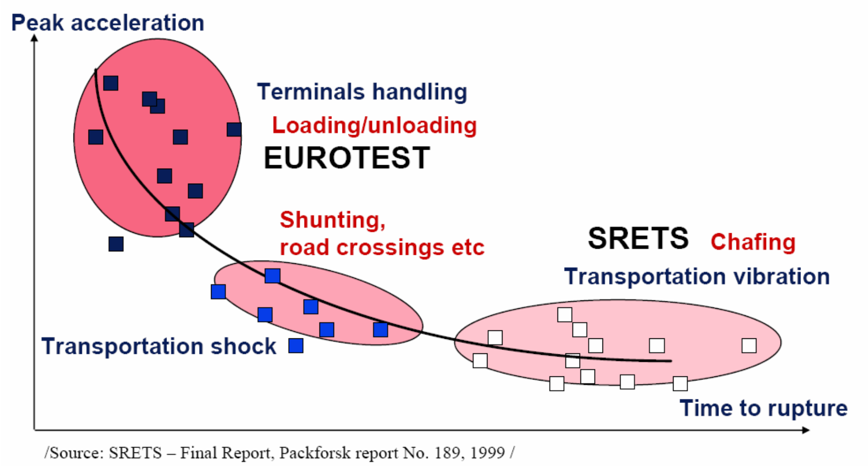


Figure 1. Fatigue vs. breakdown, dependence of amplitude of a mechanical dynamic load from the number of cycles leading to failure ([1] Braunmiller, U., 1999)

During 2005 a co-operation was initiated between Hewlett-Packard and SCA Packaging Europe in order to perform such a study in Europe. Hewlett-Packard had already participated in an industrial study mapping events during transportation, MADE Project (Measurement and Analysis of Distribution Environments), in US. The aim of that project was to develop a protocol on how transportation should be mapped. In the joint project in Europe Hewlett-Packard performed a study in Western Europe (France, Germany and UK) that was reported at Dimensions.06, and SCA started up the mapping of the eastern part of Europe (Czech-Republic, Poland and Hungary) in November 2006.

Objective

The objective of this study was to map events (primarily drops and impacts as well as temperature and humidity) during a number of shipments in Central and Eastern Europe, and to compare the data with that from last year's study of Western Europe.

The long term goal is to build up a knowledge bank of transportation events and to develop ISTA testing standards within (Eastern) Europe. Further on the data will be used for future optimisation of packages and to ensure that goods are not over packed, thus minimising the amount of packaging material, and minimising the environmental impact of materials.

Experimental (Test Conditions)

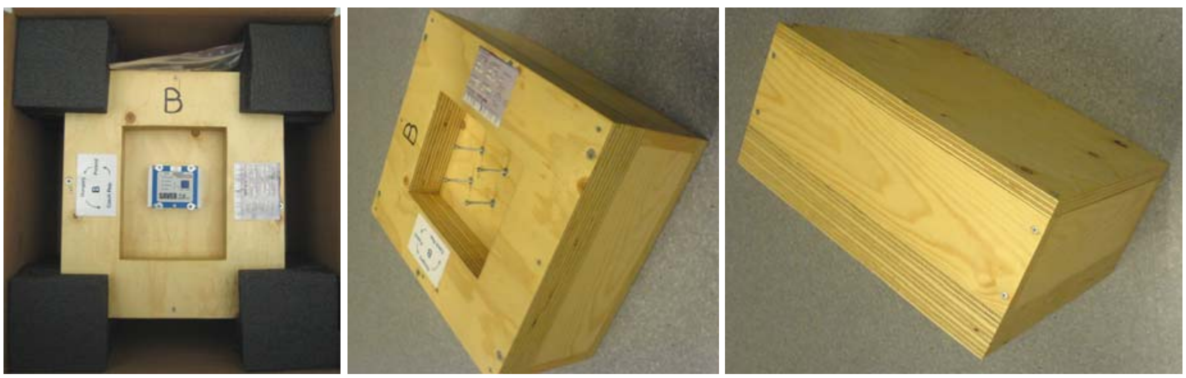
Design of Package

The concept in this project was to ship instrumented packages containing a data recorder via express carriers in order to map the distribution environment. A pre-defined package according to earlier MADE studies was used in the project. The package size and weight was designed to be comparable to HP products, in the trial replaced with a dummy product. The total weight of the package was 13,2 kg (29 lb.) divided into 10,2 kg (22.5 lb.) for the dummy product, 0,5 kg (1 lb.) for the field recorder, and 2,5 kg (5.5 lb.) for the package material.

