TRANSPORT PROBLEMS 2019 Volume 14 Issue 3
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2019.14.3.9

Keywords: food transport; transport conditions; cold chain; wireless devices; sensors

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THE IMPACT OF TRAILER CONDITIONS ON THE QUALITY OF REFRIGERATED FOOD TRANSPORT SERVICES – A CASE STUDY

Summary. The carriage of food products, in particular fresh products, is particularly sensitive to transport conditions. The aim of this paper is to examine the effect of trailer conditions on the quality of refrigerated food transport services. Six wireless measuring devices installed permanently in 3 trailers were used for the analysis. The built-in transmitter sensors have enabled the collection of data in the areas of temperature, humidity, pressure, shock and light intensity. Monitoring parameters via a wireless device can contribute to the reduction of fuel costs in the enterprise, e.g., detection with vibration sensor / acceleration of aggressive driving style of the driver causing suspended fuel consumption, detection of inappropriate transport conditions, etc. Analysis of the test results showed that in the same trailer the product distribution is very important owing to the different temperature. The analysis carried out showed that in the middle of the semi-trailer, i.e. in the place where the breeze is located, temperature fluctuations amount to 5°C, which indicates a greater risk of loss of quality of the transported products.

1. INTRODUCTION

Transportation of food globally has drastically changed largely owing to refrigeration [21]. Refrigerated transport of food products (Cold Chain) is one of the most important types of transport considering that it is primarily meant to transport food products necessary for life and proper functioning of every human being. Transport at controlled temperature is intended to provide products for consumption in a safe state for human health, which is why it is so important that it takes place in accordance with the regulations [12]. The HACCP concept is a scientific approach to assess hazards associated with food production and establish control systems to ensure food safety [1]. In the case of HACCP documentation, Polish businesses most commonly implement a model that consists of the HACCP manual as the core document; its content and structure resembles the Quality Manual in QMS based on ISO 9001 [4]. This model is applied especially with the implementation of food safety management systems according to such standards as BRC [3], IFS [9] and ISO 22000 [10]. Observance of applicable provisions is to ensure the provision of food without damage and infections, and as much as possible, eliminate the effects of factors affecting the load during all loading, storage and transport operations [20]. The method of transport must be adapted to the type of transported cargo, and it should take into account temperature requirements, methods of storing products on pallets, protection of goods from damage or appropriate transport time management. This is important especially for products with a short shelf-life. In Poland, most food is transported by isothermal trucks or cold stores, in which the goods can easily be damaged or spoiled. Such a situation can take place as a result of both overheating and freezing of the product. Consumers incur costs related to the damage / corruption of food products. According to market data, food losses in the food industry resulting from

improper transport or storage of goods reach around 30%. Each company should therefore take appropriate measures to ensure the right conditions for transporting food from the first shipment to delivery to the destinations. The transport of products is divided into categories characterized by different requirements: transport in controlled temperature of packaged and unpackaged goods (cold stores, cold stores - called cold supply chain), transport without temperature conditions of packaged / unwrapped goods or in containers and containers, and transport by tankers or containers of liquid cargo.

The carriage of food products, in particular fresh products such as fruits, vegetables, meat, fish and dairy products, is particularly sensitive to transport conditions. Subjected to too high or low temperature or too high or low humidity, they lose much of their quality, fade, wither or rot and are unfit for consumption. Transport of agri-food products, being an important link in the supply chain, may carry many risks and have a potential effect on the quality and health safety of food. In addition, improperly provided transport services may contribute to the spread of disease threats or lead to a reduction in the quality of food products. Therefore, it is very important that those responsible for the transport chain of these items (food logistics) can provide the right temperature, humidity, transport time, appropriate drivers and means of transport to meet the requirements of transporting particular categories of food products.

Drivers who are carriers are obliged to control the temperature in the load box during transport, which is enabled by the vehicle-mounted temperature recording devices during transport and equipped with a print option, so-called thermographs/thermo recorders [2].

Transport is a process that includes stages of storage, storage, packing, loading, moving and loading and unloading. Each of these stages is a potential source of threats in which various types of irregularities may occur. Food products may be malformed or improperly packed or improperly prepared for transport, and it may be carried out in violation of the regulations. In addition, changes in the conditions that may occur during transport and irregularities in the structure of the body may cause a significant reduction in the quality of transported products and the associated risks to consumers. This threat results from the cases of shortening the expiration date of products and their deterioration before the date guaranteed by the producer and the loss of key properties such as consistency, color and taste resulting in the loss of brand image. It is assumed that about half of transported food products require transport at controlled temperature, and food losses caused by abnormal transport conditions reach over 30%, which in turn generates unnecessary costs for the enterprise [8]. These costs are all the more severe, not only because of the loss of goods but also the necessity of their withdrawal from the market and utilization. An important developing direction (growing trend) of this transport is to ensure proper conditions and reduce transport costs while ensuring the quality of goods during transport. This forces constant search for innovative solutions that meet ever higher requirements.

