Analysis of Temperature and Humidity in Cold Transport Services

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Abstract

The carriage of fresh food products is very sensitive to conditions during the transport, which makes the refrigerated transport of food products one of the most challenging transport activities. The aim of this project is to analyze factors that affect the product’s quality and storage life and demonstrate the influence of the right conditions during the operation. Four devices installed permanently in three trailers were used for analysis. The sensors have enabled the data collection of temperature, humidity, and lux during transportation. TVSM tool was used to diagnose. Data analysis was performed with the purpose to analyze the research question about how well the company handles its operating conditions of temperature and humidity during transportation. In this research, we found that temperature conditions were not satisfactory compared with the standard recommended conditions, like the official agreement of carriage perishable products (ATP). A similar situation occurred with humidity. This research will be useful for those who are interested in the quality of the fruits and vegetables during transportation and companies of the same industry that wants to know the impact of the right parameters in their trucks.

Keywords
Food quality, cold transportation, fresh food transportation, temperature, humidity, weight loss

1. Introduction

According to Gajewska (2019), the cold chain is one of the most challenging types of transport, which transportation and storage are essential factors to consider at the moment you need to prolong the availability of consumption of perishable products. Donselaar, Woensel Broekmeulen, and Fransoo (2006) mention that in the food industry, there is the main differentiator between perishable and non-perishable foods: “Shelf life”. The shelf life of a product is measured in days, which is defined as “the period of time over which a food maintains its safety and/or quality under reasonably foreseeable conditions of distribution, storage, and use. The shelf-life of food begins from the time the food is produced and/or packed” (FSAI, 2019). Thus, perishable items are those with a short shelf life and non-perishable items have a long shelf life. Variables such as temperature and humidity, affect the growth rates of organisms that cause spoilage and the length of time the food remains edible and nutritious. (Tanner, 2016).
The transport of food products has been using methods of preservation of these products involving the application of the cooling systems. According to Pawlak, Maksym, and Skwarcs (2014), this allows the short-term storage of fresh food at a temperature from 10 to 0°C or long-term storage in a frozen state at a temperature from -12 to -22°C. Tanner confirms (2016) that food quality, storage, and transport covers areas associated with the impact of storage environments and duration on aspects of food quality, as well as technical considerations associated with logistics chain components such as cool and cold stores and transport systems.

According to Bacon and Khanna (2015), it is an extreme case in the perishables sector of the retail industry: gross margins and a lot of residues; significant variations in the volume-sales relationship (depending on the seasonal nature and the climatic factor) and a growth opportunity for the value and also a brand risk. An effective and rapid supply chain helps reduce waste along the chain by delivering a product to the warehouse with a long shelf life, which could mean less consumption of the shelf life between manufacture or sale. A study conducted by the Asian Food Information Center (AFIC) in 2010 states that 67% of consumers in India constantly check the expiration dates of products before purchasing to verify their expiration. A fast and good supply in the processes increases the income and gross profit proportionally.

Stragas and Zeimpekis (2006) said that as the market of perishable food is increasing (e.g. refrigerated products), regulations of the supply chain must be prescribed by public authorities to protect final customers from health hazards. Temperature and other types of conservation control at each stage of the supply chain are essential to maintain quality until it reaches the final consumer. Temperature is one of the most critical factors affecting the quality of perishable foods. This factor is influenced by delays in logistics and temperature changes during storage, which is crucial to maintain optimal conditions. For example, when refrigerated meat or salad is stored above 5°C, bacteria will multiply due to the environment. Depending on the degree of abuse of the temperature, the shelf life of food is shortened or spoiled and can lead to foodborne illness. From the moment the product is being produced until it reaches the end customer, maintaining the proper temperature will have a strong impact on the freshness, desirability, and quality of perishable food. Temperature is a factor that must be in control during the entire life cycle of the product, for which companies that are dedicated to this line of the industry have sought and developed alternatives to store their products with relevant temperature control.

Perishable foods are becoming increasingly important to grocery retailers because many consumers choose one supermarket over another and perishable food losses can reach up to 15% due to spoilage and mishandling of products and this is serious speaking of financial issue. (Wang and Li, 2012). In the European grocery sector, for example, products that are not bought before the expiration date, their costs amount to millions of dollars per year. Stragas and Zeimpekis (2016) mentioned that storage is critical in the cold chain since products are normally stored more than once by different intermediaries (producers, retailers, etc) until they reach the end customer. To preserve quality and safety, it has been established that the storage procedure is a great challenge and vital to the cold food supply chain.

