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A Brief Review on Palletized Products Transportation Technology

Palletized products are one of the most common means of goods transportation. However, recent studies show that there is still room for improvements in the packaging technology that can represent less expenses with wrapping material and also a smaller amount of damaged products. After all, an insufficient packaging might not support the stresses inferred to the pallet and lead it to tear apart during transport, representing a financial loss; on the other hand, an overdone packaging means an unnecessary material cost. Given the current overview, it becomes clear that packaging optimization techniques are a prolific area of study for generating money saving, improving safety and reducing merchandise losses, being potentially profitable for all those involved in the supply chain. In order to figure out how to improve this process, it is necessary to understand all technical branches embraced by the subject; thus, the present work thoroughly lists the most important factors to be considered in palletized products transportation through a state-of-the-art review.

Keywords: *packaging, pallet transportation, state-of-the-art, packaging stress, pallet vibration, packaging technology*

1. INTRODUCTION

Transportation is one of the most important steps of any supply chain, once it is known how products leave industrial plants and arrive at distribution centers to reach their customers. A broadly used way of shipping such products is through pallets, making both the conveyance and storage easier; demanding a strong packaging technique to wrap the palletized goods ensuring their integrity. Actually, this is a major problem encountered in industry nowadays once it has been related that many products arrive at their destinations damaged enough for them to be considered unusable [1].

Due to the waste of merchandise because of transport-related damages, companies roughly bear the impairment of almost 2.4 million dollars a year [2], besides the fact of disappointing the costumer generating mid to long-term losses in market share. Given the current scenario, companies have two options: to get used to soak up these costs, or to develop improved packaging procedures, generally by adding more wrapping material. The first option is simple and do not involve any change, although it will also not involve any gain regarding the process. Instead, the second option may reduce the number of damaged products, but it can also generate excessive expenses and represent greater environmental impact [3]. A possible solution for that is to optimize the process in a way that it will use only the right amount of material necessary to provide a reliable support for the products during transportation [1], achieving an optimal cost-benefit procedure.

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To optimize the transportation process, it is necessary to understand what is behind the simple fact of taking the goods from the factory and putting it at the costumers' reach. Hence, the present work thoroughly analyses some aspects of this industrial segment such as: wrapping materials, parameters and forces during transportation and packaging machines.

2. SAFETY IN TRANSPORTATION

A safe carriage of goods is often strictly related to safe driving [4]. Highway transportation crashes were the leading cause of fatal injuries in the United States for both workers and the general population from 2003 to 2008, where only truck transportation accounted for 2,320 highway deaths [5]. Technology has progressively evolved to meet drivers needs and keep vehicles safer day by day, where systems like the underbody lighting have been present on commercial vehicles with the purpose of enhancing driving conditions specially during the night [6]. Other technologies have also been part of crash avoidance technology, such as: side view assist, forward collision warning/mitigation, lane departure warning/prevention and stability control [7].

Not only technology has the role of improving driver safety, but also other measures like the cooperation of public health, highway safety, labor and state agencies, highway designers and transportation-related associations present an important role on this matter [5].

Technology development has also created a new world of instantaneous access to information. Shipping has become faster and more precise because of the easy access to vehicle navigation systems oriented by GPS. On the other hand, brain scan studies show conclusively that the human brain simply cannot focus on more than one task at a time [8], and technology has represented a

serious threat on distracting drivers behind the wheel. As an example, one out of six adults say they have been so caught up in their conversations that they have bumped into a person or an object while walking and talking on a phone [9]. Likewise, the National Safety Council estimated that 281,000 to 786,000 crashes in 2012 involved text messaging [10].

3. WRAPPING MATERIALS

Most packaging materials are made of polymeric films due to its low cost and little manipulation [11,12]. Even though this kind of film has a better permeability when compared to metal packaging [13], it still has some complications when dealing with fresh-cut products with high respiration rate and high tolerance to CO_2 [11]. To solve that problem, Modified Atmosphere Packaging (MAP) is a postharvest technology widely used to increase and preserve the shelf life of products, improve the product image and reduce waste [14].