As part of the analyses carried out in this paper, the following aims were achieved:

- conditions for transporting goods (temperature, humidity, and acceleration) in the cold supply chain have been identified;
- analysis of factors causing changes in the environmental conditions of the product during transport (e.g. door opening, temperature difference inside the trailer and outside, and loading of the heated product) - identification of factors, and determination of their effect as a function of time; and
- determination of the effect of the identified parameters on the quality of transport services.

Analyses carried out will help streamline the transport process in the company because they will enable identification of adverse effects that adversely affect the conditions of food transport. Such activities include too long a time of open doors, loading warm goods into a cold trailer causing condensation, too much humidity causing water to soak up boxes and crush them, etc. The number of such events is large, and without proper research, it would not be possible to develop effective cargo transportation guidelines. The service will contribute to increasing the company's competitiveness and improving the logistics services provided by increasing its quality. In addition, monitoring parameters via a wireless device can contribute to the reduction of fuel costs in the enterprise, e.g., detection with vibration sensor / acceleration of aggressive driving style of the driver causing suspended fuel consumption, and detection of inappropriate transport conditions.

2. LITERATURE REVIEW

The cold chain is a term applied to food handling and distribution where the product is maintained at suitable conditions all the way from the cooling of freezing process to the point of sale. This requires transport, various kinds of storage and display [5].

Processors of refrigerated and frozen foods invest heavily in refrigeration equipment, temperature-control devices and monitoring equipment in order to preserve their products. However, once the products leave the manufacturing facility, there is good evidence that they are almost immediately exposed to temperature abuse in the transportation system [11]. Representatives of enterprises from the Transport-Forwarding-Logistics (TFL) sector, as one of the key problems preventing full optimization of the supply chain, see the lack of the possibility of analyzing the risk of damage to goods and insufficient possibility to monitor the conditions of their environment during distribution. The food industry, i.e., production companies and stores, bear costs each year resulting from the deterioration of products before their expiry date. Very often, these are not only financial losses but also image-related losses, because large networks ordering such products have very strict quality standards. On the contrary, the manufacturer implementing the orders of a larger customer (e.g. the aforementioned store chains) has no control over the entire logistics chain, as part of the transport may be carried out by the ordering party or external companies –Third Party Logistics (3PL).

The temperature and humidity monitoring inside the means of transport and the management of information about changes in the ambient conditions inside the refrigerated vehicle are important parts of the cold chain. Commercially available hardware and software as well as solutions providers offer a variety of solutions for recording, storing and retrieving data [14]. Authors such as Martins et al. [15], Hopper et al. [6], Hsu and Shangguang [7], Ramesh and Das [18], Zhang et al. [23] and Lisińska-Kuśnierz and Gajewska [13] have focused their research on monitoring food safety during transportation. Zhang [22] suggested in a paper a design of an intelligent monitoring system based on the Internet of thing, realized monitoring temperature and humidity inside the refrigerator trucks and the intelligent cargo identification, and tracking the location of refrigerator trucks real time in the entire transportation process by using advanced RFID technology, the sensor technology and the wireless communication technology [22]. Ryan [19] states 15 main risk problem areas during food transportation: refrigeration and temperature control; transportation unit management (prevention, sanitation, etc.); packing; loading and unloading; security; pest control; container design; preventive maintenance; employee hygiene; policies; handling of rejected loads; holding; and traceability. Therefore, no matter what kind of food commodities and products are transmitted, they all require common multiple steps in their transportation between point of origin and point of use in order to ensure safe food products transportation and to avoid any contamination. Recent trends in food safety are focused on miniaturization of analytical procedures through application of sensors, biosensors, microchips lab-on-a-chip, or micro total analysis systems. This will allow fast detection of possible contamination especially during transportation. Different parameters as indicators of contamination of foodstuff could be measured by miniaturized devices. These parameters could be temperature, humidity, chemical contaminants, microbial contaminants etc [11].

The solutions available on the market and the results of the authors' research work allow us to monitor climatic conditions in the trailer, not the ambient conditions of the product. Seemingly, it might seem that there is no difference between these processes. However, with a deeper analysis of the problem, the conclusions can be drawn that the conditions prevailing in a vehicle semi-trailer can be uneven due to the uneven air circulation. Very often, the semi-trailer is cooled by the aggregate in the front part of the semi-trailer and blowing in the rear part. The result is a higher temperature in the middle part of the trailer. By mounting the temperature recorder in the wrong place, the readings will also be incorrect. Often, especially when waiting for unloading or changing a means of transport (e.g. from a car to an airplane), the goods are also subjected to temperature changes. According to independent studies carried out by one of the transport companies, the temperature differences occurring at such times can be up to 75 °C.

