Good Vibrations: Packaging Lessons for the Global Supply Chain

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Abstract
The paper, using measurements from multiple shipments, explores challenges global supply chains face in inter-modal shipping environments. Specifically, data (e.g., vibration levels, shocks, changes of temperature and relative humidity) from truck and vessel combinations in less-than-truckload shipments across continents are analyzed to pinpoint critical points in the transportation network.

Keywords: Global supply chain, transportation, packaging.

Introduction

During the last decades, there has been a renewed interest in the efficiency of distribution channels in global supply chains. Selecting the right transportation modes for a shipment can result in significant cost savings but, on the other hand, multi-mode shipments can also lead to transportation damages. Supply chain managers usually have to choose between the full truckload (or full container) and less-than-truckload distribution method (Ching-Wu Chu 2005; Ghiani 2004). The logistics and distribution hazards for less-than truckload (LTL) shipment are usually much higher than the full truckload (container) shipments due to the potentially large number of handling and transshipment operations. Due to the higher risk of physical damages, suppliers often want to avoid LTL distribution in order to reduce their transportation costs. Nonetheless, it must be noted that most of the shipments are usually “less than truckload” or “less than container-load” units. These not full truck or container loads naturally increase the number of handlings and necessary operations, constantly switching to truck, to rail, to vessel. The exact nature of how international shipping and handling operations impact the integrity of these shipments is not yet fully known. Information about the physical and climatic conditions that reduce damages in various segments of the supply chain is scarce thus the exact trade-off between packaging and logistics costs is not known.

In a global supply chain spreading between continents, most of the goods are transported by truck, rail and ship. Due to globalization, there has been an increase in maritime shipping. The volume of global maritime trade in 2012 was 9,183.7 million tons, which is 16.5% higher than the volume in 2006; the capacity and size of vessels have almost doubled since 2004 from 2,812 TEU ten years ago to 5,540 TEU in 2013 (UNCTAD 2013). Consequently, any analysis of the logistics hazards on multi-mode and varied transportations should involve both ground and sea transport as well.

In supply chain management, in connection with packaging, researchers mainly focus on the level of physical integration such as the standardization of consumer and distribution packaging (Frohlich and Westbrook 2001). Other papers presented algorithms to choose cost effective transportation routes (Ching-Wu Chu 2005; Sariklis and Powell 2000, Repoussis et al. 2007, Aksen et al. 2007, Tarantilis et al. 2004, Yu at el. 2011).

The transport and handling of these shipments produce both physical and climatic events that can affect the integrity of the products. These physical inputs include vibration and shock, whereas the most common climatic inputs are temperature and relative humidity (RH) exposure (Brandenburg and Lee 2001). Most of the package systems have got a certain degree of safety in protection to products against mentioned hazards. Under-packaging or a lack of optimum protection can cause damage, which has a serious negative impact on the entire supply chain. Replacing a damaged product requires a new product, new package and a re-use of all resources to deliver the replacement. Selecting the right mode to transport a shipment may yield significant cost savings to the company. In the field of packaging very few studies have measured and analyzed the vibration levels in less-than-truckload (LTL) shipments (e.g., Singh et al. 2008). Singh et al. (2012) presented vibration and temperature changes in global intermodal container shipments on truck, rail and ship from India to the United States and from Brazil to the United States. However, the relations between varied chains and distribution hazards still need to be fully discovered.

The goal of this paper is to measure supply chain hazards, such as physical and climatic conditions (vibration, shocks, temperature and relative humidity) during transportation and handling of electrical automotive parts in a less-than-truckload unit shipped via multiple transport modes (truck and vessel) between two companies and two continents, from South Africa to Hungary, to point out hazardous locations and events, and to show the impact of transshipments and varied environments to the units shipped between continents. It must be noted that this paper does not examine the effect of vehicles used, their velocity, the road conditions and the different payloads but reports the measured values during the entire trip as a collective international multi-modal shipment.

