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# Quality Estimation of Perishables in Cold Chain Network using Machine Learning: A New Approach

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**Abstract:- Perishable food preservation is an important aspect of cold chain logistics operations. Changes in humidity and temperature in cold reefers typically cause perishable food to deteriorate. The current cold chain design in India is ineffective at maintaining these values constant during transport. Therefore, a smart cold chain system is required to avoid food wastage in the cold chain network. In this study, an IoT-based system is developed to monitor the temperature and humidity of perishables during transit considering various vehicle characteristics. The study suggests measuring the Mean Kinetic Temperature (MKT) that takes into account the biochemical changes in food caused by temperature fluctuations. Machine learning algorithms are being used to estimate the quality of perishables, which is a significant advancement in cold chain technology. Machine learning algorithms improve the accuracy of time-temperature data prediction, thereby preserving food quality during transportation. The cloud and a mobile app are used to send an early warning message about temperature abuse to the concerned person. In addition, a comparative analysis of algorithms is carried out to recommend the best algorithm for prediction. The outcomes are compared to those of real-time applications.**

***Keywords****:- Cold Chain; IoT; Perishable Food Quality; MKT; Machine Learning Algorithms.*

## I. INTRODUCTION

India is one of the largest producers of vegetables, fruits, and milk. But unfortunately, it is one of the leading countries in food waste also. Because India's cold chain is still in its early stages, a large amount of agricultural products are at risk of rotting. There are many reasons behind it but the main reasons are lack of storage and processing infrastructure, complicated cold chain, and very poor post-harvest care. The efficient cold chain sector is essential for addressing these problems.

The application of cold temperature is divided into different categories such as Normal (>20°C), Mild Chilled (10°C to 20°C), Chilled (0°C to 10°C), and Frozen (< -18°C) [16]. The cold chain needs to be handled at chilled and mild chilled zones for horticultural food, whereas for fish and meat the temperature lies between chilled and frozen zones. There are chances of temperature abuse due to various critical internal and external parameters during the cold chain. As the temperature rises, the rate of microbial growth and the amount of water lost by the food increases. Food products deteriorate to some extent with time. This is due to organic molecules spontaneously breaking down. Food storage methods, particularly those used during transportation, as well as various characteristics of cold reefers, all have a significant impact on the product's safety and quality. This is because transportation conditions promote various deterioration and infestation processes. As a result, a system that continuously monitors temperature and humidity during the cold chain is required to ensure proper food quality and reduce food loss [12].

In this study, a technique for predicting time-temperature and time-humidity data at each stage of the cold chain is proposed. The system recommends measuring Mean Kinetic Temperature (MKT), which takes into account the biochemical changes of perishables rather than traditional average temperature measurement. The system also predicts the amount of dehumidification required to keep food in cold containers at constant relative humidity. Machine learning algorithms are used as a data mining tool for exploring information from cold chain networks. The use of machine learning algorithms for data forecasting in the cold chain sector is a new step toward modern technology. A dataset is created by taking real-time temperature readings for perishable foods such as milk, grapes, and cheese. The machine learning algorithms enhances the accuracy of predicting time-temperature data and minimizes prediction time.

## II. RELATED WORK

The cold chain sector has emerged as a significant contributor to India's agricultural GDP. However, according to the ICAR-CIPHET(Indian Council of Agricultural Research-Central Institute of Post-Harvest Engineering & Technology) report, fruit losses ranged from 6.70 % to 15.88 %, vegetables from 4.58 % to 12.44 %, and fish, meat, and milk losses were 10.52 %, 2.71 & and, 0.92 % respectively during the COVID-19 pandemic. The relative humidity and temperature tracking of perishables during the transit step of the cold chain is emphasized in this work. In previous literature, various issues and challenges of sophisticated cold chain implementation have been discussed. Most of the researchers have developed hardware as well as simulation systems to address the cold chain issues.

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Accorsi Riccardo et al. [1] have proposed an IoT-based food supply chain. They have discussed various issues of implementation for IoT-based cold chains. Aiello et al. [2] have proposed a simulation analysis of cold chain performance considering various supply chain activities. Chudasama R. et al. [3] have discussed the various issues regarding dairy data analysis. They have used advanced systems for analysis purposes. Emenike C. et al. [5] used RFID-based sensing techniques to create a real-time system for monitoring the temperature of perishable food.

