

Article

Measurement and Analysis of the Shock and Drop Levels Experienced by Small and Medium Packages in the Korean Parcel Delivery System

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Abstract: South Korea is one of the leading markets for the e-commerce industry. In line with the rapid growth of the e-commerce industry, the parcel delivery volume in Korea has also proliferated. Despite the developments in the Korean e-commerce and courier industries, consumers still experience a high package damage rate. In response, many packaging engineers in Korea have raised the need for new parcel shipping environment tests that reflect the Korean ground shipping environment in order to properly optimize packages. However, only limited information on the Korean parcel shipping environment is currently available. Therefore, this study focused on measuring and analyzing the shock and drop levels that parcels experience during ground shipping in Korea. Shock data were collected from a total of sixty one-way shipments for small, lightweight packages and medium, mid-weight packages. The findings revealed that the two types of boxes do not experience significantly different numbers of shock events or drop heights in the Korean parcel delivery environment. Furthermore, the number of shock events that occur in Korea is substantially less than the international testing standard and less than in previous studies conducted in both Europe and the USA. In contrast, however, the drop heights are higher than those in the international testing standard and previous studies. Shock events were found to occur most frequently on the edges and to be concentrated around the bottoms of the packages. Most shock events happen while packages are loaded and unloaded at hub terminals and sub terminals.

Keywords: parcel delivery; e-commerce; shock; drop; Korea; shipping environment; packaging



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1. Introduction

The e-commerce industry thrives in South Korea, making it a prominent market for this sector. South Korea was ranked as the fifth largest e-commerce market in the world in 2021, following China, the United States, the United Kingdom, and Japan [1]. Their domestic e-commerce sales reached \$168.5 billion in 2021, taking advantage of the fact that 99.7% of Koreans have internet access through the high penetration of PCs and smartphones [1], advanced and fast logistics systems, and convenient online payment systems [2]. In line with the rapid growth of the e-commerce industry, the parcel delivery volume in Korea has grown at least 7% annually since 2012 [3].

E-commerce package shipments often result in multiple intermediate steps throughout the logistics chain, including loading, unloading, sorting, transport between distribution centers, and last-mile delivery. During these intermediate steps, packages inevitably face multiple hazards and issues, such as theft, inconvenient last-mile delivery services, and harsh package handling. These hazards and issues could increase the cost and decrease the efficiency of package delivery. Thus, researchers have been introducing innovative ways to improve shipping management efficiency from different aspects. A particular focus is on improvements to last-mile delivery systems, such as the use of smart lockers [4–6] and drones [7–9], and the characterization/simulation of hazards associated with

the intermediate package distribution steps. Among these, characterizing and simulating proper hazards that occur during intermediate package distribution steps is a crucial element for shipping management efficiency because if packages are not designed for the correct shock and vibration hazards, they can be damaged. If a package is broken, it does not matter how fast it is delivered, how well the infrastructure is designed, or how good the package graphics are, as the customer still does not receive the product.

Despite developments in Korea's e-commerce and courier industries, consumers still experience high package damage rates. According to a previous study, 33% of the 1000 people surveyed had experienced delivery accidents, and 41% of those accidents were categorized as having damaged the package [10]. A high package damage rate can not only negatively affect consumer perception of the selling and courier companies but also necessitate high, unnecessary expenditures due to the returning of packages and resending the products to customers. In order to decrease the damage rate, testing packaging in a properly simulated distribution environment, and then optimizing it based on the test results, is necessary. Package optimization using proper lab simulations of package distribution hazards can contribute to significant waste and overused material reductions, leading to more sustainable, cost-effective, and highly satisfactory packages for customer.

In the past, many researchers have endeavored to define the package shipping environments of different geographical regions [11–17], service providers [14,15,17,18], and types of shipping services [14,15,17–21]. Singh and Voss [16] investigated the small parcel ground shipping environments of UPS within the USA. Singh and Cheema [18] later measured the overnight US domestic air shipping service environments for small packages through FedEx and UPS. Singh et al. [21] conducted the first study that measured the US domestic ground shipping environments of large and heavy packages through UPS. Singh et al. [19] measured FedEx's US domestic second-day air parcel delivery environments for small and lightweight packages. Singh et al. [17] compared the next-day air parcel delivery environments of the United States Postal Service (USPS), FedEx, DHL, and UPS. Russell and Kipp [12] expanded the parcel shipping environments measured to include different geographical regions than the USA. They measured the express parcel shipping environment of Western Europe and proposed a new drop test protocol for this region. Meanwhile, Garcia-Romeu-Martinez et al. [15] also conducted parcel shipping environment measurements of the transcontinental international air shipping services of DHL and FedEx between the USA and Europe. Singh et al. [20] collected data for the US ground shipping environment for products packaged in pails, while most of the historical studies focused on products packaged in a box shape. Saha et al. [14] measured and compared the inter-state and intra-state next-day shipping environments within the USA. In recent years, research on the express parcel shipping environment for small packages was also conducted in China [13].

Suh et al. [11] recently investigated the ground shipping environment for loads of packaged parcels in Korea, including the drops and vibrations that the parcels experience. The study was conducted using five different package types and two different couriers. However, this study had multiple critical limitations to it being used for establishing a new regionalized package testing protocol. The study omitted analysis of the impact orientations that could help decide which drop orientation should be included in the test protocol to simulate the shipping environment as similarly as possible. The study lacked statistical analysis of the number of drops and drop height results and only provided average numbers.