Increasing of temperature and humidity cannot give information about the type of contamination which will occur but it is a sign of contamination in many types of food stuff (milk, meat, plants, fruits

and vegetables etc.). Thus, temperature and humidity can be taken as parameters to follow in sensor design in order to have universal sensors for many different food products [14].

3. THE IMPACT OF ENVIRONMENTAL CONDITIONS ON THE QUALITY OF REFRIGERATED FOOD TRANSPORT SERVICES – A CASE STUDY

3.1. Research material

The use of humidity and temperature sensors in vehicles intended for the transport of food products is now the standard. However, many companies use thermo recorders that allow you to measure every 10, 15, and 30 minutes and ripping data via USB or direct print from the device. Such solutions are only evidence of the conditions of transport of goods, although for the transport company, they do not bring additional value. The use of light sensors, in addition, allows you to identify the time of opening and closing the door. In addition, the use of the accelerometer allows the assessment of the driver's driving style and road incidents such as sudden braking or collision.

To accomplish the aforementioned objectives, specialized sensors have been used that can perform the measurement every two minutes and on short routes even for 2 seconds (fig. 1).

Fig. 1. The measuring sensor used

Sensors allow for data recording for two weeks at a frequency of 2 minutes and enable reading from a distance of 15 meters using mobile devices equipped with Android, and Bluetooth (BT) at version 4.2 - data transmission via Bluetooth Low Energy (BLE). It allowed gathering of the necessary data for research. Six wireless measuring devices installed permanently in 3 trailers (2 sensors in 1 semi-trailer) were used: one near the unit - to analyze the warm air temperature entering the unit, and the second one at the end of blowing from the sleeve located in the middle of the trailer, to analyze the cooled air. The object of research was specialized means of transport of an enterprise specializing in the refrigerated transport of fresh fruits and vegetables operating on the Polish and international market. Built-in transmitter sensors have enabled the collection of data in the areas of: temperature, humidity, shock and light intensity. The sensor has a temperature-humidity sensor SHT30 made in CMOSens technology and a light sensor - photodiode BPW 34 S. The data from the sensor are saved to non-volatile EEPROM memory. The SKK Hive Sensor v1.2 sensor version has professional housings made in ABS casting technology. The enclosures consist of two parts screwed together. The project took into account the funnel leading to the temperature and humidity sensor. This ensures greater dynamics of measurements. The system is also tightly sealed - the devices have a degree of protection at IP 56 according to PN-EN 60529: 2003. This provides protection against access to dangerous parts with wire, protection against dust and against a strong water jet (100 l / min) cast on the casing from any side. The study was carried out during the transport of perishable cargo within 1 week in the month of April 2018.

The sensor used sends data based on the Bluetooth Low Energy technology, i.e. a slimmed-down version of the standard Bluetooth protocol. The main advantages of this standard are low energy consumption and the ease of designing mobile applications. BLE, unlike classic BT, has no legal restrictions. The protocol allows you to send small packages with selected information (e.g.

measurements from sensors) at a low cost of energy. BLE devices are able to work for up to two years using a regular button cell battery. In order to optimize the operation of the system, SKK's own SKL standard was introduced in the BLE protocol. It defines specific data items in Advertisement Data and a data transmission system using notifications.

3.2. Analysis of the environmental conditions on the quality of refrigerated food transport services

The arrangement of sensors in the trailer is shown in Fig. 2.

Fig. 2. Location of the sensors in the semi-trailer with the Thermo King unit

The comparison of temperature readings for sensors placed in the same trailer is shown in Fig. 3. Fig. 3 shows that in the same trailer the product distribution is very important due to the different temperature. Directly at the aggregate, the temperature is higher by about 0.7 °C than in the middle of the trailer where there is a blast of cooled air. This is especially important for products sensitive to sub-cooling, such as cabbage. On March 23, a significant increase in the temperature readings range to -3.66 °C ÷ 23.75 °C is noticeable. This results from the delivery of the goods to the customer, which is noticeable after the light and temperature sensor readings. Maximum temperature fluctuations during transport were recorded on March 20, and they amounted to less than 4 °C. During this time, readings in the range 3.8 °C - 7.6 °C were recorded. Therefore, despite temperature fluctuations, the conditions of carriage are correct: 2 °C - 8 °C. These fluctuations result from the aggregate operation as shown in Fig. 4.