Data

Route of shipment

During the full length of shipping, the effects of shock, vibration, temperature and relative humidity changes were measured and recorded. The observed unitized-load, after building and packing up, remained at the manufacturer's warehouse in Uitenhage (Republic of South Africa, RSA) and waited for delivery. From here it traveled by truck to Port Elizabeth (RSA) – shown in Figure 1 -, and then it waited outside of the vessel. At Port Elizabeth the shipment was loaded into a 40ft ISO container. Then it traveled by vessel to the European port of Hamburg (Germany) – shown in Figure 2 -with two stops in between.

Figures 1 - Container terminal at Port Elizabeth (Republic of South Africa)

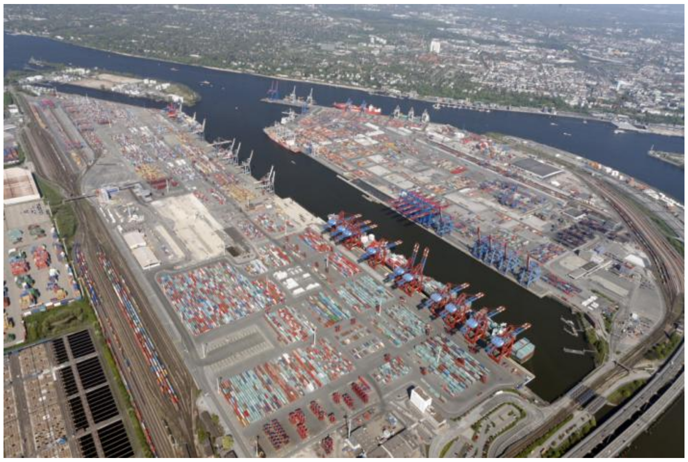

Figure 2 - Container terminal at Hamburg (Germany)

In Hamburg, the shipment was unloaded from the ship and transported by truck first to Nuremberg (Germany) and further inland in Germany to the storage center of the costumer. From here it again traveled by truck to the final customer destination in Miskolc (Hungary). The shipment traveled a distance of approximately 1,820 km on a route that included mainly highways, and even inner-city roads, and first-class two-lane roads. The recorded data accounted for three commissioning occasion and at least twelve handling events representing loading and unloading between various transportation stages, and handlings in different warehouses. The survey and measurement for this study happened between July 7, 2014 and Sept 28, 2014 for a total of 83 days. The details of the shipping and route by date are shown in Table 1.

Table 1 - Details of various events of shipment from start to end

Event	Date	Location	Activity
1	7 Jul – 11 Aug	Uitenhage (RSA)	Outdoor storage under roof, handling
2	11 Aug	En route	Forwarded by truck
3	12 Aug	Port Elizabeth (RSA)	Commissioning and loading into container
4	18 Aug	Port Elizabeth (RSA)	Port handling (and loading)
5	18 Apr – 10 Sept	En route	Forwarding by vessel
6	10 Sept	Hamburg (GER)	Port handling (and unloading)
7	17 Sept	En route	Forwarding by truck
8	17 Sept	Nuremberg (GER)	Commissioning, unloading from container
9	19 Sept	En route	Forwarding by truck
10	19 Sept	Bad Rodach (GER)	Commissioning
11	23 Sep – 25 Sept	En route	Forwarding by truck
12	25 Sept – 29 Sept	Miskolc (HUN)	Indoor storage

Packaging system

The test shipment for this study was built up as a unitized load shown in Figure 3. The unit was designed to protect the product effectively from mechanical shock and extreme climatic conditions. The package was a one-way structure and was designed to be disposed at the end of shipping. The shipment consisted of twenty pieces of the packaged product, and each package contained six electrical products.

Figure 3 - The measured shipment

The packages were produced from a five-layer (B and C flute) corrugated cardboard box with a removable lid. A one-way, disposable, 1,000 mm x 1,200 mm pallet was used to handle the unit. Furthermore EPS (expanded polystyrene), paper edge protectors and plastic straps were also used to create the unit load. Each package was 380 mm x 560 mm x 250 mm external sizes and weighed approximately 7,5 kg. The whole unit load weighed approximately 170 kilogram with approximate height of 1,140 mm. Each package was labeled according to their position. The measurement package was in the bottom row, and middle with a marker of ‘DL’ (data-logger). During the whole shipping information sheets with a title of “test transportation” were fixed on all the sidewalls of unit. The cart on the Figure 3 was only used for handling activities inside.