Estrada et al. [6] have proposed temperature indicators for cold vehicles. They have considered various vehicle characteristics for simulation. Estrada et al. [7] have discussed cold chain concepts and the need for energy optimization in the cold chain. Hongmin Sun et al. [10] have proposed a real-time monitoring system based on advanced technologies such as RFID, GPRS, and GPS for the transportation of raw milk. Jiayang L. et al. [11] have discussed the path optimization problem in the cold chain of fresh fruits, vegetables, and milk considering carbon emissions factors.

Kale S.D. et al. [12] have proposed predictive analytics in the cold chain sector on the IoT platform. They have suggested machine learning algorithms for data mining purposes in the cold chain. Liu et al. [14] have proposed a system for real-time temperature monitoring using GPS and RFID modules. Mukhopadhyay et al. [15] have developed an embedded system where temperature and pH sensors are inserted into milk cartons for continuous monitoring and if these parameters cross threshold value an optimal path is suggested for delivery of milk before the quality loss. The present architecture of Cold Chain Management (CCM) and subsequent requirements have been discussed in the report of NABARD [16]. The advantages of a good-connected cold chain and challenges in cold truck transportation for real-time temperature monitoring are also discussed in the report.

Novaes et al. [17] have proposed a solution for minimizing traveling distance or time to ensure the quality of perishable food throughout the cold chain. Pant R.R. et al. [18] have proposed a framework for the dairy supply chain considering various critical parameters of the supply chain. Wang et al. [20] have proposed a model based on RFID technologies, ZigBee, and the Grid computing management system. The model acted as an early warning system for the detection of temperature abuse during packaging, storage, or distribution.

Zakeri A. et al. [21] have proposed a system for prior detection of various events in the milk processing tank. The sensors data have been used to constantly monitor the cooling temperature of milk while storing it in the tank. Each event in a milking cycle has been determined using machine learning techniques. Gharehyakheh Amin et al. [9] presented a method for evaluating and improving food quality while in transit. They also provide a solution for energy consumption as well as vehicle routing.

## III. PROPOSED METHODOLOGY

From the previous study, it's found that there is a need for a cost-effective system that should monitor the relative humidity and temperature of perishable food during transit and send an early warning message for corrective action as well as provide a solution of dehumidification to maintain the humidity. Furthermore, for predicting food quality, the measurement of Mean Kinetic Temperature, which takes into account biochemical factors, is considered. An IoT-based system is embedded in the cold reefer to monitor the temperature levels of the food. When the temperature level increases or decreases beyond the threshold level, a message is sent on mobile phones. Fig. 1 depicts the actual implementation of the system.

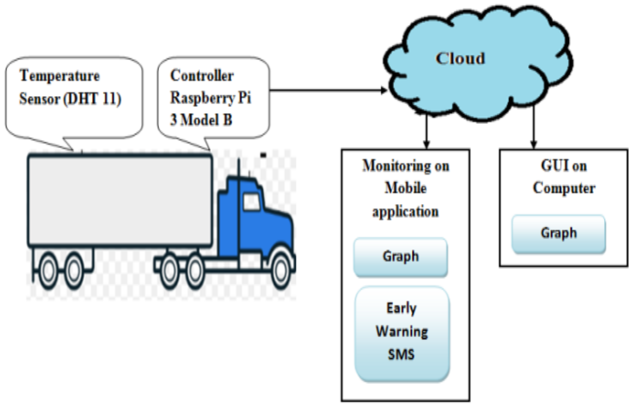


Fig.1. Implementation of system

The proposed system is designed to monitor the temperature of the milk, cheese, and grapes during the transit step of a cold chain. The parameter estimation of these perishable foods is shown in table I.

TABLE I. PARAMETER ESTIMATION OF PERISHABLE FOODS

| Perishable foods | Transit Temperature (°C) | Relative humidity (%) |
|---|---|---|
| Milk | 4 | -- |
| Cheese | 3.5 | 66 |
| Grapes | 0 | 85 |

The temperature and humidity of the perishable foods are set at their initial values. Real-time temperature data is collected from the temperature sensor at an interval of 10 minutes during the transit step of a cold chain. Total traveling time is considered as 5 hours. Then this data is processed and discretized at different intervals.

The threshold temperature is set to 10°C. Once the temperature rises above 10°C, the message will be sent to the driver or manager so that some prior action can be taken to maintain the quality of the milk.