The sensors used allow monitoring the operation of the aggregate. Fig. 4 indicates that the aggregate switches on every 1h12min. The blue line indicates the actual temperature readings, whereas the orange line shows the temperature course smoothened with a moving average of 34 measurements in order to visualize the general temperature course. The changeability of the course results from the different ambient temperature of the trailer, i.e. from the weather conditions prevailing on the route during transport. The dynamics of these changes depend on the type of insulation of the trailer.

Before starting the transport process, the trailer was cooled from 10 °C to - 2.8 °C. At 8:17 the last measurement of light was recorded which indicates the closing of the trailer door and the start of transport. Another light measurement was recorded at 3:23 three days later. It was the unloading hour, which is also confirmed by the temperature sensor reading. From this hour, there are no noticeable fluctuations in temperature corresponding to the operating mode of the unit, which indicates its

deactivation. The vehicle after unloading returned through the unloaded part of the route, taking it only on March 21 at 9:15 - this is evidenced by the reading of light shown in Figure 5 reaching the highest level of light intensity. A noticeable increase in temperature around 19:30 to 7.8 °C results from driving on an off aggregate. The aggregate was then switched on again to properly prepare (cool) the semitrailer to collect the load on the route on the way back.

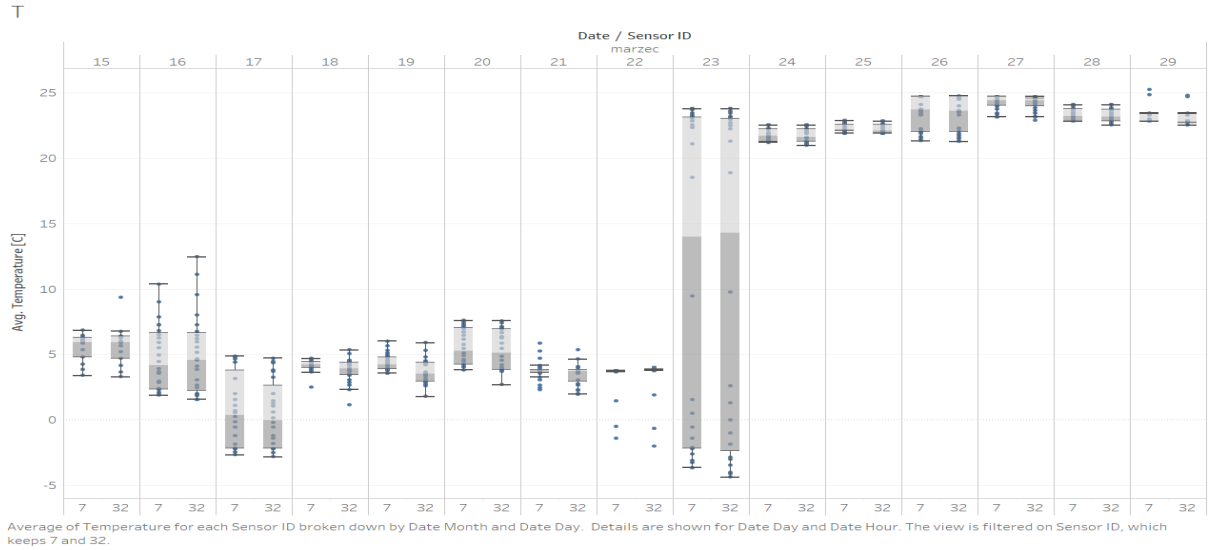

Fig. 3. Comparison of temperature in the same trailer with two sensors placed in different places