Measurement system and recording

Device and set-up

For this study a Shock and Vibration Environment Recorder (3X90 Saver, Lansmont Corp., CA, USA) was used to collect the data entire of 83 days shipping. Furthermore, Saver Xware, Microsoft Excel (Rank & Percentile and database count functions) and StatPlus (AnalystSoft) packages were also used for analyzing data. Figure 4 shows the SAVER. The SAVER contains a piezoelectric tri-axial accelerometer with a built-in microcomputer, a lithium-ion battery instrument capable of measuring and recording shock (impact/drop), vibration, temperature and humidity conditions during transportation. The equipment measured and recorded shock impacts and vibration levels in all three orientations inside the package. The internal clock of the equipment was calibrated to Central European Time standard. The instrument can be setup for recording vibration events in both the signal and timer triggered ways. For this study the setup of the recorder were the following:

- SIGNAL Triggered Data - recording time: 1.024 msec, sample/sec: 1000, sample size: 1024, signal pre-trigger: 20%, signal post-trigger: 50%, signal-trigger threshold level: 2.0 G, acceleration range: 1 – 100G, filter frequency: 250 Hz
- TIMER Triggered Data - recording time: 1.024 msec, sample/sec: 1000, sample size: 1024, wakeup Interval: every 10 minutes, filter frequency: 250 Hz

These set-up parameters were used for all three axes. The vibration levels were recorded both using the timer interval and all events that exceeded the trigger threshold level of 2G. The recorder was fixed directly to the pallet with screws, located to the center of the outside upper slat. Then a box was cut out to ensure that equipment's sensors could be inside of the packaging and record the direct input excitation of the whole transport system.

Over the journey, consisting of 83 days, the unit-load was stored and traveled on different roads and conditions, with different trucks and ship across two continents, seas and oceans. Here we must note that it is virtually impossible for the manufacturer (sender) to choose the types of truck vehicles, exact routes and locations of container on the ship for a less than truckload shipment. For moving the measured LTL unit and container, semi-trailers were used to move prior to going out to port, and were also used for moving to and from the commissioning centers.

Method of Analysis

Spectrums for measured levels of temperature and relative humidity changes are shown as a function of time, thereby showing the specific effects of single locations such as actual climate belts as well as seasons and changes by outdoor loading and unloading events. This data was recorded based on the time trigger used by the recorder based on an interval of 10 minutes for the whole shipment.

In the case of vibration analysis, the captured events were separated for normal vibration and shock events. The main difference between these two events is in the different physical description of motion. While shock events can be described as transient physical excitation, practically as sudden acceleration, vibrations can be described by a series of random sine waves. For both of them the pulse durations are equally important; for instance a short 20g and 1 millisecond shock has got a little damage potential (low energy) and is not too interesting but a 20g and 50 millisecond shock can cause serious damages. The situation is the same with vibration. So, the real work of the pulse is equal to the area under the curve. There are two different ways of expressing the acceleration. The first one is the peak acceleration amplitude, and the second is the root mean square (RMS) acceleration amplitude. Latter is proportional of the area under the pulse's curve, so the RMS can be thought of as the effective energy (intensity) of the vibration.

This study to the analysis of vibration presents the values in 'G_{rms}' and to the analyses of shocks presents the acceleration resultant values in 'G' as a function of time in order to define the location and the transportation activity of the entire shipping. But shock acceleration values in three orientations with its duration are also presented based on intensity and peak value of recorded events.

Discussion

The first set of data, representing climatic environment, was analyzed to show the measured temperature and relative humidity levels during the entire 83 days. We must note that the travel went through the equator, so there was winter season in South Africa during July and August at the start of travel and it changed to autumn in Europe. All recorded data contain measurement values for all climate zones from southern hemisphere to equator and then to the northern hemisphere. According to the Köppen classification, the shipment traveled through oceanic, dry and humid, and Mediterranean climate zones. Figure 5 shows recorded values—divided into columns of South Africa (SA)–Continent, South Africa–Port, Maritime, Europe (EU)–Continent—inside the packaging.

