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Projection of Residual Storage Viability for Fresh Produce During Transit

K Padmanaban[1], J Akshitha[2]

[1] Assistant Professor Dept. of MCA, Annamacharya Institute of Technology and Sciences (AITS), Karakambadi, Tirupati, Andhra Pradesh, India

[2] Post Graduate, Dept. of MCA, Annamacharya Institute of Technology and Sciences (AITS), Karakambadi, Tirupati, Andhra Pradesh, India

ABSTRACT

During transportation, forecasting the Remaining Usable Life (RUL) of Fresh Produce and Vegetables (FPVs) is crucial for scheduling and quality expense projection. The Internet of Things (IoT) permits gauged environmental factors to be processed in real-time. However, there is a requirement for a validated, real-time computational approach that translates environmental measurements to dynamic RUL estimations. Most existing generic RUL models for FPVs are qualitative, invasive, or static. This study establishes a generic RUL model for FPVs under dynamic and unplanned logistic circumstances. The model is founded on approximating the current rate of general deterioration based on the anticipated respiration rate of the product, and integrating the deterioration rate concerning time. Its implementation is non-destructive, non- invasive, and does not necessitate accelerated shelf-life experiments before deployment." **KEYWORDS:** Respiration Rate, deterioration rate, Fruits, Vegetables

I. INTRODUCTION

The wastage of Fresh Produce and Vegetables (FPVs) is a significant concern in food supply chain industries and it was reported that food retailers experience profit margin deductions due to cold chain risks such as transport delays and breakages, temperature abuse, and cross-contamination. Food losses are a burden to society as well, with one-third of all edible human food squandered annually.

Forecasting the shelf-life of sealed, dehydrated, highly processed, and chemically-preserved edibles is well-comprehended and established with straightforward and reliable mathematical models. On the contrary, predicting the shelf-life of unsealed, unprocessed, and biologically active comestibles (such as fresh fruits and vegetables, milk, fish, and meat) shipped alongside other types of fresh provisions under chaotic logistic circumstances remains a largely divisive and elusive predicament. This is not due to the lack of intricate mathematical models that cater to the main decay factors of such edibles. Rather, the numerous limitations, high specificity to a food species, and the need for destructive tests and/or time-consuming pre-tests render current theoretical models unsustainable in practice.

The conveyance of fresh produce and greens is a critical constituent of the supply chain, ensuring that perishable commodities reach consumers in a timely manner. However, during transit, factors such as temperature fluctuations, humidity, and handling conditions can impact the quality and usable lifespan of these products. Efficient and accurate estimation of the remaining shelf life of fresh crops during transportation is essential to minimize wastage, optimize inventory management, and deliver high-quality goods to consumers.

The current challenge in the conveyance of fresh fruits and vegetables lies in the need for a robust and accurate system to estimate the remaining shelf life of perishable items. Key issues include:

1. **Variable Transportation Circumstances:** Fluctuations in temperature, humidity, and handling practices during transportation can accelerate the deterioration of fresh crops, making it challenging to predict their remaining usable lifespan accurately.
2. **Data Variability:** Limited availability of real-time data on transportation conditions, such as temperature logs and environmental parameters, may hinder the development of precise shelf-life estimation models.
3. **Product Variability:** Different fruits and vegetables exhibit varying sensitivity to transportation conditions, requiring customized models for accurate shelf-life predictions.
4. **Integration with Supply Chain Systems:** Efficiently integrating shelf-life estimation models with existing supply chain management systems to enable timely decision-making and minimize wastage.

In this project, we present a new, real-time, non-destructive, highly generalizable computational method to predict the remaining shelf-life of FPVs under unplanned logistic conditions.

II. LITERATURE SURVEY

In [1], The objective of this paper is to undertake structural analysis of potential supply chain hazards and performance metrics in fresh food retail by applying interpretive structural modeling (ISM). Design/methodology/approach are Inputs were obtained from industry experts in identifying and comprehending interdependencies among food retail supply chain risks on different levels (sourcing and logistics outside the retail outlets; storage and customer interface at the stores). Interdependencies among risks and their impact on performance indicators are structured into a hierarchy in order to derive subsystems of interdependent elements to derive useful insights for theory and practice. Findings are Utilizing the ISM approach, the risks and performance metrics were clustered according to their driving power and dependence power. Alteration in/inadequate government regulations' are at the bottom level of the hierarchy implying highest driving power and require higher attention and focused mitigation strategies. Hazards like lack of traceability, transport delays/breakdowns and temperature abuse, cross-contamination in transport and storage have medium driver and dependence powers.