Although ISTA 3A [22] and ASTM D7386-16 [23] are viewed as renowned international standards, their shock testing sequences are built predominantly to simulate US delivery systems. However, historical studies have proven that different countries have unique characteristics to the shock events that packages experience during transportation. For example, packages transported in different countries can experience different numbers, extents, and directions of shock events based on the various warehousing technologies

used in the countries; they will also have different loading/unloading methods, sorting technologies, and numbers of handling points. Therefore, the previously introduced historical studies have provided valuable data on which packaging engineers can base the establishment of laboratory package testing procedures that reflect their country's environment. The International Safe Transit Association (ISTA) is also conducting major research work on characterizing the shock and vibration profiles in different countries' package distribution systems, such as China, India, European Union, Mexico, and Japan, in order to have more country-specific package test profiles [24,25]. This implies that characterizing package distribution environment hazards is highly demanded and needed by the industry. However, due to the lack of regional standards, packaging engineers in Korea are still relying on international testing standards, such as ISTA 3A [22] and ASTM D7386-16 [23], to test their packages. Given the limitations of previous studies and the lack of information on the shock environment in the Korean parcel delivery system, one of the largest food companies in Korea, CJ CheilJedang, and one of the leading Korean logistics companies raised the need for a more extensive study to fully understand the ground shipping environment and establish proper parcel testing for Korea. This study selected ground shipping services to investigate since they account for 93% of parcel delivery in Korea [26] due to their shorter delivery distances when compared with larger geographical regions such as USA, Europe, or China. Two out of the three main components of package test protocols, over-the-road truck vibration profiles [27] and last-mile delivery vehicle vibration profiles [28], have recently been investigated for the Korean package distribution system. Despite the above-mentioned critical impact of regionalized package testing standards, to the best of our knowledge, no previous studies have thoroughly investigated the remaining component of package testing protocols, which is the shock profile for packages in Korea. Therefore, this paper aims to serve as a pioneering study, conducted for the first time in Korea, and endeavors to utilize statistical analysis to characterize the levels of shocks and drops experienced by small-sized, lightweight packages (small) and mid-sized, mid-weight packages (medium) transported through ground shipping services. This study can significantly contribute to the Korean packaging industry by filling the last knowledge gap in order to establish regional package testing standards for Korea, allowing them to optimize their packages for their distribution environment instead of optimizing them for the US environment, where different shipping management technologies are used.

2. Materials and Methods

Instrumented decoys that contain field data recorders and methods of processing and analyzing recorded data were required to characterize the numbers and levels of the shocks and drops experienced by packages in the Korean parcel delivery system. In this section, how the field data recorders were set up, how the instrumented decoys were built, the experimental design, the calibration process for the decoys, and the data analysis methods used are discussed in detail.

2.1. Instrumentation and Recording Parameters

Saver 3X90 data loggers, manufactured by Lansmont Corporation (Monterey, CA, USA), were used as field data recorders in this study (Figure 1) to capture the levels of shocks and impacts experienced by parcels traveling through the Korean parcel delivery system. The data loggers provided the ability to measure the full triaxial acceleration time history waveform data with user-defined pre-trigger recording settings. The recording parameters used for this study were as follows:

Signal triggered recording:

- Record time: 1.64 s
- Sampling rate: 2500 Hz
- Signal pre-trigger: 65%
- Trigger level: 2 g
- Data retention mode: max overwrite



Figure 1. Field data recorder (3X90).

2.2. Instrumented Decoys

In this study, four instrumented decoys of two different sizes and weights (small and medium) were used. Due to the absence of published data on the most used package sizes and weights, the sizes and weights of the decoys were determined based on recommendations from one of the largest shipping companies in Korea. The sizes and weights of the decoys were chosen to simulate the physical characteristics of the most commonly used e-commerce packages, as per the Korean shipping company's internal data. This study aimed to provide shock data for a range of package sizes, enabling packaging engineers to utilize the study's data to effectively test a broad spectrum of package sizes. The decoys were composed of regular slotted container (RSC)-style outer shipper corrugated boxes, polyethylene (PE) cushioning foam planks, RSC inner corrugated boxes with no minor flaps, and aluminum frames with steel plates that held the Saver 3X90s in the middle (Figure 2).



Figure 2. Structures of instrumented decoys: (a) small decoy and (b) medium decoy.

2.2.1. Aluminum Frame

Aluminum frames were created to simulate the product in the package. The aluminum frames were manufactured using 38.1 mm × 38.1 mm (1.5 in. × 1.5 in.) and 50.8 mm × 50.8 mm (2 in. × 2 in.) t-slotted framing rails for the small- and medium-sized decoys, respectively. A steel plate placed in the middle of the frame was used to match the desired weight of the instrumented decoy and to hold the field data recorder in the middle. The outside dimensions of the aluminum frames were 377.8 mm × 252.8 mm × 171.8 mm and 277.8 mm × 177.8 mm × 151.8 mm for the medium and small decoys, respectively.

2.2.2. Inner Box

The aluminum frame was placed in the inner corrugated box to increase the contact surface area between the aluminum frame and the cushioning foam in order to prevent damage to the cushioning foam, which occurs when it experiences highly concentrated forces, such as at the corners. The internal dimensions of the inner box were selected to snugly contain the aluminum frame and to prevent any internal movement. They were made of nominal, 32 ECT, B flute, single-wall corrugated board and manufactured by Virginia Tech researchers using a Kongsberg X Edge computerized cutting table (Kongsberg Precision Cutting Systems, Ghent, Belgium). The inner boxes were sealed with 55 mm (2 in.) packaging tape (3M, St. Paul, MN, USA).