Other complications considering polymeric films are related to their poor adhesion, low printability and low chemical resistance. There are two common options for solving this problem: using multilayers packaging films, each layer adding one property, or using surface treatments to improve the polymer properties [12].

Pre-stretching the plastic film is a very important step for providing stability in a way to assure the product will accomplish the goal of arriving its destination in a mint condition [1]. It is also possible to reduce the amount of plastic film used in this process by using machines to pre-stretch the film instead of a hand wrap operator [15]. The use of machines to wrap the product can reduce film cost by 30% to 50% and reduce product damage by 40% [16]. Some polymers can get to even 300% elasto-plastic elongation [15,17], which represents a limit force of 500N for the case of a 0.3μm thickness film of 60mm large polyethylene [17].

Cushioning package is the most important subject in theoretical studies and real world applications of pac–kaging dynamics [18]. There are several different mate–rials on the market with the purpose of protecting the goods in transportation. Corrugated paperboard is widely applied in packaging design because of its excellent protective performance and energy absorbing capacity [19]. The kind of cardboard structure can be divided into 4 mainly types: single-wave, double-wave, gripper cardboard and honeycomb. Among these kind of structures, the honeycomb is the most recommended whenever a very large amount of energy absorption is required [1].

Many commonly used packaging materials have nonlinear characteristics. It is therefore essential to analyse this dynamic behavior of the packaging system to understand how the structure will react in different situations. The compression stress-strain curve for corrugated paperboard is illustrated in Figure 1.

Apart from cushioning materials, the effect of wrap film on stability and protection has also been recently investigated. In particular, it was noted that wrapping solutions can be used toward an optimal package. By a proper wrapping methods, it is possible, in fact, to increase resistance and stability of palletized products [1].

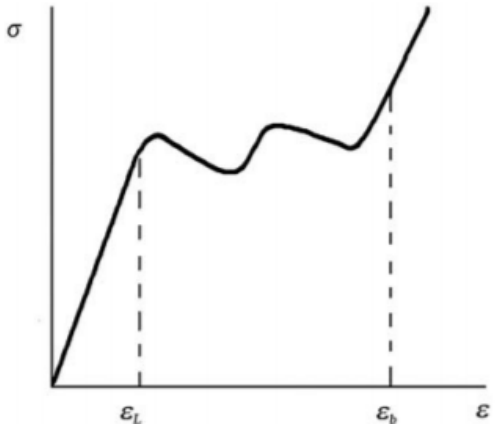

Figure 1. Typical stress-strain curve of corrugated paperboard [19].

4. PARAMETERS IN TRANSPORTATION

The use of truck for conveyance is the most used mean of transportation compared to others like trains, ships or airplanes [1]. In a wide country such as Brazil, for instance, the truck fleet is estimated at 1,733,300 vehi–cles. Even though this kind of shipment is not always the cheapest modal, most of the times it is the only choice to get products to its destination due to the arduous access to some locations [20]. An example of their truck conveyance can be seen in Figure 2.

Figure 2. Packaging products by truck conveyance [21].

When analysing the condition of goods being carried by truck, it is important to consider track conditions, such as the use of paved or unpaved roads [1]. Also, parameters like speed, load level and load distribution have direct relation with the number of damaged products, especially because of vibration forces [1,20].

Studies show that the dimensions, shape and weight of the product being transported are relevant factors to take into consideration, especially when it is a small dimension package that is being shipped. Also, characteristics of the vehicle, such as truck size, truck suspensions, number of axels and gross weight, are important parameters [20,22,23].

Even though trucks represent a great portion of the total transportation fleet, there are other important con–veyance sources predominant in Europe and North America, like trains (Figure 3).

Vibration levels in trains depend on rail type, which varies from country to country. Studies show that vibrations at lower levels are 10 to 70 times more relevant than at higher levels [24], as can be seen in Table 1.

Figure 3. Rail transportation [24].