The package was replaced every 3rd or 6th trip when passing one of the locations in the route, the location in Hungary. The other two locations could also replace the package if needed.

Dummy Product

The dummy product was made out of wooden material according to the photographs below. The outside dimensions of the dummy product is 432*381*203 mm (17 x 15 x 8 inches) and the weight is 10,2 kg (22.5 lb.), in line with the EMEA-MADE project. The weight of the dummy product was tuned using metal plates mounted inside the dummy. Space for the field recorder was prepared on top of the dummy enabling a rigid and safe mounting.



The dummy product made out of wood. Photo at left shows the recorder mounted.

Field Recorder

The Saver, 3X90, from Lansmont Corporation was used as field recorder in the project. The field recorder was mounted rigidly onto the dummy product and oriented with X and Y directions of the Saver parallel to the sides of the box and Z direction pointing to the top of the box. The project had access to two Saver 3X90.

The Saver 3X90

Corrugated Board

The corrugated board box was a FEFCO#0201, regular slotted container, with a board make-up being BC-flute with KN186-RF140-RF140-RF140-KN186 (KN=Kraftliner, RF=Recycled based fluting and the figures are the grammage in g/m²). The dimensions of the box were 534*483*305 mm (21 x 19 x 12 inches), inside measures. The physical properties for such board grade are according to Table 1.

Table 1. Board physical properties.

Board property	Estimated average	Measurement method
Board Thickness	6,8 mm	ISO 3034
Board Weight	915 g/m²	ISO 536
Edge Crush	10,8 kN/m	ISO 3037
Puncture	12,2 J	ISO 3036
Board Burst (dry)	1908 kPa	ISO 2759
Bending Stiffness MD	38,49 Nm	SCAN P65:91
Bending Stiffness CD	17,58 Nm	SCAN P65:91

Cushion Material

A cushion material of 50 mm (2 inches) thick expanded poly ethylene EPE foam was used for the corner protection. 8 corner blocks were included in each box. The request was to protect the field recorder from accelerations above 50 G's when dropped from 1,5m (60 inches). The acceleration for the final configuration was tested and the maximum acceleration detected was 45 G's when dropped on the Edge - Front Top from 1,5m (60 inches).

Data Collection Phase

Local offices of SCA Packaging were chosen as destinations to ship and receive the package during the trial in Eastern Europe. The shipments were between Budapest in Hungary, Poznan in Poland, and Pardubice in Czech-Republic according to Phase two in Figure 2.