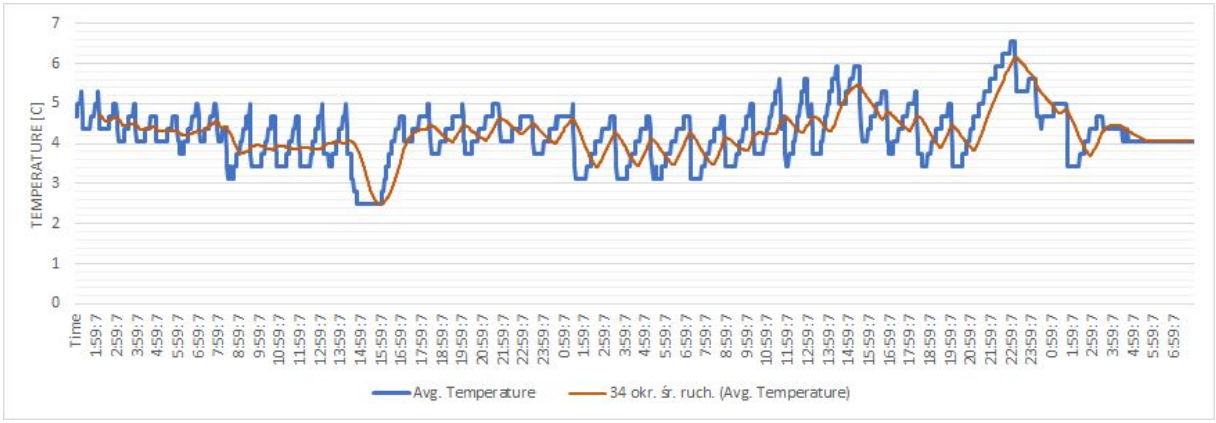

Fig. 4. Temperature fluctuations showing the operations of the aggregate

The aerometer, on the other hand, allows you to analyze the driver's driving style such as sudden braking and acceleration of the vehicle and traffic events. The LIS2DH accelerometer used is made in ultralow-power technology, providing acceleration measurement in three axes. The device has configurable interrupts for two independent events, such as drop detection and motion detection.

Based on the acceleration reading, you can analyze the driver's working time. The acceleration sensor makes a constant measurement by storing the data to the internal error and registering the maximum value in the set measurement interval (2 min). Therefore, if the vehicle is moving for more than 2 minutes at a constant speed or acceleration, this is not recorded by the sensor. However, events such as starting off or braking are recorded due to their dynamics. Analyzing the readings, it can be seen that the driver very often makes longer pauses and rests than required by law.

Based on the light readings, it can be stated that opening the door for 16 minutes (fig. 7b - opening the door for 10 and 6 minutes) causes the air inside the semi-trailer to be exchanged. As a result, it results in a two-time impediment to the cooling of the trailer (hours from 8 to 15). However, the door

opening time above 1h (fig. 8) even with breaks (opening and closing the door of the trailer in accordance with the need to unload) results in a temperature increase of around 2 °C / h, and a humidity drop of about 6% / h.