1.1 Importance of the Problem
According to Jedermann, Nicometo, Uysal, and Lang (2017), shelf life mainly depends on temperature deviations during transport and storage. Knowing the maximum or maximum temperature measured at which products should be stored is not particularly helpful. If there is a deviation of 1-2°C for several days it could be significant for the loss of shelf life, while if you look at the product during charging, it hardly affects the shelf life. The shelf life gives the period of time during which the product can be stored at a certain reference temperature until it is no longer consumable, so the consumer would not buy it or if they already have it at home, they would not use it. Aung Min and Seok Chang (2013) mention that of all the factors that can affect the storage life of food products after their harvest, the temperature is the most important. For that, there are refrigeration systems that are designed so that they can operate at an optimal range of conditions such as temperature and humidity, with the ability to adjust depending on the fruits or vegetables that are going to be stored.

Different studies of storage of fruits and vegetables, like Postharvest Center of University of California (2016), Engineering Toolbox (2004), and the official Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be used for such Carriage (ATP, 2016); suggest different parameters of temperature, which is confusing for the company under study. With the help of sensors providing information
about temperature and humidity during the transport of products to control this important parameter, we can see in Figure 1 such differences for the most common food transported.

1.2 Research Purpose
The purpose of this project is to analyze the current situation of the cold chain food transportation process in the company under study to propose strategies for operational solutions to ensure quality during transport. Things to do will be to develop a diagnosis about how is the process in the transport of products (fruits and vegetables) and with the support of the sensors in trucks, to identify the relationship between the factors like temperature and humidity to the quality of the products.

1.3 Methodology
Among the different research and improvement methodologies are Deming, DMAIC (Díaz et al, 2018), Lean Six Sigma, etc. There are some suggestions focused on quantitative research, but they can also be kept in mind in qualitative research whenever appropriate. For this research, which is for diagnosis and to find better conditions for food preservation during transport, the methodology proposed by Bisquerra (2010) with the support of other researchers, is selected. The remaining of this paper continues following this process which includes in section 3 a relevant literature review, the collection method in section 4, data analysis in section 5, and finally, conclusions and recommendations.

2. Literature Review
This section focuses on the TVS mapping relevance for the study, and the most relevant concepts that affect the senescence of fresh food: temperature, transpiration rate, humidity, and weight loss.

2.1 Transportation Value Stream Mapping
The Transportation Value Stream Mapping (TVSM) tool proposed serves to identify and define specific types of waste during transportation with the aim of improving efficiency as a relevant performance measure. According to Villarreal (2012), waste is related to each efficiency factor, availability, performance, and quality. In the supply chain, the value stream is called the series of added value steps from the origin of the raw material.
to the final consumer. The purpose of TVSM is to identify and eliminate wastes and optimize the value-adding activity across the whole supply chain and the wastes impact the availability, performance, and quality. In Figure 2, there is a methodological approach using lean thinking to develop a good Value Stream Mapping.

2.2 Temperature conditions
According to Sánchez, Martínez, Castillejo, Frutos, and Hernández, (2020), one of the main challenges of the food industry is the control of the main environmental factors that have influenced the quality of perishable products. Temperature is the main factor affecting quality, but there are others such as humidity and gas concentrations that also play an important role in maintaining postharvest quality. For this reason, monitoring these factors is a key procedure to assure quality during the useful life and evaluate losses. Once this parameter is controlled, longer service life will be ensured but it is still a problem due to all the factors that may arise. According to the University of Maine Cooperative Extension (2002), fruits and vegetables that require warmer storage temperatures (40 to 55°F) can be damaged if they are subjected to near-freezing temperatures (32°F). Cooler temperatures interfere with normal metabolic processes. This is referred to as a chilling injury.

Figure 2. Methodological approach followed to conduct the improvement of road transport operations using lean thinking. Villarreal (2012)

2.3 Transpiration Rate
Transpiration is the process by which fresh fruits and vegetables lose moisture (Becker and Fricke, 2000). The process includes the transport of moisture through the skin of the commodity, the evaporation of this moisture from the commodity surface, and the convective mass transport of the moisture to the surroundings. The storage life of a commodity is influenced by its respiratory activity. At low temperatures, respiration is reduced, and senescence is delayed. To minimize losses due to transpiration, and thereby increase both market quality and shelf life, commodities must be stored in a low temperature, high humidity environment.

2.4 Relative Humidity and weight loss
The University of Maine Cooperative Extension (2002), defines that transpiration rates (water loss from produce) are determined by the moisture content of the air, which is usually expressed as relative humidity. At high relative humidity, produce maintains salable weight, appearance, nutritional quality, and flavor, while wilting, softening, and juiciness are reduced. Lufu, Ambaw, and Opara (2020) say that high temperatures, low relative humidity, and high air velocity increase transpiration rates, as consequence, weight loss will be present in the products. At a constant temperature, small changes in relative humidity can significantly affect the rate of water loss in fresh produce. According to with Postharvest Center and the study by Lufu, Ambaw, and Opara (2020), the recommended relative humidity for fresh food is between 90% - 95%. This can also be demonstrated with a study in the case of pears about the same temperature (0°C) at different relative humidity, on the study of Xanthopoulos G. (2017) about the behavior of pears in different humidity in Figure 3.
3. Data Collection

For data collection of the conditions of refrigerated products, the use of humidity and temperature sensors in vehicles intended for the transport of food products is now the standard. To accomplish the objectives, specialized sensors have been used that can perform the measurement every two minutes. The sensor SHT30 showed in Figure 4 measures temperature (± 0.3°C), humidity (± 3%) and lux (lx). The information about how the process of transportation is provided by the supervisor of the company. 2 sensors in one truck and another 2 trucks with one sensor per each were analyzed.