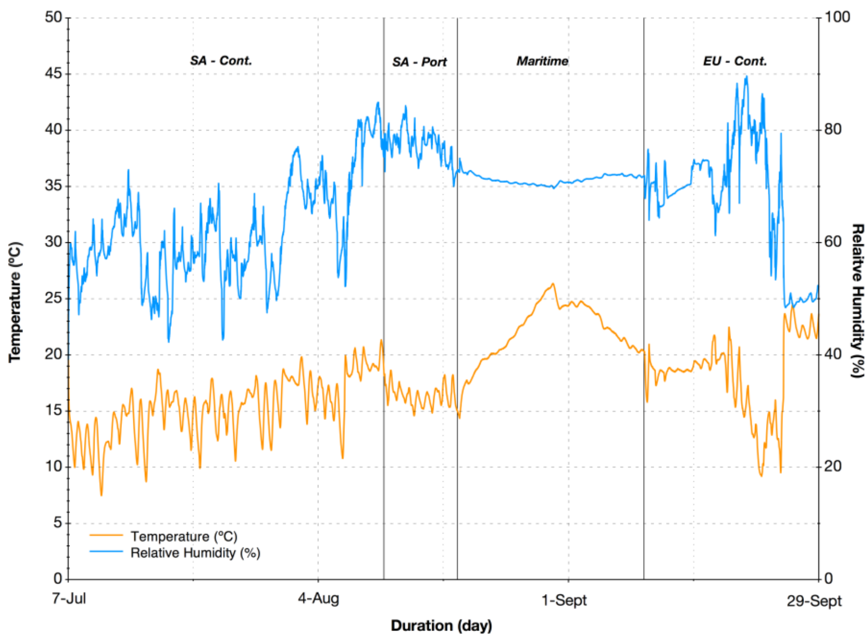

Figure 5 - Temperature and relative humidity (RH) values by timer trigger

The highest and lowest temperatures and RH values were measured to be 26.34°C and 7.46°C, with RH values varying between 89.66 % and 39.13 RH. Figure 5 shows that the values were varied heavily when the unit-load was stored outdoors (but under roof) prior to delivery, and it also shows how extreme values were caused by the weather for the one day when the package was outside, and then at the port the container smoothed these values. During maritime travel in oceanic climate, an almost linear increase and decrease of the temperature toward and from the Equator can be seen, while RH stays constant.

Figure 6 shows the temperature rise and fall when the unit load was moved from and to transport vehicles at commissioning or transshipment. Because of condensation temperature changes can be damaging for paper packaging.