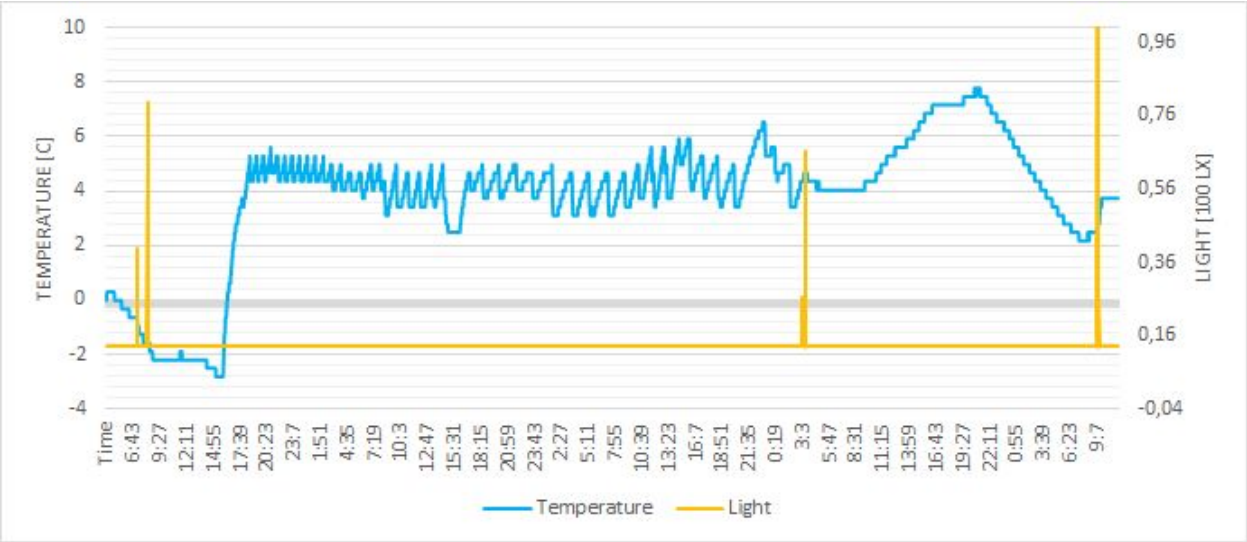

Fig. 5. Temperature and light registration during the transport process

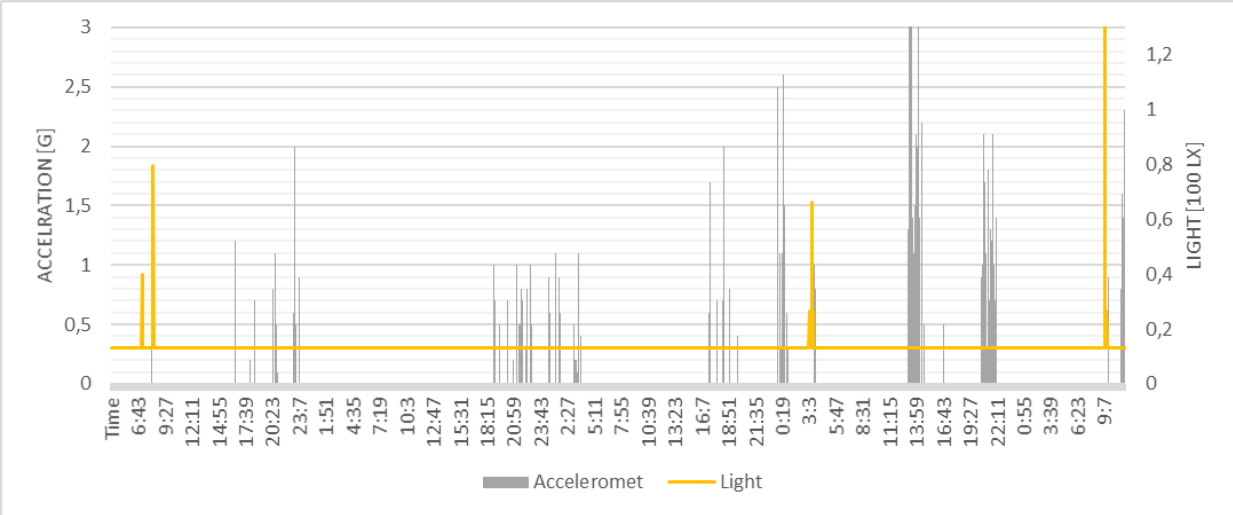

Fig. 6. Acceleration and light reading for the sensor about id 7

The temperature and humidity readings collected by the sensors located at the aggregate and in the middle of the trailer are important for maintaining the quality of the transported goods (fig. 8b and fig. 8c). It is noticeable that the sensor with the numbers 7 does not notice any major temperature changes than 1 °C; therefore, the front part of the trailer is a better place for products sensitive to temperature fluctuations (fig. 8a). In the middle of the semi-trailer, i.e. in the place where the blast is located, such fluctuations are at the level of up to 5 °C, so this place is more vulnerable to the loss of the quality of transported goods. A similar relationship is observed in the case of humidity, i.e., for the front of the semitrailer, up to 9%, whereas for the middle up to 13%. Humidity is strongly related to temperature, i.e., the higher the temperature, the lower the humidity (fig. 8c).