Table 1. Frequency X Powerd Density [24]

Frequency (Hz)	Power Density x10^{-4} [G^2/Hz]
1	3
1.5	5
3	5
7	0.6
9	0.8
12	0.8
50	0.1
100	0.1

5. FORCES DURING TRANSPORTATION

Some of the most relevant forces can be found in regular products while in carriage are due to: sloshing, vibration and shocks [1,4,20,25,26,27,28]. The present work will mostly cover these three sources, since other forces do not affect the conditions of products as much as the aforementioned ones.

5.1 Sloshing

Whenever a partially filled tank is set to motion, there will be sloshing or even splashing acting on the tank structure. Sloshing is an important factor to be analysed during transportation of liquid merchandise, specially when the vehicle is breaking or turning. This pheno–menon produces a force that can affect not only the structure of the tank, but also the vehicle stability [25].

The amplitude of sloshing is a function of the tank geometry, the volume of the liquid, the volume of the gas inside the tank and the nature, amplitude and frequency of the tank motion [25,29]. In other words, sloshing forces depend on the freedom that the liquid has to move inside the tank, and on the amount of the substance that displaces [30]. It also considers the characteristics of the liquid phase (density, dynamic viscosity) and the characteristics of the gas (dynamic viscosity, compressibility and pressure).

The dynamic behavior of a free liquid surface de–pends on the type of excitation and its frequency content. The orientation of the excitation with respect to the tank can be lateral, parametric, pitching/yaw or roll, as well as a combination. The most important kind of liquid motion is the rotary sloshing or swirl motion: this type of sloshing usually occurs near the lowest liquid natural frequency, and it is expected to cause large sloshing amplitudes [29].

The sloshing effect can be reduced by introducing baffles at the right position and proportion inside the tank [25]. These baffles produce a jump-like effect, which reduces the magnification of the dynamic loads on the vertical walls out of resonance, and a strong reduction of the dynamic loads in the resonance condition [31].

A great source of damage caused to palletized packaging products is because some products might fall during the trip when turning or braking the vehicle, which is mostly caused by the sloshing phenomenon. The roll stability of a partially filled tank is influenced by both: the centre of gravity height and the magnitude of lateral load transfer [30].

One way to measure the forces due to sloshing that affect the structure of a container of liquid is by using Nonlinear External Excitation to build a Liquid Slos–hing model. With that, it is possible to achieve an Euler transform 6-degrees of freedom motion equation of the container [30], and the use of a moving coor–dinate system is used to include the non-linearity and avoid the complex boundary conditions of moving walls [29].

5.2 Vibration

Vibration forces are a major cause of product damage during shipping, usually occuring because of magnifi–cation of vehicle vibration caused by cushioned product packages. They are the second major source of mecha–nical damage to apples, behind only of compressive forces due to apple to apple contact [26].

A usual way to understand this influence is by putting specific instruments of vibration data recording together with a GPS to trace the route, such as EDR-3C or DER-1000 models [20,22]. Most vibration data re–corders use power spectral density (PSD) spectrums [30]. A typical PSD function shows the strength of the variations (energy) as a function of frequency. In other words, it shows at which frequencies variations are strong and at which frequencies they are weak. The unit of PSD is energy (power density in G^2/Hz) versus frequency (Hz). The energy within a specific frequency range can be obtained by integrating PSD within this range and representing it in Grms for the entire spec–trum or a portion of it. Computation of PSD is done directly by the method called Fourier transformation or computing autocorrelation function and then trans–forming it [24].

Vibration forces have direct connection to the parameters such as vehicle speed, vehicle characte–ristics, road conditions and load level [33]. Vehicle speed relates to vibration levels in a direct relation (the faster the speed, the greater the vibration), as reported by Figures 4 and 5. On the other hand, it has been re–ported that overloading probably suppresses transport vibration levels, specially at low speeds, what can be seen by the comparison of Figures 5 and 6. Regarding road conditions, higher vibration levels have been de–tected on rough road surfaces, and these levels are even more significant at high speeds than at low speeds [23].