2.2.3. Cushioning Foam

The inner box was surrounded with PE foam planks. The material and thicknesses of the PE foam planks used as cushioning materials were selected to ensure the field data recorders did not experience more acceleration than they could handle (200 g). Ethafoam 220 planks with laminated Ethafoam 600 skin manufactured by Sealed Air Corporation (Charlotte, NC, USA) were used for the medium decoys. Six planks were placed all around the inner box, with a thickness of 44.45 mm (1.75 in.). For the small decoys, 38.1 mm (1.5 in.) thick Ethafoam 220 planks manufactured by Sealed Air Corporation were used.

2.2.4. Outer Shipper Box

The inner dimensions of the outer shipper boxes for the medium decoys were 473.17 mm × 349.76 mm × 281.46 mm (similar to CJ The Market N4-1 (CJ CheilJedang, Suwon-si, Republic of Korea)). These boxes were made of nominal 71 ECT, BC flute, double-wall corrugated board and manufactured by the researchers using a Kongsberg X Edge computerized cutting table (Kongsberg Precision Cutting Systems, Ghent, Belgium). The small decoys' outer shipper boxes were provided by the sponsoring company. Their internal dimensions were 354 mm × 254 mm × 228 mm (identical to CJ The Market N3 (CJ CheilJedang, Suwon-si, Republic of Korea)), and they were made of nominal 32 ECT, BB flute, double-wall corrugated board. The outer shippers were sealed with 50 mm (2 in.) packaging tape (3M, St. Paul, MN, USA).

2.2.5. Tested Package Weight

The total package weights for both the medium (12.5 kg) and small decoys (5.4 kg) were selected in order to simulate the most commonly used e-commerce package sizes. The actual weights of the individual decoys differed slightly from the desired weights: 12.5 kg, 12.61 kg, 5.39 kg, and 5.37 kg for decoy 1 (medium), decoy 2 (medium), decoy 3 (small), and decoy 4 (small), respectively.

2.3. Experimental Design

A total of five different shipping routes were selected to represent the Korean shipping environment. Two different destinations were selected within Seoul (S1 and S2) since the parcel delivery volume is highly concentrated within the Seoul capital area [29]. Further regions, such as Busan, Namwon, and Gongju, were also selected as destinations to allow the decoys to experience various handling points (different regions' hub terminals and sub terminals). All the decoys were shipped out from a fulfillment center (FC) located in Dongtan, Korea, to their destinations and then shipped back to a Research Center (RC) in Suwon, Korea, via a ground shipping service. The mapped-out shipping routes can be seen in Figure 3.

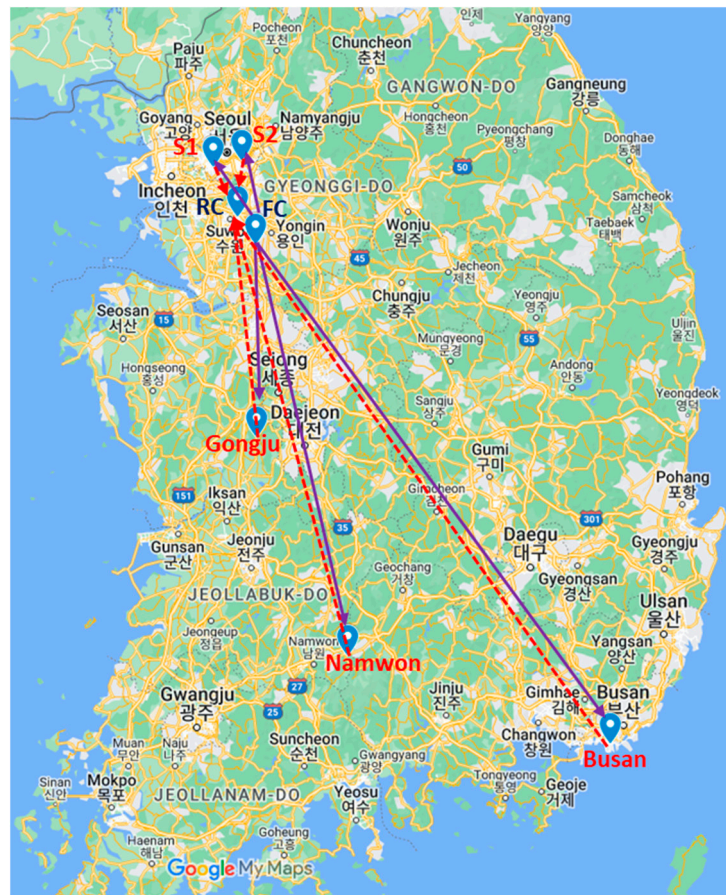


Figure 3. Map of the experimented routes. Purple lines indicate the forward trip and red lines indicate the return trip.

The decoys were intended to be shipped six times to each destination (three round trips) for the small and medium decoys, respectively. Two different sizes of decoys and five different shipping routes resulted in a total of 60 single trips (30 round trips). Details of the shipping routes are listed in Table 1.