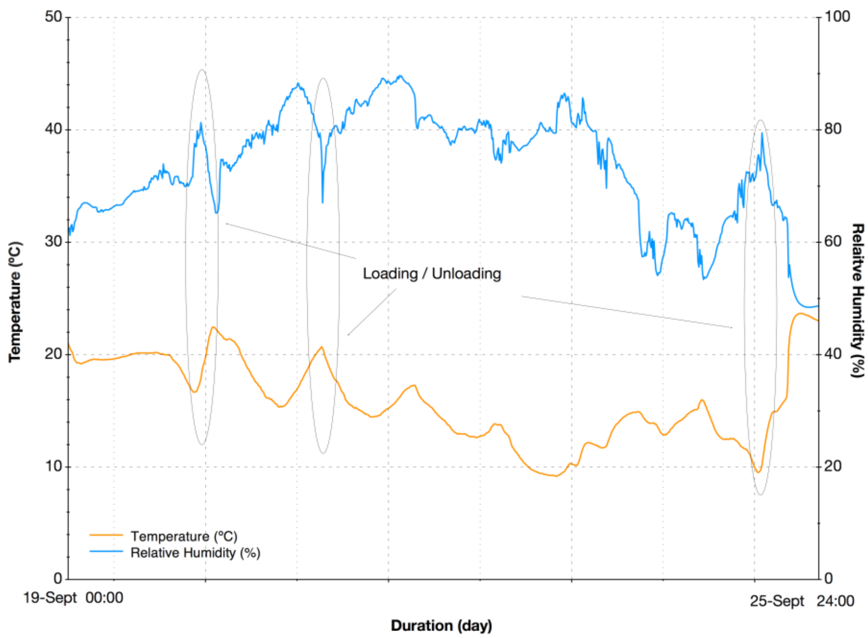

Figure 6 - Temperature and RH values at transshipments

The second step of analysis was to observe the vibration and shock inputs to the package system. Figure 7 shows the acceleration levels in G_{rms} for vertical vibration events, and Figure 8 presents the shock events chronologically to determine the exact location of shocks. The timer data are shown only by G_{rms} over 0.009g in order to make the locations of the significant events clearly visible. Levels below 0.01g are not likely to cause any damages to the product from any noise or not-vibration movements. The varying intensity of the G_{rms} values can be attributed to the different transportation environment (i.e. vehicle suspension, road condition, traveling speed, etc.) and handlings associated with transfers between these modes.