In [2], Cold supply chain (CSC) distribution frameworks are critical in preserving the integrity and freshness of transported temperature-sensitive commodities. CSC is also known to be energy- intensive with a significant emission footprint. As a result, CSC requires strict monitoring and control management system during storage and conveyance to improve safety and reduce profit losses. In this research, a systematic review of recent literature related to the distribution of food CSC products is presented, and possible areas to extend research in modeling and decision-making are identified. Design/methodology/approach The paper analyzes the content of 65 recent articles related to CSC and perishable foods. Several relevant keywords were used in the initial search, which generated a list of 214 articles. The articles were screened based on content relevance in terms of food vehicle routing modeling and quality. Selected articles were categorized and analyzed based on cost elements, modeling framework, and solution approach. Finally, recommendations for future research are suggested. Findings The review identified several research gaps in CSC logistics literature, where more focused research is warranted. First, the review suggests that dynamic vehicle modeling and routing while considering products quality and environmental impacts is still an open area for research. Second, there is no consensus among researchers in terms of quality degradation models used to assess the freshness of transported cold food. As a result, an investigation of critical parameters and quality modeling is warranted. Third, and due to the problem complexity, there is a need for developing heuristics and metaheuristics to solve such models. Finally, there is a need for extending the single product single compartment CSC to multi-compartment multi-temperature routing modeling.

In [3], In the supply chain of perishable food commodities, substantial losses are incurred between farm and fork. Given the limited land resources and an ever-growing population, the food supply chain is confronted with the challenge of augmenting its handling efficiency and minimizing post- harvest food wastage. Immense value can be appended by optimizing warehouse management systems, taking into account the estimated remaining usable lifespan of the product, and matching it to the requisites of the subsequent part of the handling chain. This contribution focuses on how model approaches estimating quality changes and remaining usable lifespan can be amalgamated in optimizing first-expired-first-out cold chain management strategies for perishable products. To this end, shelf-life-related performance indicators are utilized to introduce remaining usable lifespan and product quality in the cost function when optimizing the supply chain. A combinatorial exhaustive-search algorithm is shown to be feasible as the complexity of the optimization problem is sufficiently low for the size and properties of a typical commercial cold chain. The estimated usable lifespan distances for a particular batch can thus be taken as a guide to optimize logistics.

In [4], The function of packaging cannot be refuted in the life cycle of any food commodity. Intelligent packaging is an emerging technology in the food packaging sector. Although it still needs its full emergence in the marketplace, its significance has been proven for the maintenance of food quality and safety. The present review delineates several aspects of intelligent packaging. It first highlights different implements utilized in intelligent packaging and elucidates the role of these packaging devices for maintaining the quality of different food items in terms of controlling microbial growth and gas concentration, and for providing convenience and easiness to its users in the form of time-temperature indication. This review also discusses other intelligent packaging solutions in supply chain management of food products to control theft and counterfeiting conducts and broaden the image of the food companies in terms of branding and marketing. Overall, intelligent packaging can ensure food quality and safety in the food industry, however, there are still some concerns over this emerging technology including high cost and legal aspects, and thus future work should be performed to overcome these problems for further promoting its applications in the food industry. Moreover, work should also be carried out to combine several single intelligent packaging devices into a single one, so that most of the benefits from this emerging technology can be achieved.

In [5], Despite the recent interest towards food safety and control, it is generally arduous to ensure full products traceability through industrial food chains, due to the lack of efficient information and communication systems. Consequently, nowadays, the protection of food commodities often concludes at the gates of the producer without any investigation about the status of their quality at the consumer's location. The aim of this paper was the development of a supply chain monitoring system based on a smart logistic unit (SLU) to support the integrated management of the food supply chain from "farm to fork" in order to guarantee and control food safety and shelf life (SL) of products in agreement with logistic efficiency and system sustainability. For this purpose, we have conducted research involving the selection of a perishable commodity significantly affected by logistic decisions, the determination of the set parameters representative of its quality, and the development of a prototype of SLU, based on a sensor network for monitoring the identified parameters. Finally, an experimental SL model has been determined, based on the volatile organic compounds emitted from fruits and monitored by the SLU. We have validated the model by simulating real transport conditions and assessing the residual SL of the commodity at different time intervals. Practical Applications The practical application obtainable from our research is the development of a prototype of a smart logistic unit able to translate the acquired parameters into valuable information for supply chain management.

III. PROPOSED SYSTEM

There are five types of deterioration in relation to Fresh Produce and Vegetables (FPVs): Preharvest biological deterioration, senescence, microbiological deterioration, chemical degradation, and physical degeneration. Despite the temperature and headspace gas composition being just two of many sources of degradation of fresh crops, they are still considered major predictors of post-harvest degradation and distribution losses. As a result, temperature and gas measurements can be utilized to provide an optimistic prediction of the Remaining Usable Lifespan (RUL). All other sources of deterioration, such as vibration and moisture loss, can be disregarded if they are not significantly different from the logistic conditions under which the initial shelf-life was estimated. Hence, for all future discussions, we shall use the word 'deterioration' to refer to the amalgamation of all post-harvest, undesirable quality changes that are affected by temperature and/or atmospheric composition, namely: Senescence, chemical degradation, and microbiological deterioration.

The proposed system presents a new, real-time, non-destructive, highly generalizable computational method to predict the remaining shelf-life of FPVs under unplanned logistic conditions. The method uses real-time measurements of temperature and humidity and - most significantly - precludes the need for characterization pre-tests as it is initialized with only well- documented and easily accessible thermophysical properties of the product.