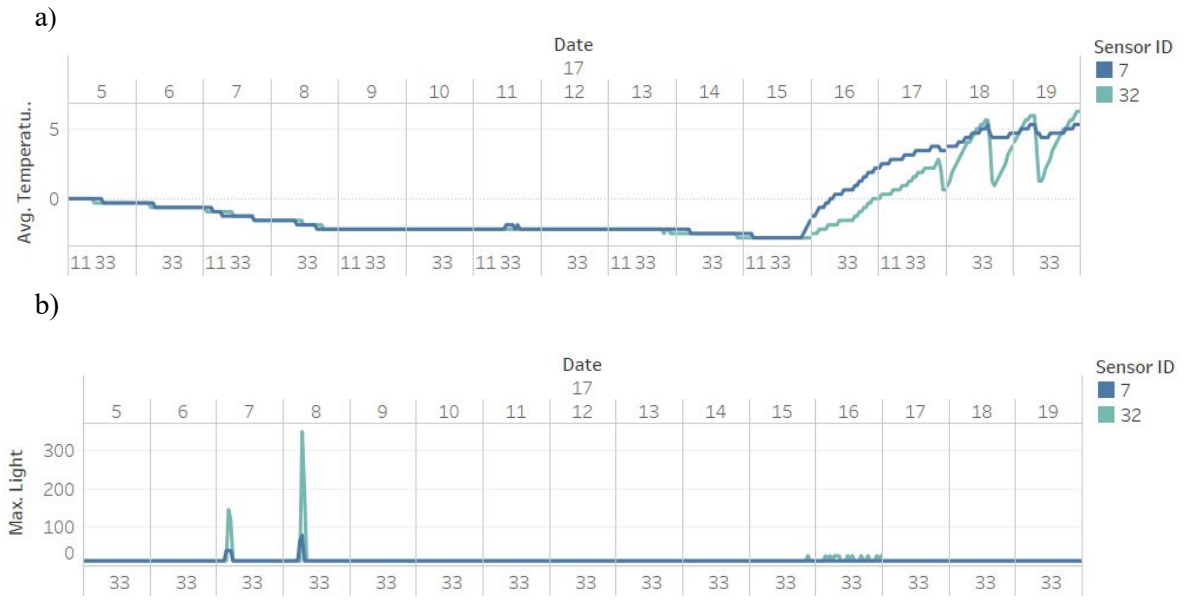

Fig. 7. (a) temperature reading; (b) light reading

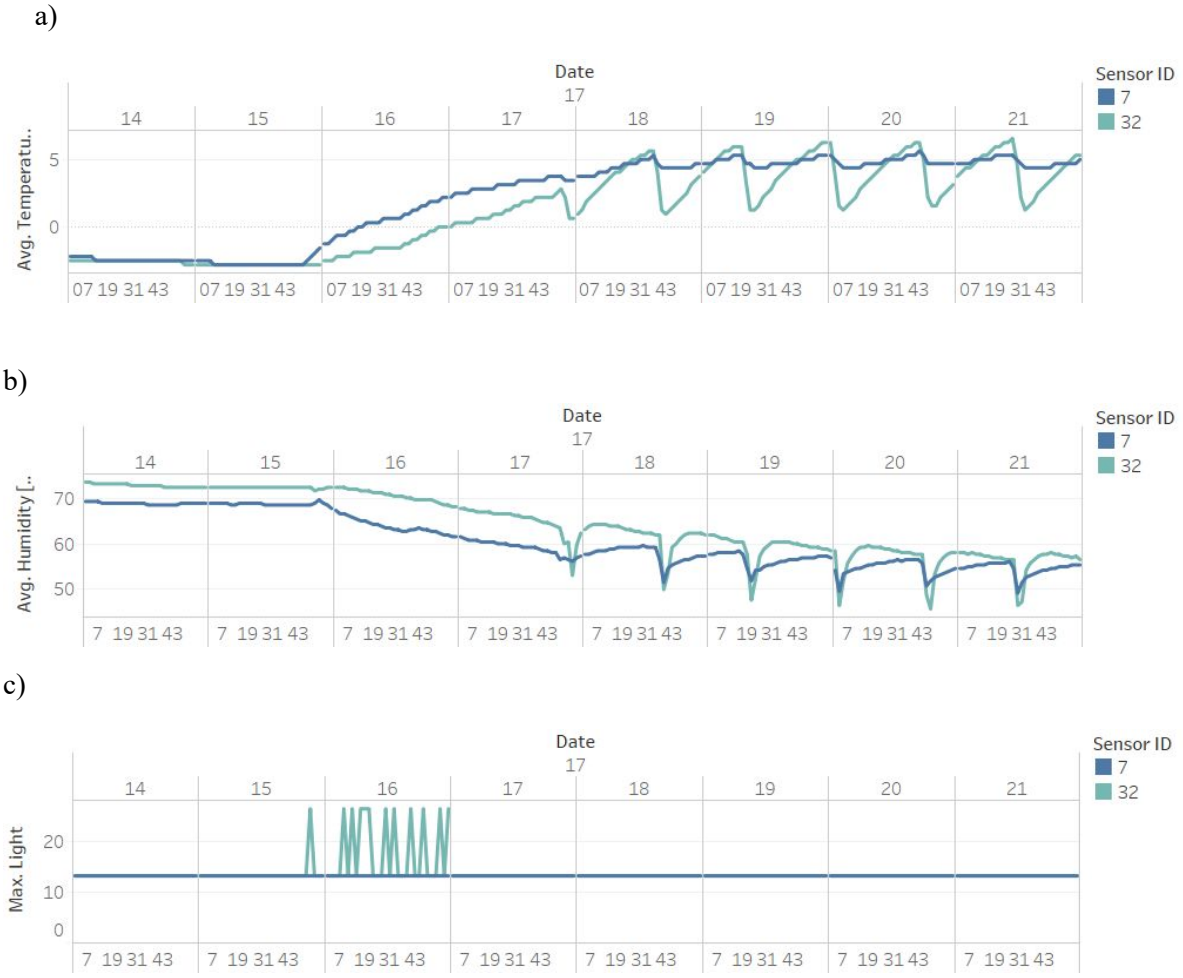

Fig. 8. (a) Change in temperature as a result of unloading goods; (b) Change in humidity as a result of unloading goods; (c) Change in light as a result of unloading goods

4. DISCUSSION

The transport of fresh vegetables and fruits is a technical challenge, because the products, both during the growing season and after harvest, are associated with living microorganisms, which are constantly present, and there are physiological processes causing products' maturation and aging. Processes like these cannot be completely stopped, but using the right technologies can be significantly slowed down. Chilling is such basic and well-known technology.