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One of the most important aspects of the proposed work is the measurement of Mean Kinetic Temperature (MKT). Temperature fluctuations in the cold chain make it difficult to select a single consistent temperature for product viability testing. Because it ignores biochemical changes in food, the average temperature calculation is not an acceptable method. As a result, MKT is defined as a single temperature that takes into account the cumulative effect of multiple temperature shifts over time. MKT is a nonlinear weighted average that illustrates the effects of temperature changes over time [8].

MKT is the ideal temperature that is used to maintain during various cold chain operations calculated as shown in equation 1.

$$T_k = \frac{-E_a/R}{\ln\left(\frac{e^{-E_a/RT1}+e^{-E_a/RT2}+\cdots+e^{-E_a/RTn}}{n}\right)} \tag{1}$$

Where R is the universal gas constant, Ea is the heat of activation, T1 – Tn is the measured temperature data points, TK is the MKT in degrees Kelvin.

Temperature and relative humidity are both interrelated parameters that are affected during the transit step of the cold chain, primarily due to cold reefer characteristics such as reefer size, door protection, and frequency of door opening, duration of the door opening, initial and environmental temperature, and humidity of perishable food. Certain perishable foods are extremely sensitive to humidity. Therefore, the humidity in the reefer must be controlled. The developed system provides the necessary dehumidification to retain the relative humidity constant based on the size of the reefer, initial humidity and temperature of the food. When the cold reefer's door is opened, moisture from the outside air condenses inside and raises the humidity. We recommend a desiccant type dehumidifier that absorbs moisture with silica gel instead of a water outlet which is more suitable for cold storages. The size of the dehumidifier is determined by the cold reefer's current relative humidity and temperature, preferred relative humidity, and cold reefer volume. In our system, the dehumidification capacity is calculated for 10ft, 20ft, and 30ft containers .

To explore the relative humidity and temperature information during transit various machine learning algorithms are used as a data mining tool. These algorithms are used to predict temperature abuse during the traveling of cold reefer. Following algorithms are implemented for prediction of food quality in proposed system.

*A. Support Vector Regressor (SVR)*

Support Vector Regression is a supervised learning algorithm for predicting discrete values. The same principle underpins Support Vector Regression as it does SVMs. SVR's basic concept is to find the best fit line. In SVR, the hyperplane with the highest number of points is the best fit line.

*B. Decision tree (DT)*

DT is a supervised learning algorithm. It is used for both continuous and categorical input and output variables. A decision tree is a type of predictor that travels from a tree's root node to a leaf to predict the label associated with an instance x.

*C. Random Forest(RF)*

Random Forest is made up of multiple decision trees as base learning models. In this algorithm, multiple decision trees are combined to determine the final output instead of depending on individual decision trees [19].

Using these algorithms the quality index of perishable foods is calculated when the door of the reefer is opened. The observations are made for 5 hours with the door opening frequency of 4 for all 5 days. The corresponding temperature is measured when the door is opened and the quality retained by the food is calculated by using the following equation.

$$\%\ \text{Quality retained} = \left(1 - \sum_{1}^{m} \frac{t_{T_i}}{\theta_{T_i}}\right) 100 = 1 - \frac{t_{tot}}{\theta_{Teff}} \tag{2}$$

The total time $t_{tot}$ is assumed to be 5 hours. $\theta_{Teff}$ is the temperature measured. Depending upon the analytics, an early warning message is generated and sent to the driver of the truck for corrective action. The accuracies of the algorithms are checked to find their suitability.

## IV. RESULTS AND DISCUSSION

The proposed system is implemented for monitoring the temperature continuously. The live variation of temperature with time for milk sensed by the system is shown in Fig.2.

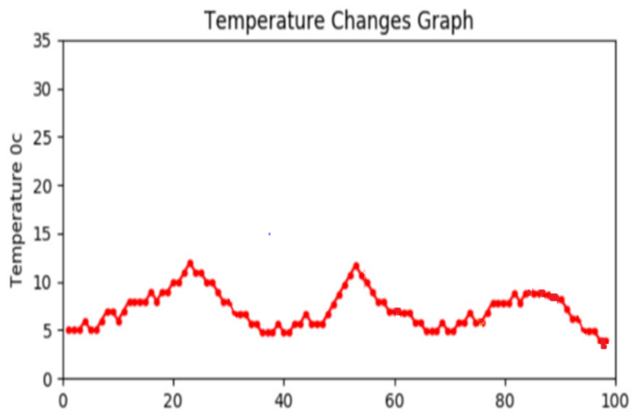


Fig.2. Variation of Temperature w.r.t Time

Also fig.3.a and b illustrate how temperature and humidity of grapes change over time due to various crucial parameters in the cold chain.