Table 1. Experimental route information and the number of trips made.

| Region | Shipping Route | Decoy Size | Number of One-Way Trips |
|--------|---------------------------------|------------|-------------------------|
| Seoul | S1: FC—Dongjak-gu, Seoul—RC | Small | 6 |
| | | Medium | 6 |
| | S2: FC—Gangnam-gu, Seoul—RC | Small | 6 |
| | | Medium | 6 |
| Busan | FC—Saha-gu, Busan—RC | Small | 6 |
| | | Medium | 6 |
| Namwon | FC—Inwol-myeon, Namwon—RC | Small | 6 |
| | | Medium | 6 |
| Gongju | FC—Gyeryong-myeon, Gongju—RC | Small | 6 |
| | | Medium | 6 |

2.4. Decoy Calibration

Measured shock pulses from the field do not provide the conversion of shock events from different directions to the equivalent free-fall drop heights (EFFDH) on their own. The area under an acceleration-versus-time shock pulse correlates with the total velocity

change of the event, encompassing both the impact velocity and the rebound velocity. However, it is specifically the impact velocity component that relates to the EFFDH. As the velocity change is the sole measurable quantity in the field, it becomes necessary to isolate the impact velocity from the shock pulse by subtracting the rebound velocity. The rebound velocity is a fraction of the impact velocity determined by the package's elasticity, quantified by the coefficient of restitution (e). Therefore, if we build a package with defined elasticity, the coefficient of restitution becomes a characteristic of the package that will not change. In this study, a package with defined elasticity is called a decoy. Prior to starting the shipping experiments, the coefficients of restitution as functions of the impact orientation for each type of decoy were experimentally determined in the laboratory through a decoy calibration process. The decoys were dropped from six different heights using a PDT-80 free-fall drop tester (Lansmont Corporation, Monterey, CA, USA). The drop heights used for the calibration process were 304.8 mm, 457.2 mm, 609.6 mm, 812.8 mm, 914.4 mm, and 1066.8 mm (12 in., 18 in., 24 in., 32 in., 36 in., and 42 in.). At each specified drop height, a single drop test was conducted on every possible impact orientation: six flat drops, twelve edge drops, and eight corner drops. The e value for each impact orientation was then determined using the known free fall drop height and resultant velocity change (vector sum of the velocity change from each axis) collected from the field data recorder through the following relationship (Equation (1) [30]):

$$e = \frac{\Delta v}{\sqrt{he(2g)}} - 1 \quad (1)$$

where:

e = coefficient of restitution

Δv = resultant velocity change (m/s or in./s)

he = drop height (m or in.)

g = acceleration due to Earth's gravity (9.81 m/s² or 386.4 in./s²)

2.5. Drop Height Calculation

One method used to determine the free-fall drop height is called the '1 g shift method'. This method measures the duration between the 1 g state where the package is not in motion, the 0 g state where the package is free falling, and when the impact happens with several gs [20]. This method can be used to effectively determine the drop height when a pure free-fall drop event occurs, but it cannot be used to determine different types of impacts. However, packages experience various kinds of shocks and impacts, such as free-fall drops, tumbles, side impacts, tosses, and kicks, when they go through the parcel delivery system [20]. Therefore, a method was employed to analyze and convert different types of shocks and impacts into the 'equivalent free-fall drop heights' (EFFDH) by reversing the relationship introduced in Equation (1). It can significantly ease the process of laboratory-based package testing by simplifying the different types of shocks into simple free-fall drops while keeping the same stress applied to the packages. The EFFDH for each shock event can be calculated using predetermined e values from the calibration process, resultant velocity change collected from the field, and Equation (2) [30]:

$$EFFDH = \frac{1}{2g} \left(\frac{\Delta v}{1+e} \right)^2 \quad (2)$$

where:

$EFFDH$ = equivalent free-fall drop height (m or in.)

e = coefficient of restitution

Δv = resultant velocity change (m/s or in./s)

g = acceleration due to Earth's gravity (9.81 m/s² or 386.4 in./s²)

2.6. Data Analysis

A drop or EFFDH study usually aims to create a laboratory test procedure that simulates the real-world parcel shipping environment of a one-way shipment. Therefore, treating and analyzing the collected data from multiple shipments as one large population may result in distortions and is not recommended by the ISTA data analysis guideline [30]. In this study, all the data were analyzed as individual one-way shipments to ensure accurate results that could guide the creation of an effective laboratory test.

Data points below the 152.4 mm (6 in.) drop height were excluded from the analysis since they tend to be caused by small shock events during vibration [19,20]. Among the filtered data points, the Nth highest EFFDH (highest, second, third, and fourth) and the number of impacts during each individual one-way trip were determined. Datasets of the number of impacts during each individual one-way shipment and the Nth highest EFFDH from each individual one-way shipment were then fitted to a Weibull distribution using MATLAB R2022b (MathWorks Inc., Natick, MA, USA) to provide the Nth highest EFFDH and the number of impacts to be expected with 90th, 95th, and 99th percentile levels from the parcel delivery system in Korea.

Then, the two-sample Kolmogorov–Smirnov (KS) test was applied to analyze the significance of the discrepancy between the cumulative distribution functions (CDFs) of the number of drops and the EFFDHs for small and medium boxes. The two-sample KS test is a nonparametric statistical test method that assesses the similarity between two CDFs. The null hypothesis assumes that the two CDFs are derived from the same underlying distribution. The two-sample KS statistic quantifies the maximum absolute distance between the empirical cumulative distribution functions of two samples using the following statistic (Equation (3)):

$$D = \max(|\hat{F}_1(x) - \hat{F}_2(x)|) \quad (3)$$

where:

D = the distance between the empirical distribution

$\hat{F}_1(x)$ = the proportion of first-sample values less than equal to x

$\hat{F}_2(x)$ = the proportion of second-sample values less than equal to x

The percentage of each impact orientation, including faces, edges, corners, on and around the bottom (O/A bottom), on and around the top (O/A top), vertical faces, and vertical edges, was also calculated. This analyzed data could then be used to establish new laboratory test procedures for Korea.