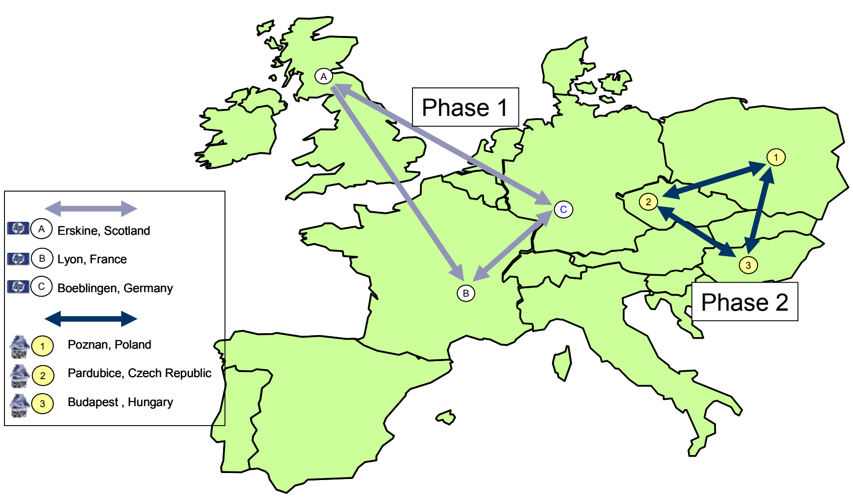


Fig. 2: Route map for the MADE study in Europe

The project had access to two Saver 3X90 and as we could not supply each route with its own field recorder it was decided to ship one Saver in the direction Poland – Czech Republic – Hungary and one Saver in the opposite direction, Poland – Hungary – Czech Republic. This was decided in order to build up data from all routes at the same time as we did not want to exclude any of the routes.

The intention when planning the project was to carry out 15 roundtrips for each route, i.e. a total number of 90 single trips. However this turned out to be more time consuming than expected and in the end data from a total of 40 single trips were collected divided into 13-14 trips per route according to Table 2.

Table 2. Number of trips made for the different routes.

Route (both directions)	No. of trips
HU – PL	14
HU – CZ	13
PL – CZ	13

Procedures for Administering the Package During the Trial

Instructions for sending and receiving the Savers was prepared and distributed to the project members that were going to administer the packages. These were in line with the procedures already tested in previous MADE studies. After each trip the data from the data recorder was downloaded and saved in an e-room or to CD. The recorder was restarted, repacked and sent for the next trip according to the same procedures as in earlier MADE studies.

Procedure 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 e-room, or put it on a CD and send to Olle Söderström, Box 716, SE-851 21 Sundsvall, Sweden
7. Send tracking number or information report from the carrier’s web site as a PDF file to olle.soderstrom@sca.com
8. Continue to Procedure for SAVER™ 3X90™ preparation for shipment

Procedure 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

Data Recorder Set Up

The data recorders’ setup parameters were also chosen according to the earlier MADE studies. Figure 3 shows a screen dump from the saver set up.

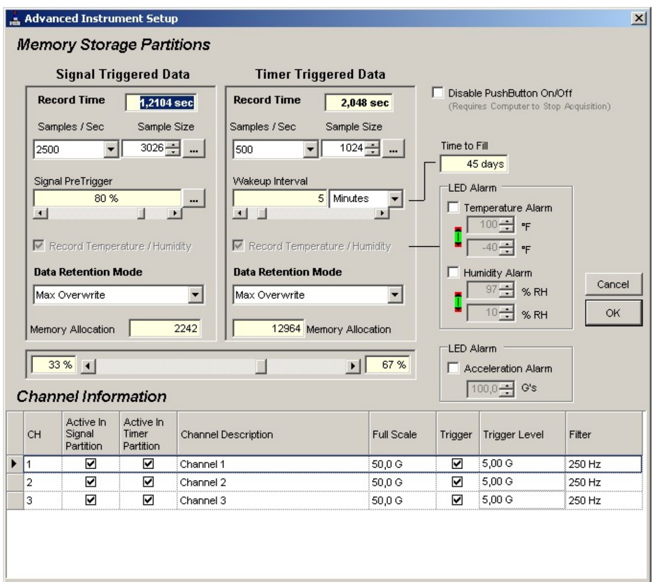


Fig. 3: Data recorder setup.

Carriers

For the shipments some different carriers were used, i.e. UPS, DHL and Schenker, depending on local agreements. Tracking information received from the websites of the transportation companies was also collected and included in the data collection.

Data and Analysis

A total of 11,539 events were recorded from the 40 one-way trips. Of these, 472 were determined to be “significant”, i.e. with *equivalent free-fall drop heights* (see explanation below) of 6 inches (15 cm.) or greater.

The total number of recorded events was much larger than necessary, due to the recording threshold being inadvertently set too low for many of the trips. Fortunately this did not reduce the data validity nor the quality of the results, the only effect was to make analysis somewhat more time-consuming.