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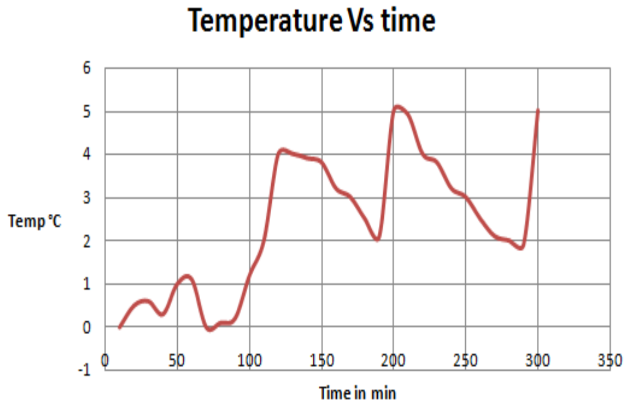
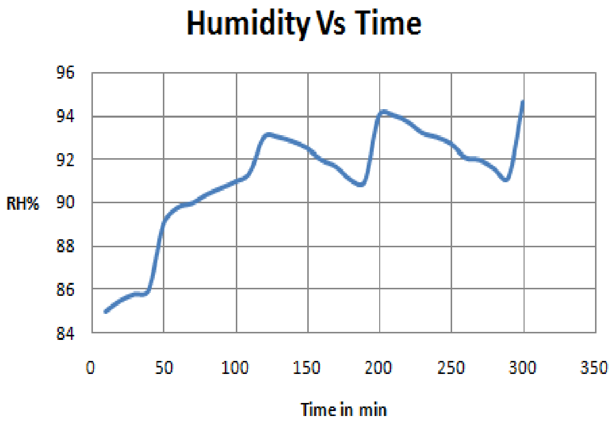



(a)

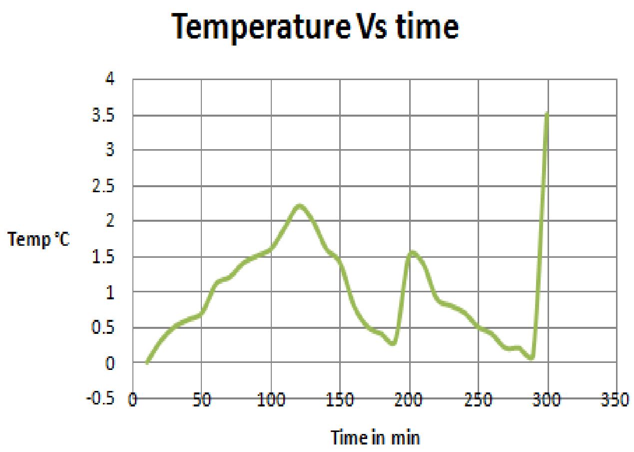
Temperatures of 0°C and relative humidity of 85 % are ideal for grapes. Temperature swings occur during the unloading and loading process, causing grape quality to deteriorate.



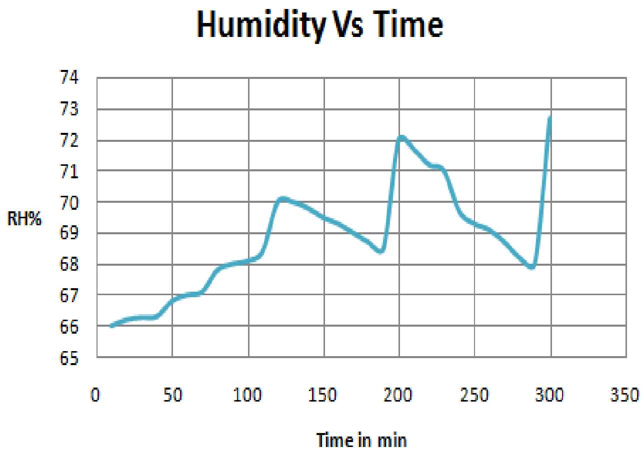

(b)

Fig.3. (a)Temperature Vs Time (b) Humidity Vs Time relation for Grapes

Figures 4-aand 4-b show how temperature and humidity of cheese change over time. Temperatures of 3.5°C and relative humidity of 66 % are ideal for grapes.