Respecting vehicle characteristics, it has been reported that smaller vehicles at low speeds (the case of the last leg delivery method in Thailand and Indonesia), present lower vibration levels than those measured in

truck and container shipment across road and rail trans–portation [33]. Likewise, the type of truck's suspension is associated with vibration levels, as presented at Figures 6 and 7. It reveals that that the levels of RMS(G) of the air ride suspension of the truck are significantly lower than the levels of RMS(G) of the leaf spring suspension [21].

Also, products on different locations inside the truck feel different levels of vibration that are higher on the rear of the vehicle [1,23]. At the same time, acceleration raises along the load, raising from the bottom to the top of piled products [1], as reported in Figure 8.

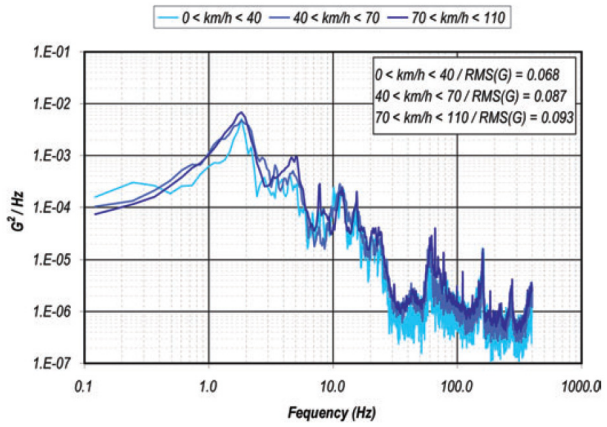

Figure 4. PSD of empty air ride trailer for each speed interval [21].

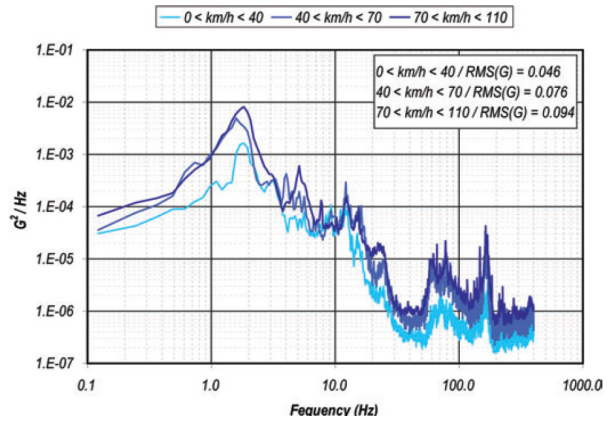

Figure 5. PSD of loaded (21,000 kg) air ride trailer for each speed interval [21].

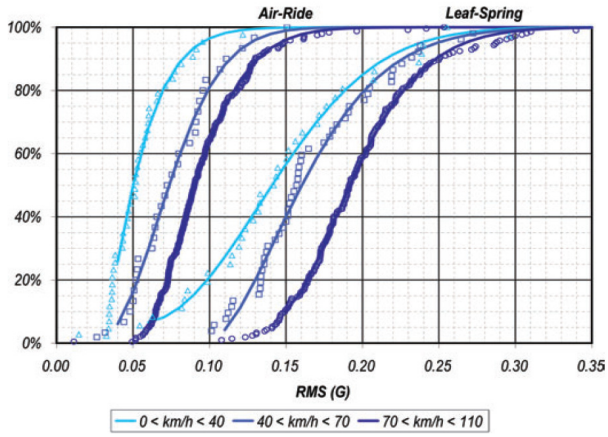

Figure 6. Cumulative Distribution Function of the RMS (G) for each speed interval [21].

When analysing the data, measured vibration levels in lateral should be used in conjunction with vertical levels for packages and products that may not be perfectly cubed in the trailer and result in void spaces [24]. Also, vibration levels are significantly higher in the vertical axis as compared with the longitudinal and lateral axes [32]. Another important factor to take into account is that amplitude of vibration does not represent the only aspect to be considered for evaluating the damage effect on packages, but also the frequency is noteworthy [1].