In addition, the time stamp of each data point was compared with tracking information. This analysis allowed us to determine which delivery stage produces the most impacts. It provided useful information for packaging engineers about what to target to optimize their packages and for courier engineers about which stages need to be improved to reduce the parcel damage rate.

3. Results and Discussion

The individual one-way shipments to five destinations were analyzed to calculate the drop heights, number of drops, and impact orientations. Table 2 shows the 90th, 95th, 99th percentile, average, and maximum number of drops as a function of the different package sizes and weights in the current study. It also compares the current study's results with past studies conducted in Europe [12] and the USA [16], and to the ISTA 3A testing standard [22]. Figure 4 visually presents CDF plots of the number of drops found during this study. The results showed a small, but not statistically significant, difference in the number of impacts between the medium and small boxes: less than or equal to eight shock events occur for 95% of medium package shipments, and less than or equal to seven shock events occur for 95% of small box shipments. The CDFs of the number of drops for small and medium packages were compared using the two-sample Kolmogorov–Smirnov (KS) test with a significance level of 95%. The obtained p -value of 0.76 suggests that there is

no significant difference between the CDFs of the number of drops for small and medium packages at the chosen significance level. The computed D statistic of 0.17 indicates the maximum absolute difference between two CDFs. These findings confirm that there is no strong statistical evidence to support a significant difference between the cumulative distributions of the number of drops for the small and medium boxes. These results did not follow what a previous study had found: heavier packages usually experience less harsh handling [13]. This may have been because the difference in the weight and size of the tested small and medium decoys was not big enough for the Korean parcel delivery system to cause disparity in the number of drops. Furthermore, the number of drops observed in the Korean parcel delivery environment was significantly lower than the similar studies conducted in Europe [12] and the USA [16,17], and the ISTA 3A testing standard [22] (Table 2). This seems to be due to fewer handling points in Korea than in countries with larger territories. Packages in Korea mostly go through only one hub terminal and one sub terminal during any trip. In contrast, packages in Europe and in the U.S.A have a higher chance of going through more handling points, such as multiple hub and sub terminals, before they reach customers.

Table 2. Shock/impact frequency observed depending on the package size and weight, reported in the previous study, and ISTA 3A standard.

| Percentile | Number of Shocks/Impacts | | | | USA [16] (Ground) | USA [17] (Next Day) | ISTA 3A [22] |
|------------|--------------------------|------------------|------------------|-------------|----------------------|------------------------|--------------|
| | Medium + Small | Medium Box | Small Box | Europe [12] | | | |
| 90th | 6.16 \approx 7 | 6.44 \approx 7 | 5.81 \approx 6 | 16 | - | - | 17 |
| 95th | 6.85 \approx 7 | 7.11 \approx 8 | 6.50 \approx 7 | 17 | - | - | |
| 99th | 8.17 \approx 9 | 8.37 \approx 9 | 7.81 \approx 8 | 19 | - | - | |
| Maximum | 9 | 9 | 8 | 21 | 74 | 184 | |

Note: Highest numbers from the literature are listed in this table.

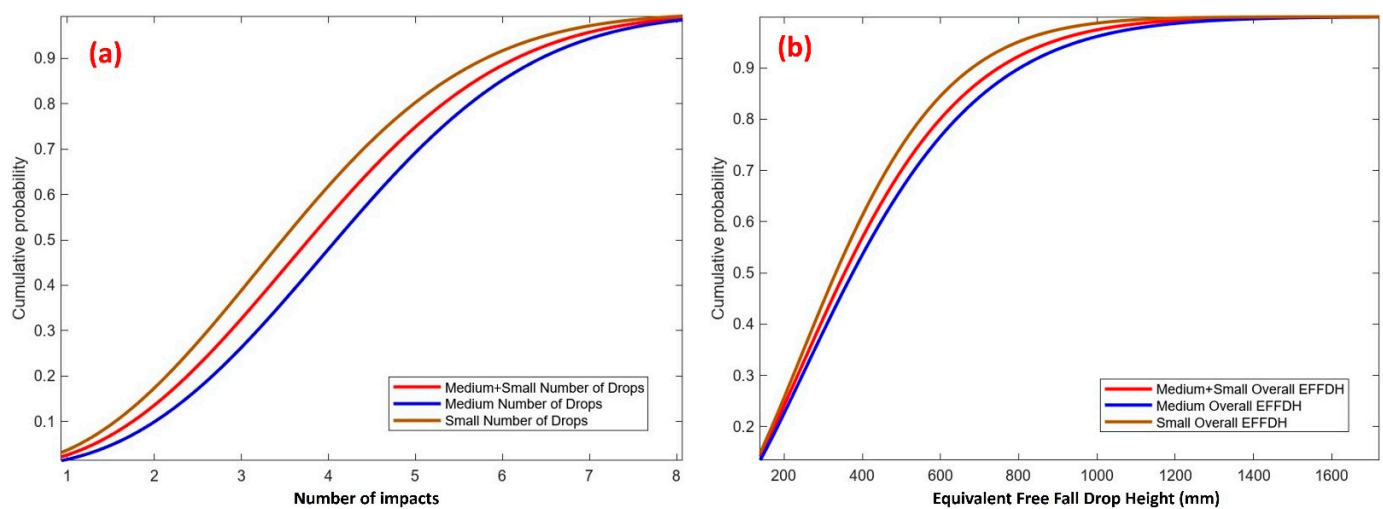


Figure 4. CDF plot of the (a) number of drops and (b) the calculated equivalent free-fall drop height (EFDH) for the overall dataset as a function of package size and weight. Medium + small indicates a combination of data obtained from both medium- and small-sized boxes, medium indicates data obtained from medium-sized boxes, and small indicates data obtained from small-sized boxes.