(a)




(b)

Fig.4. (a)Temperature Vs Time (b) Humidity Vs Time relation for Cheese

Fig.5 gives a graphical user interface of the system in which textbox numbered from 1 to 10 represents a reading of milk temperature after every 10 minutes. These entries are fed into machine learning algorithms that predict the time.GUI also shows the accuracy score of the implemented algorithm along with predictions about the temperature.

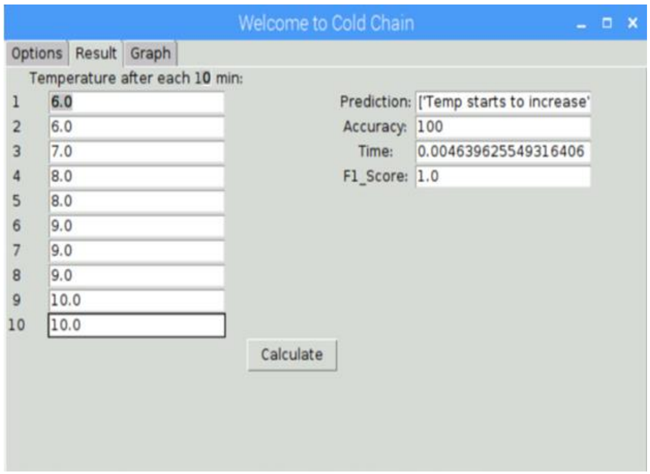



Fig.5. System GUI

With the help of the proposed system, the real-time temperature can be seen on the mobile application. For this, the ThingView application is used which is part of the ThingSpeak cloud. We can observe temperature variation simultaneously on cloud and ThingView. Fig.6. a. shows the real-time temperature-time relation on the mobile application.

One of the most important aspects of the system is an early indication of the temperature variations of perishable foods. As shown in fig. 6.b, when the temperature increases above the threshold, the message will be sent.

Fig.6. a) Real-time graph on mobile app b) Early warning SMS

The above results show fluctuation with time for the milk cold chain prototype. The readings are taken in real-time for 5 days. When temperature increases above the threshold value for specified time limits, alerts are sent to the manager.

According to the observations, many parameters such as ambient conditions, cold vehicle size, beginning and intended temperature of food, the time and frequency of door opening of the vehicle are responsible for temperature excursions at the transit step of the cold chain.

Machine learning algorithms are used to calculate the quality retained by perishables. The frequency of door opening is regarded as 4. Every time the door is opened, the MKT and quality retained by perishables are calculated.

Table II shows these parameters for milk.

TABLE II. QUALITY RETAINED BY MILK

| Door opening frequency | Temperature (°C) | Time (hours) | Quality retained (%) |
|---|---|---|---|
| 1 | 5.13 | 1.5 | 99.52% |
| 2 | 6.75 | 3 | 98.95% |
| 3 | 7.95 | 4.5 | 98.33% |
| 4 | 8.15 | 5 | 97.73% |

The MKT threshold value is set at 10°C for milk. Observations show that the highest measured MKT is 8.15°C and the lowest quality index is 97.73 % for a period of 5 hours with a frequency of 4 times door opening.

Table III and table IV show these parameters for grapes and cheese respectively.

TABLE III. QUALITY RETAINED BY GRAPES

| Door opening frequency | Temperature(°C) | Time (hours) | Quality retained (%) |
|---|---|---|---|
| Depot | O.166 | -- | 99.99% |
| 2 | 2 | 0.66 | 99.93% |
| 3 | 3.3 | 2.22 | 99.86% |
| 4 | 5 | 3.31 | 99.80% |

TABLE IV. QUALITY RETAINED BY CHEESE

| Door opening frequency | Temperature (°C) | Time (hours) | Quality retained (%) |
|---|---|---|---|
| Depot | O.166 | -- | 99.99% |
| 2 | 2 | 3.99 | 99.92% |
| 3 | 3.3 | 4.58 | 99.88% |
| 4 | 5 | 4.32 | 99.78% |

Grapes and cheese are humidity-sensitive perishables. So when the cold reefer door is opened relative humidity inside the reefer increases. The required dehumidification capacity depends on the size of the reefer. The graphs below depict the dehumidification requirements for each reefer. The dehumidification capacity is calculated and predicted with the help machine learning algorithms.