Data was analyzed in exactly the same manner as for the Western European study reported last year [2], not only because the approach is technically sound and can lead directly to meaningful laboratory testing protocols, but also to allow direct comparison with the previous work. Recorded events were analyzed in terms of *equivalent free-fall drop heights* (EFFDH), then the 4 highest drops/impacts from each trip and the number of drops per trip were statistically analyzed in accordance with the "Sheehan Method" [4], [5].

Equivalent Free-Fall Drop Heights

In the laboratory, we typically simulate *all* the shocks of the express shipping environment (not only from drops and tosses, but from slides, conveyor operations, diverter strikes, package-to-package impacts, manual sorting, etc.) with free-fall drop tests onto a hard surface. Therefore it makes sense to analyze the data in terms of *equivalent free fall drop height* (EFFDH), corresponding to how it will eventually be used. This means that *every* significant shock event, not only drops and tosses, is examined and analyzed in such a way that the resulting lab tests, insofar as possible, will have similar damage potential.

Velocity Change, Coefficient of Restitution, and Impact Velocity

The SAVER™ 3X90 companion software, SaverXware, currently does not automatically calculate EFFDH. SaverXware's automatic drop height analysis is intended for free-fall drops and is based primarily on a "zero-g / fall-time" algorithm. Our goal, however, was to express the shock events (drops and otherwise) recorded from the express shipping environment as EFFDH. The instrument's three-channel recorded shock pulses *can* yield EFFDH information with good accuracy, and the software allows the manual interpretation to produce the information we desired. SaverXware's "zero-g" channel information was used as part of a more extensive overall analysis strategy as described below.

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 Data

The coefficient of restitution ***e*** may be derived from package calibration data. Since the packages, cushions, and dummy products used for this project were identical to those of the previous study [2], the same calibration data was used. This resulted in using ***e*** = 0.43 for impacts with hard surfaces, ***e*** = 0.3 for impacts with moderately soft surfaces, and ***e*** = 0.2 for impacts with very soft surfaces.

Calculation of Impact Velocity from Velocity Change

The procedure for calculating impact velocity from recorded shock pulses was as follows:

- The overall three-channel velocity change was calculated from the square root of the sum of the squares of the velocity changes from channels with applicable shock data.
- If peak accelerations indicated impact with a hard surface, an ***e*** of 0.43 was used to calculate impact velocity.
- If peak accelerations indicated impact with a moderately-soft surface, an ***e*** of 0.3 was used to calculate impact velocity.
- If peak acceleration indicated impact with a soft surface, an ***e*** of 0.2 was used to calculate impact velocity.

Determination of EFFDH

For each of the 472 "significant" events (EFFDH of 6 inches {15 cm.} or greater), the analysis was conducted as follows:

- If, from examination of the "zero-g" data, the event appeared to be essentially a "pure" free-fall drop, the software analysis was either taken directly or used to determine drop height and entered as the EFFDH.
- 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 in the previous section.
- 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.

Statistical Analysis

Typically the goal of studies such as this is ultimately to translate the 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 have called the "Sheehan Method" – put forward by Richard L. Sheehan of 3M Packaging Systems in his Dimensions.01 presentation [4], [5]. 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).

The distribution type is not critical, only that the fit be a good one. The statistical software used for this study, XLStat from Addinsoft [6], allows 25 different types to be tried. Of these, it was found that the data fit a normal or a log-normal distribution as indicated below.