Figure 4b presents the CDF for the calculated EFDH based on the overall dataset, while Table 3 shows the 90th, 95th, 99th percentile, and maximum EFDH as a function of the different package sizes and weights in the current study. These results showed no significant difference between the medium and small boxes based on the two-sample Kolmogorov–Smirnov test (p value = 0.14, D = 0.15). This confirms that the two investigated package sizes and weights are not treated differently or separately during handling in the Korean

parcel delivery environment. The max EFFDH in Korea was at least 46% higher than both the US [16] ground shipping service and Europe [12]; however, the maximum EFFDH level observed in China [13] was still at least 16% higher than in Korea. The EFFDH from the overall data at the 95% occurrence level in Korea was higher than both the ground shipping services of the USA and China by 4% and 79%, respectively. Table 4 and Figure 5 present the EFFDH at a 95th percentile level for the highest, 2nd, 3rd, and 4th drops. It is important to report the EFFDH of the Nth highest drop height at the 95th percentile level since they are the recommended datasets to utilize when developing a drop test according to ISTA guidelines [30]. The 95th percentile of the highest EFFDH in this study was at least 28% and 17% higher than those in Europe [12] and recommended by ISTA 3A [22] for testing packages less than 37 kg, respectively. The Korean parcel delivery system also had a higher max EFFDH than most of the other compared regions except for China [13]. The Korean parcel delivery system had characteristics closer to the EFFDH of next-day shipping services in the USA [17]. Next-day shipping service in the USA had an approximately 4% higher maximum EFFDH and an approximately 2% less EFFDH at a 95th percentile level [17]. This trend indicates that packages shipped in the Korean parcel ground shipping service environment will most likely experience higher shock levels compared to historically investigated ground shipping services in different regions, but their maximum possible shock levels would be less than in China. Both the number of drops and the EFFDH results prove the uniqueness of the Korean parcel delivery system and show the need to establish their own laboratory testing standards.

Table 3. Equivalent free-fall drop height (EFFDH) observed depending on package size and weight, and reported in the previous studies.

| Equivalent Free-Fall Drop Height (EFFDH) (mm) | | | | | | | |
|---|----------------|------------|-----------|-------------|----------------------|------------------------|------------|
| Percentile | Medium + Small | Medium Box | Small Box | Europe [12] | USA [16] (Ground) | USA [17] (Next Day) | China [13] |
| 90th | 747.79 | 802.08 | 679.73 | - | - | 620 | 459 |
| 95th | 880.78 | 947.49 | 795.44 | - | 762 | 860 | 347 |
| 99th | 1150.9 | 1244 | 1028.4 | - | - | 1420 | 292 |
| Maximum | 1706.63 | 1702.82 | 1706.63 | 1066.8 | 1069.34 | 1770 | 2000 |

Note: Highest numbers from the literature are listed in this table.

Table 4. Equivalent free-fall drop height (EFFDH) results for the nth drops height using the 95th percentile.

| 95th Percentile Equivalent Free-Fall Drop Height | | | | |
|--|------------------------|-----------------------|-----------------------|-----------------------|
| | Highest | 2nd | 3rd | 4th |
| Medium + Small | 1290.57 mm (50.81 in.) | 751.08 mm (29.57 in.) | 610.87 mm (24.05 in.) | 456.18 mm (17.96 in.) |
| Medium | 1440.43 mm (56.71 in.) | 766.57 mm (30.18 in.) | 551.94 mm (21.73 in.) | 481.08 mm (18.94 in.) |
| Small | 1078.23 mm (42.45 in.) | 720.85 mm (28.38 in.) | 653.80 mm (25.74 in.) | 504.44 mm (19.86 in.) |
| Europe [12] | 812.8 mm (32 in.) | 660.4 mm (26 in.) | 584.2 mm (23 in.) | 533.4 mm (21 in.) |
| ISTA 3A [22] | 910 mm | | 460 mm | |

Table 5 categorizes the drop orientations of the top four highest EFFDH events. The results indicate that the packages are dominantly (approximately 50%) impacted on the edges, followed by the corners (approximately 35%) and then the faces (approximately 16%) regardless of the package size or weight. The impacts were also concentrated on orientations that are on and around the bottom of the package. This seems to be due to the large tendency of the shipping label to be located on the top face of the package. It was observed during multiple site audits conducted by this study's authors in several hub and sub terminals located in Korea that packages are usually handled top face upwards to be able to scan the labels using either a fixed loop-style scanner or a handheld scanner. These results were in line with the previous study conducted in Europe [12] and the ISTA 3A standard [22].