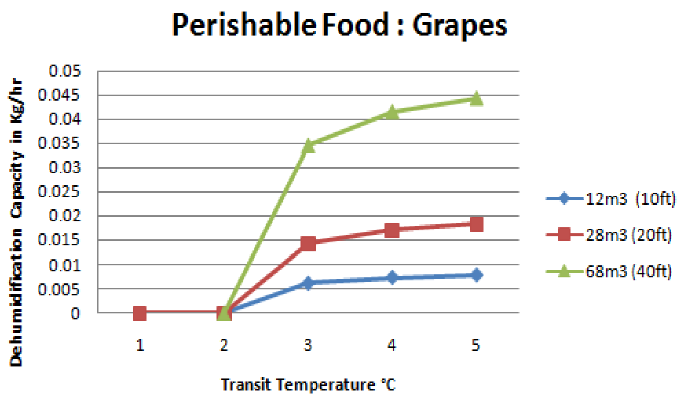


Fig.7. Dehumidification capacity required for Grapes

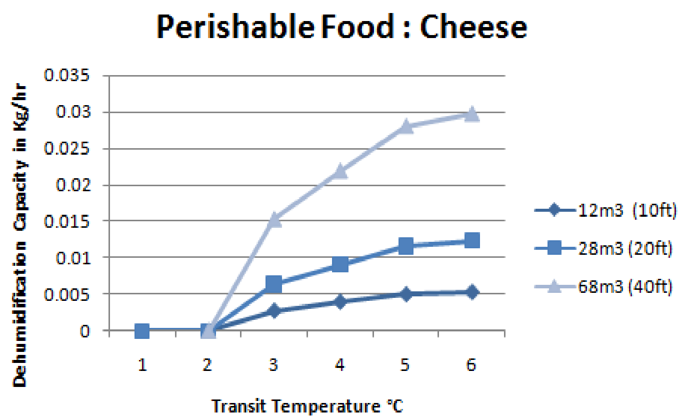


Fig.8. Dehumidification capacity required for Cheese

From the above observations it is observed that when the door of cold reefer opened the MKT and relative humidity inside the reefer increases. The developed system takes the action before the quality deterioration of food in terms of early warning message. Also predict the dehumidification required for various sizes of vehicle. The dehumidification capacity is measured in kilograms per hour (Kg/hr). The required capacity for larger container sizes is higher.

The machine learning algorithms are used to explore the information during the cold chain. Their suitability is checked by a comparative analysis given in table V.

TABLE V. TECHNIQUES AND ACCURACY SCORE

| **Techniques / Parameters** | **SVR** | **Random Forest** | **Decision Tree** |
|---|---|---|---|
| Accuracy score (%) | 91.46 | 98.67 | 92.59 |
| The time required to predict the result (Seconds) | 0.27 | 0.0055 | 0.0242 |

The random forest algorithm gives the best accuracy with a minimum time of prediction as compared with other algorithms. The SVR algorithm gives almost the same accuracy as the Decision tree algorithm but the time required to predict the output is more in comparison with the Decision tree.

## V. DISCUSSION

Mostly due to temperature change during transportation stage of cold chain quality of food is affected. In the proposed work we have provided a system to monitor the temperature and relative humidity continuously and send an early warning message to the concerned person for temperature abuse. Also with the help of machine learning algorithms, we have predicted the dehumidification capacity of different reefers for humidity-sensitive food.

## VI. CONCLUSION

The developed system monitors the real-time humidity and temperature of milk, grapes, and cheese in the cold chain. When temperature abuse exceeds the specified time limits, an early warning message is generated and sent to the concerned person. Also, the required dehumidification capacity is predicted for different reefers for maintaining the humidity of perishables. Data is analyzed utilizing machine learning techniques. The Random Forest method has the greatest accuracy of 98.67 % among the SVR and Decision Tree algorithms.

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## REFERENCES

[1]. Accorsi Riccardo, Bortolini Marco, Baruffaldi Giulia, Pilati Francesco, Ferrari Emilio 2017. Internet-of-things Paradigm in Food Supply Chains Control and Management, Procedia Manufacturing, Volume 11, pp.889-895.

[2]. Aiello, Giuseppe & La Scalia, Giada & Micale, Rosa 2012. Simulation analysis of cold chain performance based on time-temperature data. Production, Planning & Control. 23. pp.468-476.

[3]. Chudasama R., Dobariya S., Patel K. And Lopes H. 2017. DAPS: Dairy analysis and prediction system using technical indicators. 3rd International Conference on Sensing, Signal Processing and Security (ICSSS), Chennai, pp.176-180.