The following spreadsheet represents a summary of the data from this study to which the "Sheehan Method" of analysis was applied (readings 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
CZ-HU-1	88	7	16	11	10	10
CZ-HU-3	24	5	28	16	15	12
CZ-HU-4	297	15	28	26	24	17
CZ-HU-5	199	15	21	18	17	17
CZ-HU-7	154	10	23	22	17	15
CZ-PL-1	219	8	28	11	10	9
CZ-PL-3	134	7	14	12	12	9
CZ-PL-4	45	11	24	21	20	17
CZ-PL-5	67	6	13	12	11	11
CZ-PL-6	187	6	23	21	8	8
CZ-PL-7	586	9	27	20	14	14
CZ-PL-8	427	9	16	15	15	15
HU-CZ-1	341	21	22	19	18	17
HU-CZ-2	204	10	21	17	15	14
HU-CZ-3	199	15	29	23	19	17
HU-CZ-4	30	10	18	17	14	13
HU-CZ-5	39	9	18	17	16	14
HU-CZ-6	91	14	18	16	14	13
HU-CZ-7	922	11	25	18	18	14
HU-CZ-9	675	12	24	17	15	15
HU-PL-1	264	14	18	17	15	14
HU-PL-2	184	19	28	22	21	20
HU-PL-3	44	10	17	14	14	13
HU-PL-4	177	12	26	20	18	18
HU-PL-5	449	15	32	21	21	16
HU-PL-6	187	9	26	20	15	11
HU-PL-8	148	14	24	20	20	17
PL-CZ-1	544	15	32	23	15	15
PL-CZ-2	26	11	19	19	13	12
PL-CZ-3	32	12	20	16	14	14
PL-CZ-4	133	5	11	10	8	7
PL-CZ-5	162	10	19	16	15	13
PL-CZ-6	198	17	18	12	11	11
PL-HU-1	147	21	43	16	14	12
PL-HU-2	180	18	24	16	15	13
PL-HU-3	36	11	20	18	18	17
PL-HU-4	33	10	22	16	10	8
PL-HU-5	191	15	25	18	17	17
PL-HU-7	1675	15	20	19	15	11
PL-HU-8	1801	9	29	16	15	11

Highest EFFDH

The data was found to fit a log-normal distribution with a significance alpha level of 5%. The mean of this distribution is 3.089 and the standard deviation is 0.267, expressed in ln inches. At the 95th percentile (the level ordinarily recommended by Sheehan), this highest EFFDH is 37.1 inches (94.2 cm).

Second-Highest EFFDH

The data was found to fit a log-normal distribution with a significance alpha level of 5%. The mean of this distribution is 2.837 and the standard deviation is 0.220, expressed in ln inches. At the 95th percentile this 2nd highest EFFDH is 26.3 inches (66.8 cm).

Third-Highest EFFDH

The data was found to fit a normal (not log-normal) distribution with a significance alpha level of 5%. The mean of this distribution is 15.15 inches and the standard deviation is 3.549 inches. At the 95th percentile this 3rd highest EFFDH is 22.1 inches (56.1 cm).

Fourth-Highest EFFDH

The data was found to fit a log-normal distribution with a significance alpha level of 5%. The mean of this distribution is 2.577 and the standard deviation is 0.247, expressed in ln inches. At the 95th percentile this 4th highest EFFDH is 21.3 inches (54.1 cm).

Number of Drops/Impacts Per Shipment

The "Number of Drops/Impacts at or Above 6 in." data from the summary spreadsheet was found to fit a normal distribution with a significance alpha level of 5%. The mean of this distribution is 11.8 and the standard deviation is 4.096. At the 95th percentile, the number of drops/impacts per shipment calculates to 19.8. Of course one cannot perform fractional drops in the lab, so this number is rounded to 20.

Impact Orientations

Impact orientation for each event is calculated by an algorithm in the SaverXware software. As with the Western Europe study of last year, SaverXware's determinations were used without modification.

Reported orientations for the 4 highest drops/impacts from the 40 trips were as follows:

- Flat-face impacts accounted for 22% of the total.
- Edge impacts were 46% of the total.
- Corner impacts were 32% of the total.

Further,

- Impacts on and around the bottom of the package (bottom face, bottom edges and corners) accounted for 71% of the total
- Impacts on and around the top of the package (top face, top edges and corners) accounted for 14% of the total.
- Flat vertical-face impacts were 6% of the total.
- Vertical edge impacts were 9% of the total.

Comparison with Data from Western Europe

EFFDH and Number of Drops/Impacts

The table below compares the data from this study with the data from last year's study of Western Europe. All readings are 95th percentile.