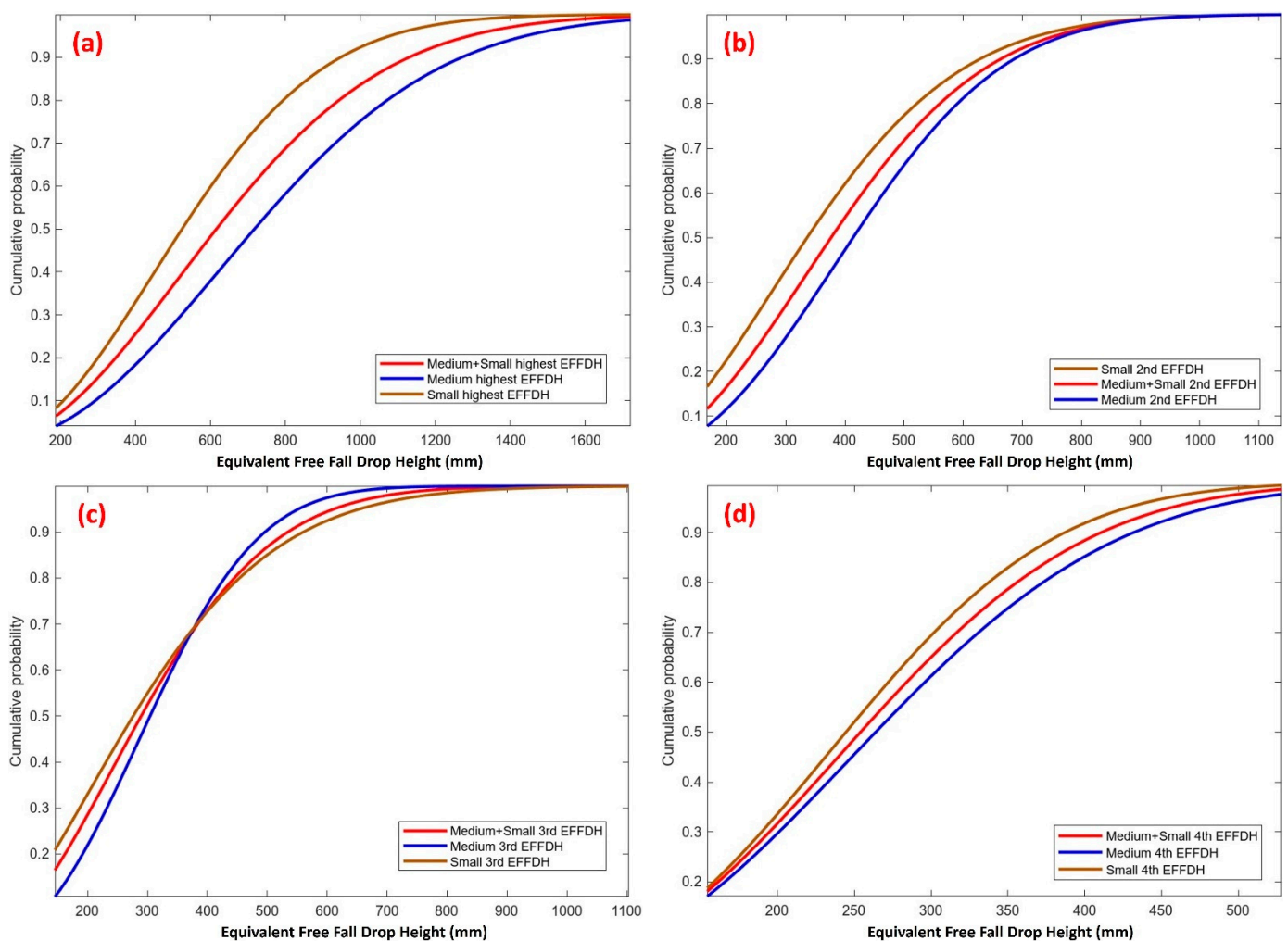


Figure 5. Cumulative percentage versus EFFDH for medium boxes, small boxes, and medium and small boxes combined. (a) CDF plot for the highest EFFDH. (b) CDF plot for the second highest EFFDH. (c) CDF plot for the third highest EFFDH. (d) CDF plot for the fourth highest EFFDH. Medium + small indicates a combination of data obtained from both medium- and small-sized boxes, medium indicates data obtained from medium-sized boxes, and small indicates data obtained from small-sized boxes.

Table 5. The shock frequency of each drop orientation of the packages.

| Impact Orientation | Medium + Small | Medium | Small | Europe [12] | ISTA 3A [22] |
|--------------------|----------------|--------|--------|-------------|--------------|
| Faces | 16.84% | 17.65% | 15.96% | 21% | 24% |
| Edges | 48.98% | 52.94% | 44.68% | 49% | 47% |
| Corners | 34.18% | 29.41% | 39.36% | 30% | 29% |
| O/A Bottom | 81.63% | 82.35% | 80.85% | 60% | 71% |
| O/A Top | 7.14% | 4.90% | 9.57% | 19% | 23% |
| Vertical Faces | 2.55% | 4.90% | 0.00% | 9% | 0% |
| Vertical Edges | 8.67% | 7.84% | 9.57% | 12% | 6% |

Figures 6 and 7 present the shock and impact occurrence as a function of the handling and facility type. It was observed that approximately 80% of shock and impact events occurred within the hub and sub terminals. This could be explained by the significantly higher frequency of shock/impact events that occur during the loading and unloading processes, which mostly happen when trucks arrive at the hub and sub terminals. Sorting

and last-mile delivery processes also produced a considerable number of shock events. This may be due to the manual sorting processes that are occasionally required to clear out jammed conveyors or to delivery personnel throwing packages at the door to speed up the delivery process.