Using various types of refrigeration equipment, monitoring and recording of ambient conditions inside the vehicle, fresh fruit and vegetables, kept in a low temperature environment, can be transported in a chain refrigeration, even over long distances: land, sea and air.

The market for technologies to trace consumable products such as foods is driven by three forces. The first is the safety of foods, which must be continuously monitored and occasionally recalled to prevent intrinsic or emerging pathogens, or human error prevention during production processes, from adulterating the product to harming the consumer. The second is the security of foods, which is increasingly threatened by theft, counterfeiting, adulteration and the possibility of terrorism. The third is consumer demand for traceability, which reflects public perception of the safety and security of foods, as influenced by local cultural and economic factors (Nightingale, 2004). Rapid, low-cost tests are needed for food suppliers to determine, beyond visual audits, what is really going on with their products. Such testing could be applied to farm harvests, distribution, transportation, and virtually any place in the food supply chain. The hard and objective data supplied by testing could support quality and food safety control, management of decision making and preventive and corrective actions. Traceability technology is available to measure temperatures, humidity, and tampering throughout all transportation processes, and the application of these technologies can be shown to provide not only return on investment but also marketing leverage [19].

The data on the measurement of food transportation safety and food quality costs and losses are rarely collected, summarized or published. Therefore, the work attempts to identify the ambient conditions inside the refrigerated vehicle. Next, the influence of the analyzed parameters inside the vehicle was examined, such as: temperature, humidity, shock, and pressure on the quality of food transport services. There are many devices available on the market for the re-monitoring and monitoring of parameters inside the means of transport. However, it is particularly important that the measurements take place in a short time interval so that the refrigeration chain is not interrupted at any stage of the transport process. The approach proposed in the paper enabled the measurement of the ambient conditions of the refrigerated vehicle at a frequency of 2 minutes, and on short routes, even every 2 seconds on the selected route.

Food quality and safety in the transportation sector of the supply chain will eventually be driven by the industry and the people depended on the food supply chain. Although government agencies enact laws, promote good practices, create guidelines, attempt to enforce weak standards and manage recalls, their effect is minimal and ineffective.

Food transported in a dirty container is more likely to become adulterated, and therefore presents a higher risk to consumers than food transported in a sanitized and refrigerated container. An enterprise that has a system for sanitizing, tracking and controlling the temperature and others parameters inside the means of transport is less likely to provide opportunities for food adulteration than an enterprise with no system, no standards, and no business strategy designed to protect them from liabilities that go along with such risky behaviour [19].

5. CONCLUSION

Analysis of the test results showed that in the same trailer the product distribution is very important due to the different temperature. Directly at the aggregate, the temperature is higher by about 0.7 °C than in the middle of the trailer where there is a blast of cooled air. This is especially important for products sensitive to sub-cooling, such as cabbage.

Analyzing the work of the aggregate in turn, it was found that in the analyzed case the aggregate turns on every 1h12min. The changeability of the course results from the different ambient temperature of the trailer, i.e. from the weather conditions prevailing on the route during transport. The dynamics of these changes depend on the type of insulation of the trailer. The light readings showed that the driver opened the door for 16 minutes, which causes the air to be exchanged inside the semi-trailer. However, the door opening time over 1h including breaks results in a temperature increase of around 2 °C / h, and a humidity drop of around 6% / h.

The temperature and humidity readings collected by the sensors located at the aggregate and in the middle of the trailer are important for maintaining the quality of the transported goods. The analysis carried out showed that in the middle of the semi-trailer, i.e., in the place where the breeze is located, temperature fluctuations amount to 5 °C, which indicates a greater risk of loss of quality of the transported products. A similar relationship was observed in the case of humidity analysis, in the middle of the trailer, at the blow, where it is 13%. Humidity is strongly related to temperature, i.e. the higher the temperature, the lower the humidity.

Analyses carried out will help streamline the transport process in the company because they will enable identification of adverse effects that adversely affect the conditions of food transport. Such activities include too long a time of open doors, loading warm goods into a cold trailer causing condensation, too much humidity causing water to soak up boxes and crush them, etc. The number of such events is large, and without proper research, it would not be possible to develop effective cargo transportation guidelines.

The service will contribute to increasing the company's competitiveness and improving the logistics services provided by increasing its quality. In addition, monitoring parameters via a wireless device can contribute to the reduction of fuel costs in the enterprise, e.g. detection with vibration sensor / acceleration of aggressive driving style of the driver causing suspended fuel consumption, detection of inappropriate transport conditions, etc.

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Received 12.05.2018; accepted in revised form 27.08.2019