4. Data Analysis

4.1 Transformation Value Stream Mapping

With information from the company, a Value Stream Mapping was developed with purposes of the diagnosis about how the operation of transport is. The company first collects goods from the customer, then goes back to the warehouse and finally performs the distribution. It is a long process, where there are different areas to optimize, but the purpose of this research is to analyze the quality during the transport, so the result of the exercise of VSM is summarized in Figure 5.

Suggestions to the company about how to improve some of the processes and perform some activities at the same time were presented. As a small example, prepare documentations and cooling the trailer could be done at the same time. Here, the most important thing, according to the observations, the total time of the operation is 4,925 minutes counting the transportation. Just the operations of transportation (to import to delivery to the warehouse and then to the clients), is 74% of the operation time, so this is why we focus on the analysis of sensors during transportation.
4.2 Analysis of Temperature and Light Conditions

It has already been mentioned that temperature is one of the most important critical factors in the transport of fruits and vegetables. The total time of each reading was around 20 thousand minutes. We can observe in Figure 6 the temperature readings of the two sensors in truck 1. A high-temperature behavior is observed around 11,500 minutes, which indicates that the truck stopped transporting products or is at rest. This situation can be verified in Figure 7 with the behavior of the lux measured during the same time as the temperature in the first truck, where lux means light detection in a square space; so the data analysis is concentrated in an average period of 1 week. It is important to say that the data analysis is carried about the tangerine, and considers the company operation conditions (8°C – 14°C), ATP Agreement with the consideration of chilling injury (0° - 6°C) and Postharvest Center of the University of California (5°C – 8°C) (Postharvest Center, 2016). In Figure 6, the suggested limits by these different studies are contrasting the actual behavior of the temperature.
For the first truck with two sensors, a paired difference test was performed to show that the difference between each amount of data, can be equal considering the specifications of the sensor (±0.3°C, ± 3% Relative Humidity). The results were a mean of .19 for temperature and -1.22 for Humidity, so average will be considered. After this, in Figure 8, the temperature during 11,500 minutes for the first truck behavior is shown.

From Figure 8, percentages in conditions were calculated. The most frequent condition (43% of the time) was 2°C to 4°C, followed by 4°C to 5°C (17.8% of the time), and 5°C to 6°C (10.4%). The percentage complying with the standard company conditions (8 – 14°C) was just 1.42% of the time, according to ATP 78.14%, and Postharvest Center the 19.10% of the time.

For truck 2, the results are shown in Figure 9 with the same lux and temperature criteria, the data from 2 weeks was reduced to approximately one week for the analysis. The behavior of the temperature indicates that during almost 5,000 minutes, the product was stored at temperatures below 0°C t, which can indicate a problem since extreme or lower temperatures than necessary, can affect the product. Also, this situation opens an improvement window for cost reductions.
Figure 9. Temperature behavior of the Truck 2

From Figure 9, the percentage in conditions was calculated. The most frequent percentage was -20°C to -17°C with 39.4% of the time, followed by 6°C to 7°C, 22% of the time, and 0°C to 2°C, 15.5% of the time. The percentage in the standard company conditions (8 – 14°C) was 0%, for ATP 30.74%, and Postharvest Center with 31.96%.

For truck 3, the results are shown in Figure 10. The temperature in truck 3 is the best graph according to the company standard parameters. There are 2 critical temperatures that are below freezing, but during the trip, indicates a closer behavior to the standards.

Figure 10. Temperature behavior of truck 3

From Figure 10, the percentage in conditions was also calculated. The most frequent percentage was 5°C to 6°C (21.3% of the time), followed by 4°C to 5°C (12%), and 2°C to 4°C (11.4%). The percentage in company standard conditions (8 – 14°C) was 21.67%, for ATP 57.55%, and Postharvest Center with 42.09%.

4.3 Analysis of Relative Humidity Conditions
Despite the fact that the available sensors measure relative humidity inside the truck, the company is not controlling this parameter, even though its great influence on the fruits and vegetable shelf life has been shown. With low humidity in the ambient conditions, it affects the transpiration rate, and then the weight loss of the
products. In this work, we have shown there are different sources that corroborate that the right humidity for products, 90% - 95% is the ideal, according to Postharvest center. Figure 11 shows the behavior of the % humidity in the three trucks. Figure 12 summarizes these results by showing the relative frequency of the time that the vehicle is in every % humidity range.