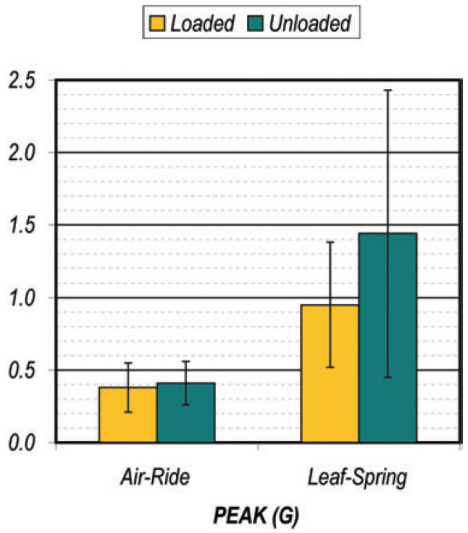

Figure 7. Peak versus the type of suspension and load [21].

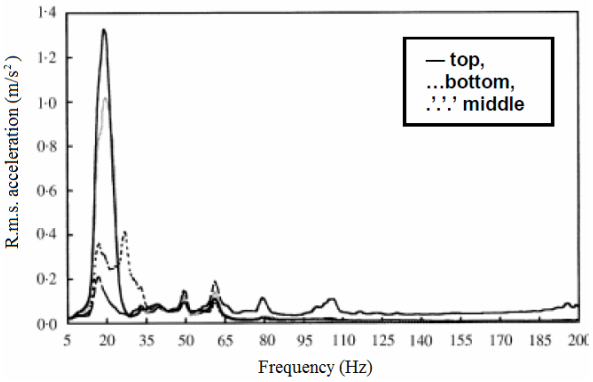

Figure 8. Acceleration peaks [1].

Most researches done in this field were basically accomplished by collecting field data and comparing it with laboratory simulations or with norms or theoretical models. The reproduction of environment conditions, as measured by experiments, represent a better way towards more reliable packaging in respect to the application of standard regulations or theoretical models. It has also been noted that reproducing vibration on a 6 Degrees of Freedom (DoF), instead of a 3 DoF, shaking table generates more reliable results. Furthermore, it is remarkably better to consider solutions including the reproduction of all the real motions at the same time, instead of analysing each single vibrational mode [1].

5.3 Shock

Differing from vibration, shock parameters during products transportation remain to be clarified. In a research done in Japan, an accelerometer and a camera

were installed on a truck to measure shock acceleration and, with the help of the camera, identify the source of the shock. On highways, shocks were caused mostly by road roughness and metal joints at access points of junction. On local roads, the source of the shocks was a result of difference in levels on the asphalt-surfaced road, pedestrian crossings, manholes, road curves, left and right turns, and railroad crossings. This research results suggest that irregularities in road surfaces greatly influence shock levels [4].

Another research analysed the effect of impact on apple bruising as a function of cushioning protection material. The research proposed to investigate bruise volume versus impact energy comparing six combinations of cushioning: bare fruit (BF), foam net (FN), new double-wall corrugated board (NDW), single face corrugated board with flute on the inside (SFI), single face corrugated board with flute on the outside (SFO) and used double-wall corrugated board (UDW). The results show that impact varies greatly when different cushioning materials are used to prevent shock [26], as shown in Figure 9.

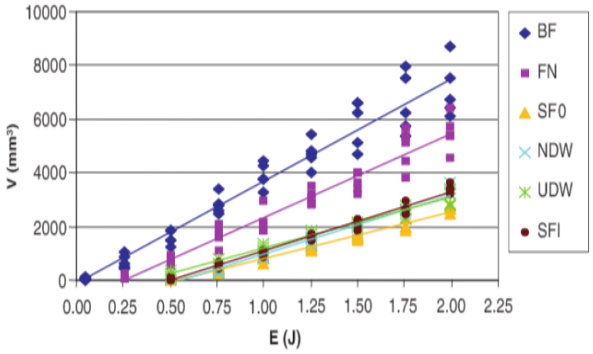

Figure 9. Bruise volume versus impact energy [26].