[4]. Duyvesteyn W.S., Shimoni E., Labuza T.P. 2001. Determination of the End of Shelf-life for Milk using Weibull Hazard method. LWT-Food Science and Technology, Volume 34, Issue 3, pp. 143-148.

[5]. Emenike C. C., An Eyk N. P., Hoffman A. J. 2016. Improving Cold Chain Logistics through RFID temperature sensing and Predictive Modelling. IEEE 19th International Conference on Intelligent Transportation Systems (ITSC), Rio de Janeiro, pp. 2331-2338.

[6]. Estrada-Flores, Silvia & Eddy, Andrew 2006.Thermal performance indicators for refrigerated road vehicles. International Journal of Refrigeration. pp. 889-898.

[7]. Estrada-Flores, Silvia. 2010. Achieving temperature control and energy efficiency in the cold chain.

[8]. Evans, J.A., "Frozen Food Science and Technology", (2009). 10.1002/9781444302325.

[9]. Gharehyakheh Amin, Caroline C. Krejci, Jaime Cantu, and K. J. Rogers 2020."A Multi-Objective Model for Sustainable Perishable Food Distribution Considering the Impact of Temperature on Vehicle Emissions and Product Shelf-Life" Sustainability 12, no.16:6668. https://doi.org/10.3390/su12166668.

[10]. Hongmin Sun, Guihua Jiang, Qingming Kong, Zhongqiu Chen And Xiaoming Li 2016. Design of Real-Time Monitoring System on Raw Milk Transport Process. International Journal of Multimedia and Ubiquitous Engineering Vol.11, No.4, pp. 335-342.

[11]. Jiayang L., Linan F & Dongyan D. 2018 A new route optimization approach of cold chain logistics distribution based on fresh agricultural products. Chinese Control And Decision Conference (CCDC), pp. 6652-6657.

[12]. Kale S.D., Patil S.C. (2021) Need for Predictive Data Analytics in Cold Chain Management. Advances in VLSI and Embedded Systems. Lecture Notes in Electrical Engineering, Vol 676, Springer, Singapore, pp.115-130.

[13]. Karim, Hassan, Akanda, et al. Monitoring food storage humidity and temperature data using IoT. MOJ Food Process Technol. 2018;6(4):400-404. DOI: 10.15406/mojfpt.2018.06.00194.

[14]. Liu, Dan & Cao, Xin & Zhou, Xinghai & Zhang, Mengya 2019. Cold Chain Logistics Information Monitoring Platform Based on the Internet of Vehicles. ICITB, pp.348-351.

[15]. Mukhopadhyay Debajyoti, Chakurkar Priti, Shikalgar Sajeeda, Kulkarni Shradha, Jain Shailly & Jagtap, Shubham. (2017). An Internet of Things (IoT) based Monitoring System for Efficient Milk Distribution. ICAC.

[16]. NABARD Report 2017. Cold Chain Technologies (Transforming Food Supply Chain). ASSOCHAM INDIA.

[17]. Novaes, Antônio G.N., Lima Jr, Orlando F., Carvalho, Carolina C. De, & Bez, Edson T.(2015).Thermal Performance of Refrigerated Vehicles in The Distribution of Perishable Food. Pesquisa Operacional, 35(2), pp.251-284.

[18]. Pant R.R., Prakash Gyan, Farooquie Jamal A. 2015. A Framework for Traceability and Transparency in the Dairy Supply Chain Networks, Procedia - Social and Behavioral Sciences, Volume 189, pp. 385-394.

[19]. Shwartz Shai Shalev & David Shai Ben, 2014. Understanding Machine Learning From Theory to Algorithms. Cambridge University Press.

[20]. Wang, Gaoxiang & Xu, Wensheng & Wang, Mei (2010).The Grid-Computing Based Instrumented Monitoring Platform for Cold Chain Logistics. LEITS, pp.1-3.

[21]. Zakeri A., Saberi M., Hussain O. K., & Chang E. 2018. Early Detection of Events as a Decision Support in the Milk Collection Planning.IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), pp. 516-520.

[22]. Zhang W., Cheng T., Chen H., Guo X., Gao G. 2018. Design of Whole Chain Temperature Monitoring System for Raw Milk. 14th IEEE International Conference on Signal Processing (ICSP), pp. 70-73.