	Highest EFFDH	2nd Highest EFFDH	3rd Highest EFFDH	4th Highest EFFDH	No. of Drops/Impacts per Shipment
Western Europe	31.6 in. (80.3 cm)	25.7 in. (65.3 cm)	23.4 in. (59.4 cm)	20.7 in. (52.6 cm)	17
Central/Eastern Europe	37.1 in. (94.2 cm)	26.3 in. (66.8 cm)	22.1 in. (56.1 cm)	21.3 in. (54.1 cm)	20

Certainly there appear to be differences in the results. But are the numbers *statistically* different? Statistically, results must be judged not only in terms of the differences in their means, but also relative to the variability of the underlying data. If the underlying data is not tightly grouped, it may not be possible to actually identify dissimilarities.

To test for *statistical* differences, a t-test / ANOVA (Analysis of Variance) was applied to the data. Not surprisingly, it was found that the means for the 2nd, 3rd, and 4th highest EFFDHs were not statistically different (i.e., the results from the two studies may be essentially the same). What <u>was</u> surprising, however, was that the means for the highest EFFDHs were *also* not significantly different, although in this instance the conclusion was not as statistically certain. Perhaps there *is* a difference, but maybe not as great as the numbers in the table would indicate.

When the t-test / ANOVA was applied to the Number of Drops/Impacts per Shipment, it indicated a real difference in the two numbers. So it appears that there actually may be a few more shock events during distribution in Central and Eastern Europe as compared to Western Europe.

Impact Orientations

The table below shows a comparison of the impact orientations from this study with those of last year's Western Europe study, as a percentage of the total number of impacts of the 4 highest EFFDH from the 40 trips.

	Flat	Edge	Corner		o/a Bottom	o/a Top	Vertical Flat Face	Vertical Edge
Western Europe	21%	51%	28%		52%	22%	12%	14%
Central/-Eastern Europe	22%	46%	32%		71%	14%	6%	9%

While the proportion of flat, edge, and corner impacts is quite similar for both studies, the Central/Eastern European data shows a greater prevalence of impacts on and around the bottom of the package, with correspondingly lower percentages of impacts on and around the top, and on the vertical faces and edges.

Conclusions

The Central/Eastern Europe study data showed the 95th percentile Equivalent Free-Fall Drop Heights to be as follows:

- Highest EFFDH per shipment = 37.1 inches (94.2 cm).
- Second-highest EFFDH per shipment = 26.3 inches (66.8 cm).
- Third-highest EFFDH per shipment = 22.1 inches (56.1 cm).
- Fourth-highest EFFDH per shipment = 21.3 inches (54.1 cm).

A comparison with data from Western Europe indicated that the results from the two studies were statistically similar, with the possible exception of the highest EFFDH. Taken together, the information would suggest a lab drop testing protocol consisting of a few drops from 32 - 37 inches (81 - 94 cm) along with a larger number of drops from perhaps 60-70% of the highest value.

The Central/Eastern Europe study data showed the 95th percentile Number of Drops/Impacts per Shipment (above 6 inches {15 cm}) was 20, compared with 17 for the Western Europe study of last year. The difference cannot be explained at this time; perhaps a visual observation or further information about the various express shipment systems would suggest a reason.

Impact orientation proportions between flat face, edge, and corner impacts were 22%, 46%, and 32% respectively. This is very similar what was reported in last year's study of Western Europe. However, when analyzed as proportions of impacts "on and around the bottom of the package", "on and around the top", "vertical faces", and "vertical edges", the Central/Eastern Europe data showed a significantly greater percentage of bottom impacts. Again, this difference cannot be explained from the data alone; perhaps a visual observation or further information about the various express shipment systems would suggest a reason.

More information could be obtained from this data than what is presented here. Using the tracking files collected, it might be possible to differentiate between carriers, routes, and locations, and to correlate specific events with specific sites. We did not perform these analyses, but the data is available for others to use if desired.

It is hoped that this paper can serve as a model regarding the analysis of drop/impact data. In our opinion, detailed examination and analysis of each significant event is required to ensure results integrity, regardless of the recording instrument used. And emphatically, we are convinced that the "Sheehan Method" of statistical analysis should become the standard procedure for anyone doing this type of work.

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