Shock events are captured with the same instrument as the one used to monitor vibration levels. In order to obtain a better signal analysis, it is recommended to separate the shock event from the overall signal. When it is done, it is possible to observe a significant change in PSD level, especially at 20 Hz frequency [1], like shown in Figure 10.

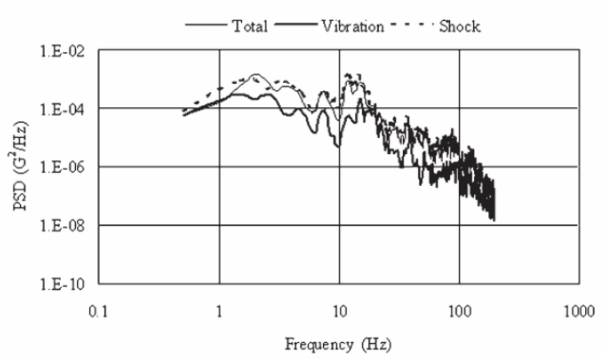

Figure 10. Vibration and shock signal [1].

6. CONCLUSION

The present work provided a brief review on products transportation technology, focusing on palletized goods. The topics analysed were safety in transportation, wrapping materials, parameters and forces during transportation. Safety in products transportation is strictly related to the drivers' safety. Their security is a factor of technology developments combined to security authority measures and drivers' attention to the road. These combined factors can reduce accidents occur–rence and possible resulting injuries and damages to shipments.

Packaging products with an appropriate amount of wrapping material are an important step to keep products with their right properties after the journey of a transportation. Several wrapping materials and proce–sses are being studied pursuing the improvement of fresh-cut products life and numbers of undamaged products. Machine wrapping has grown because of higher pre-stretching values and better productivity compared to hand wrapping.

Conveyance parameters also involve conditions that may affect the integrity of products. In the truck modal for example, parameters that are relevant are the size, structure and speed of the vehicle as well as load level and load distribution.

Forces during transportation are mainly the results of sloshing, vibration and shock. The sloshing effect occurs whenever a partially filled tank is put into motion, and can affect the structure and stability of vehicles. Studies show that part of the sloshing effect can be reduced using baffles at the right size and position. Vibration forces are the biggest source of pro–ducts damage during transportation. Researchers have collected and compared field data of laboratory simulations and analysed how parameters influence in products vibration during shipment. Shock forces are mainly the cause of small packages damage and irregu–larities in road surfaces greatly influence shock levels.

The study on products transportation technology is an ongoing research topic, as technology keeps evol–ving. Understanding this issue is useful for developing new methods of packaging and transportation that can represent better use of materials and longer product life.

ACKNOWLEDGEMENT

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КРАТАК ПРЕГЛЕД ТЕХНОЛОГИЈЕ ТРАНСПОРТА ПАЛЕТИЗОВАНИХ ПРОИЗВОДА

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Палетизовани производи су једно од најчешћих начина превоза робе. Међутим, недавне студије показују да још увек постоји простора за побољшање технологије паковања која може представљати мање трошкове коришћењем материјала за обмотавање, а тиме и мању количину оштећених производа, ипак, недовољно паковање може да не подржава оптерећење који се подстиче на палету и тиме доведе до разарања током транспорта, што представља финансијски губитак; с друге стране, прекомерно паковање указује на непотребни материјални трошак.

С обзиром на тренутно стање, јасно је да су технике оптимизације амбалаже плодно подручје студија за генерисање уштеде новца, побољшање сигурности и смањење губитака робе, што је потенцијално профитабилно за све оне који су укључени у ланац снабдевања. Да бисмо открили како да побољшамо овај процес, неопходно је разумети све техничке границе; на тај начин, представљени рад детаљно наводи најважније факторе који је потребно размотрити у транспорту палетизираних производа путем овог кратког прегледа.