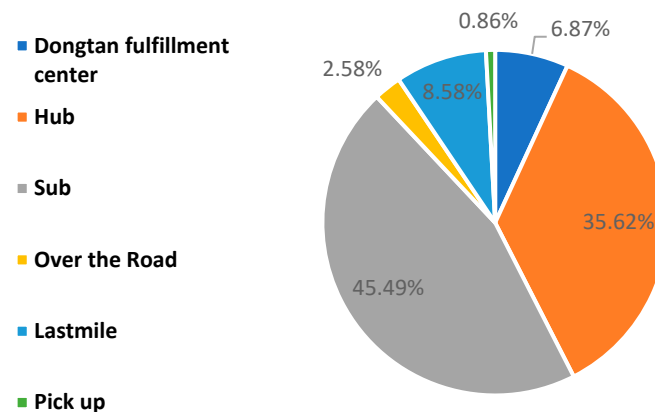


Figure 6. Shock/impact occurrence as a function of the facility type.

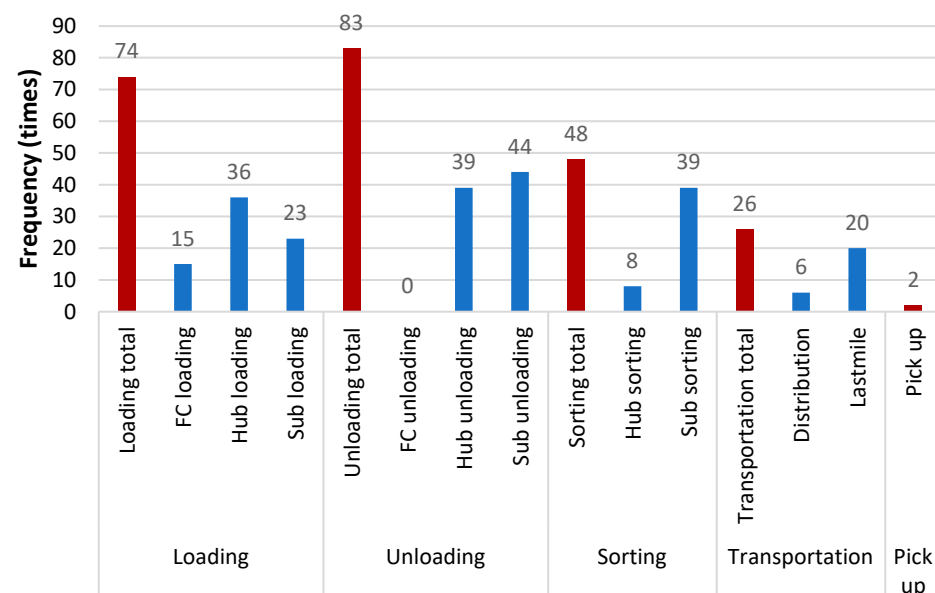


Figure 7. Shock/impact occurrence as a function of the handling mode and facility type. Red bars indicate the total number of shocks and impacts of each type of handling mode. Blue bars indicate the number of shocks and impacts of certain handling modes from different types of facilities. Red bars indicate the total number of shocks that occurred during each handling mode, and blue bars indicate the number of shocks that occurred during each handling in different facilities.

4. Limitations of Study

The limitations that exist in this study are identified as follows:

1. The scope of this study was limited to two types of packages (small, lightweight packages and medium, medium-weight packages). Future studies that cover larger, heavy packages, such as packages for large furniture, and/or smaller, lighter packages, as compared to the investigated types of packages, such as pouches for apparel, are recommended.
2. The scope of this study was limited to investigating the ground parcel shipping service environment in Korea. Further investigations of different types of parcel shipping services, such as next-day shipping service or same-day shipping services that use

different modes of transportation, such as motorcycle, rail, boat, or airplane, are encouraged for future studies.

5. Conclusions

This study concludes the following:

- With the 90%, 95%, and 99% occurrence levels, there were no distinct differences in the number of drops and drop heights found between the small and medium packages.
- Seven and eight shock events at the 95% occurrence level were found in the Korean parcel shipping environment for the small and medium packages, respectively. This finding indicates a significantly lower number of shock events compared to the parcel shipping environments in Europe and USA and the ISTA 3A standard. This may be due to the relatively fewer handling points than in other countries with larger territories.
- The drop heights experienced by ground-shipped parcels in Korea are 17–28% greater than observed in Europe or simulated in the ISTA 3A testing.
- The edges (50%) of the instrumented decoys and the orientations on and around the bottoms (80%) of the packages were most frequently impacted during shipment. This trend was also shown in the past study conducted in Europe and the ISTA 3A standard. Shock events most frequently occurred during the loading and unloading processes within hub terminals and sub terminals.
- The data presented in this study distinctively show that the Korean parcel delivery system has a very unique package handling environment in terms of the shock frequency and level of shock experienced by packages. Therefore, packaging engineers are encouraged to re-evaluate their protective packaging designs when the packages are shipped through the Korean parcel delivery system.
- This study marks the first comprehensive exploration and statistical analysis of the characteristics of the shock and drop events that parcel packages undergo in the ground shipping service environment within Korea. The results of this study indicate that there are differences between the intensity of the parcel delivery handling environment in Korea, commonly used international standards, and the handling environments in other geographical regions. The data presented in this study could serve as crucial foundational information that aligns with the realities of Korea, enabling the establishment of regional package testing standards and updating regulations regarding limiting the overuse of packaging materials. However, to fully characterize the extent of the differences, further research is recommended using a broader range of package sizes, additional routes, and different types of shipping services. This expansion will help capture additional potential variances present in the Korean parcel shipping environment.

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