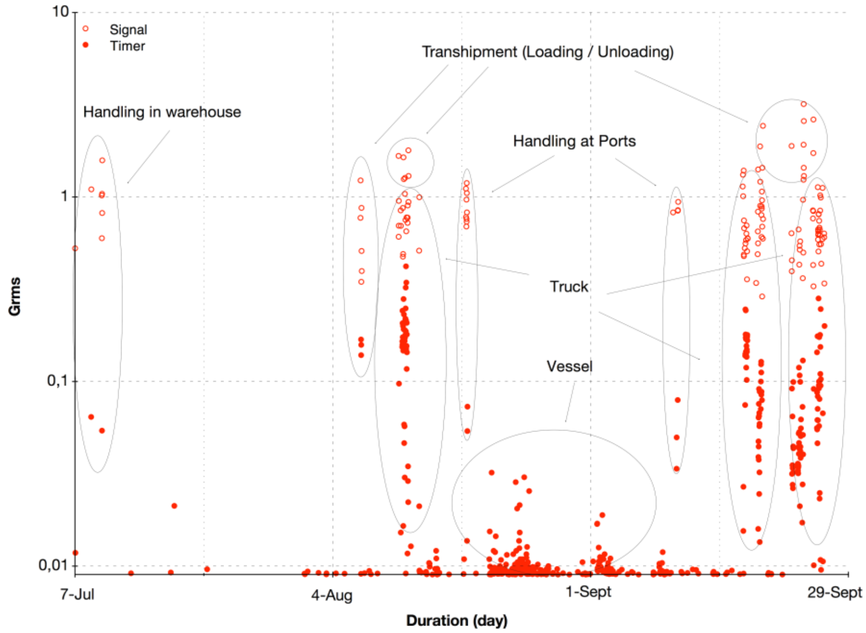

Figure 7 - Vibration events recorded close to the product

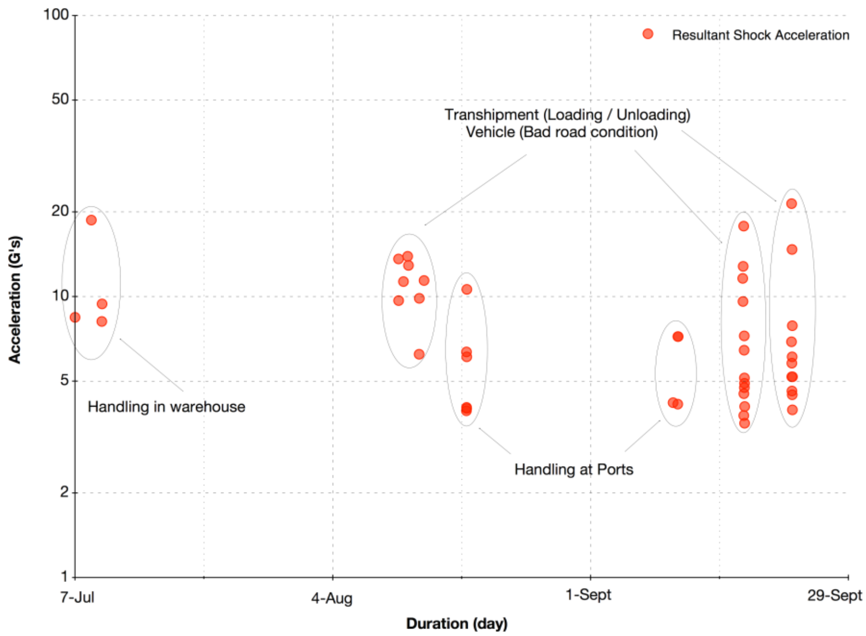

Figure 8 - The resultant Shock events

Figure 9 presents shock events in Gs along with duration in all three orientations. These two values can give accurate physical description about the accurate characteristic of the hazardous pulse. It can be seen that the highest pulse happened with 8 msec, while 4,1G was the peak acceleration beside the longest duration (45 msec).

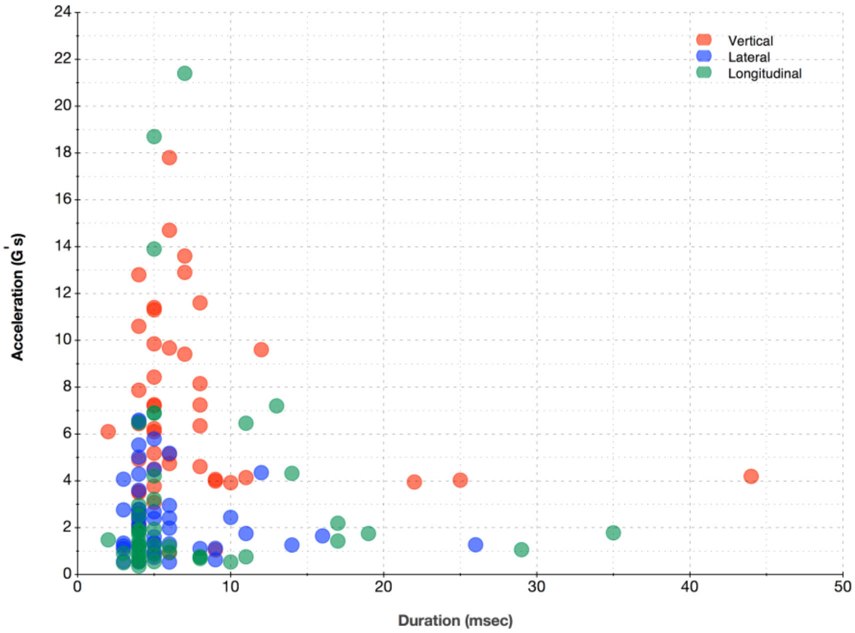

Figure 9 - Recorded shock events in the all three axes with durations

The ten most severe shocks with their magnitude and orientation during the whole shipment can be found in the Table 2. The results show that the most severe physical events happened when the unit was handled during transfer between storage and (un)loading on trucks. The vibration and shock levels were very low when the package was forwarded by vessel.

Table 2 - Levels of the ten most severe shock pulses

Event	Activity	Acceleration (G)	Orientation
1	Handling at transshipment	21.4	Flat – Left
2	Handling at storage	18.7	Flat – Right
3	Handling at commissioning	17.8	Flat - Bottom
4	Handling at transshipment	14.7	Flat – Bottom
5	Handling at port	13.9	Flat – Left
6	Handling at port	13.6	Edge – Front Left
7	Handling at port	12.9	Edge Bottom
8	Handling at commissioning	12.8	Flat – Bottom
9	Handling at commissioning	11.6	Flat – Bottom
10	Handling at storage	11.4	Flat - Bottom

Conclusion

Conceptually, this study is exploring linkages between product and supply chain characteristics; a stream that, perhaps, started with Fisher (1997). In this case, product and existing supply chain characteristics determine the level and nature of packaging needed on the one hand and packaging costs – derived from the level of protection needed - may override the existing choices in supply network design.

Based on the results of this study, the following preliminary conclusions can be drawn:

- Supply chain managers have to consider the hazards of possible distribution channels as multi-modal shipments present more risks (and costs).
- Warehouse handling operations are also major risk factors that should be considered.
- It is worth measuring and analyzing the hazards of possible physical events in supply chains, especially when long-time supply relationship exists between parties. This analysis contributes to an optimal distribution form and channel with comparing and determining the variable dynamics.

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