Figure 11. Humidity behavior (a) truck 1, (b) truck 2, (c) truck 3
Figure 12. Relative frequency per % humidity for the three trucks

From these figures, we can observe that the percentage in conditions of Postharvest Center which is 90% - 95% is just 10.3% in truck 1, 13% in truck 2, and truck 3 never reached this range. About one-fourth of the time the % humidity was between 80% and 90%, and the same, between 50% and 60% humidity. 40.6% of the time truck 2 was under 50% humidity, which is an extremely unsafe condition for fresh food. In general, the average % humidity ranged between 66% and 70% for all trucks.

Table 1 shows a summary of the diagnosis of the transport sample analyzed. Finally, based on the equation (1), Holcroft, D. (2015), that relates weight loss with the vapor pressure deficit, which is proportional to the relative humidity, we conclude that the fresh foods transported by the company lose around 0.44% of their weight/day during transport. This value is at least 0.37% (or six times) more than it should or they would be if the transport conditions were under control.

\[ \text{Weight Loss (%/day)} = \text{Transp. Coef (K)} \times \text{Vapor Pressure Deficit (VPD)} \]  \hfill (1)

Table 1. Summary of compliance

<table>
<thead>
<tr>
<th>Results</th>
<th>Truck 1</th>
<th>Truck 2</th>
<th>Truck 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total min per trip</td>
<td>11,130 min</td>
<td>11,516 min</td>
<td>11,510 min</td>
</tr>
<tr>
<td>Average Temp. of trip</td>
<td>3.49 °C</td>
<td>-5.53 °C</td>
<td>5.3 °C</td>
</tr>
<tr>
<td>% Temp °C (Company standards)</td>
<td>1.55%</td>
<td>0%</td>
<td>21.67%</td>
</tr>
<tr>
<td>% Temp °C of ATP</td>
<td>90.28%</td>
<td>30.74%</td>
<td>57.55%</td>
</tr>
<tr>
<td>% Temp °C of Postharvest</td>
<td>19.73%</td>
<td>31.96%</td>
<td>42.09%</td>
</tr>
<tr>
<td>Average %RH. of trip</td>
<td>71.66%</td>
<td>66.15%</td>
<td>65.76%</td>
</tr>
<tr>
<td>% RH between 90-95</td>
<td>10.71%</td>
<td>13.08%</td>
<td>0%</td>
</tr>
<tr>
<td>% Lux 13.21</td>
<td>94.7%</td>
<td>94.7%</td>
<td>92.8%</td>
</tr>
</tbody>
</table>

5. Recommendations

The immediate recommendations that arise from this work are:

- Based mainly on the ATP Agreement and the consideration of chilling injury, the authors recommend setting the temperature optimal conditions between 0°C to 8°C for citrus products.
- There is a potential for energy cost savings by controlling the temperature inside the trucks, and avoiding extreme refrigeration (or freezing); that is, temperatures below 0°.
- The company must introduce as part of its quality standards, the control of the relative humidity. The standard should be set to 90% - 95%. The sensors available already measure this factor and it should be recorded and control. Focus on humidity is one of the most critical factors according to the literature.
because weight loss is directly related. To validate this effect, weight loss sampling should be performed and taken into consideration as a quality indicator of good transportation service.

- The presence of light can also influence quality. The lux in the trucks satisfy the recommendations. Some intermittence in light could be added, as some research suggests.

6. Conclusions

The cold chain is one of the most difficult topics in logistics because it is related directly to the quality and if the products are not in ideal conditions, it affects directly the health of their consumer. In this research, there are a lot of opportunities to continue to develop these issues. The company under study showed that the most important factors that affect the senescence of the fresh products: temperature, humidity, and light, are not under control, and they directly affect the shelf life and cause an excessive weight loss (0.25%/day extra). From the sample, the temperature compliance with its own standards occurs less than 25% of the time. Besides, a reconsideration of the company standards must be done, since they do not agree with any of the literature or official standard, even there are several international standards and most of them did not match. The relative humidity is related directly to weight loss and shelf life. If the relative humidity is low, the transpiration rate will increase because the Vapor Pressure Deficit will grow, and consequently, weight loss increases.

References

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Biographies

**Alejandro Lerma Carrillo** is a mechanical engineer from the University of Monterrey with a degree in Master of Engineering Management from University in Monterrey. He had an academic international experience of six months at Cracow University of Technology, Poland in 2020 during his master concluding a final project in a company dedicated of transport food services. He has experience as production planner and tasks related to project manager with different focuses on the industry.

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