Moreover, the proposed model has been validated with three types of FPVs under various packaging conditions and frequencies of temperature disruptions. The model proposed in this project has been designed such that the effects of instantaneous temperature and CO2 gas concentration in the local atmosphere are captured without the need for directly measuring the latter. In addition, the model can be applied independently of whether the product is in standard air or a modified atmosphere, shipped alone or with other storage compatible products.

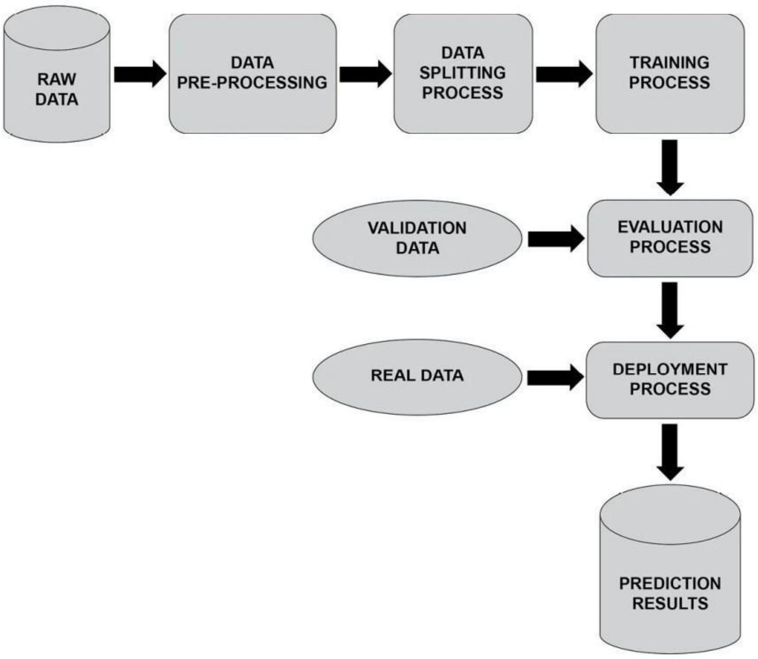

Fig 1. System Architecture

IV. RESULT AND DISCUSSION

Based on the model inputs reported in Supplementary File 3 (including the respiration rate vs. time and temperature datasets as well as other Fresh Produce and Vegetables (FPV) properties used to initialize the model), the predicted Remaining Usable Lifespans (RULs) and error quantities derived using the numerical method are reported, while the same is reported for the QnD method. We define the model error as the percent deviation of the predicted RUL from the observed RUL. Since the numerical method is presumed to yield the model's most accurate prediction of the RUL and the QnD method being proposed as a surrogate, faster method to potentially substitute the numerical method in real-time applications, the approximation error was defined as the percent deviation of the QnD prediction from the numerical method prediction.

For sealed-bunched greens, however, the numerical method yielded much more acceptable results than the QnD method, with the former not exceeding 1.5 days in prediction error, while QnD prediction for this case reached 2.9 days in error, possibly due to the length of the greens experiment, which was almost twice as long as those of berries or stone fruits. Thus, there was more room for approximation errors in QnD calculations to accumulate.

Moreover, the sealed and bunched greens problem involved several sources of error, namely, the assumption of a perfect seal and human error in estimating (1) the exact time the greens samples were declared to have spoiled (since green leaves spoil less noticeably by wilting as opposed to forming mold), (2) the volume of trapped headspace air Vhsair, and (3) the macroscopic porosity ϕ. It is noteworthy that the model results were exceptionally sensitive to the value of ϕ.

Therefore, we recommend using the Numerical method for estimating the midplane temperature of sealed, bunched leafy vegetables.

As for stone fruits, both QnD and the Numerical methods performed acceptably well, with a maximum of 1.2 days in prediction error and negligible difference between the predictions made using the two methods. Hence, we have no reservations about using either method for unsealed fruits, whether or not they are climacteric.

It is noted that the SLEM consistently overestimated the RUL for stone fruits. This is likely due to the stone fruit's decay rate being accelerated by exposure to exogenous ethylene, which is unaccounted for in the model. Even though the model and approximation errors are high in terms of percentages, they could still be tolerable, considering that they are no more than 1.2 days in error and the fact that a model which accounts for endogenous ethylene production and its interaction with temperature and time is still an improvement over models that do not account for the variation of either endogenous or exogenous ethylene interaction over temperature and time.

V. CONCLUSION

Despite simplifying assumptions, the SLEM was found to generate statistically sound predictions nonetheless, which supports the view that the respiration rate and its interaction with time, temperature, and the local CO2 concentration are the key predictors of deterioration, notwithstanding the effects of microbiological activity, relative humidity, and exogenous ethylene. Even though the original and surrogate model results are statistically sound, the surrogate model is not recommended for sealed fresh commodities or prolonged experiments if prediction errors exceeding 2 days are unacceptable by the end consumer. In summary, we consider this model to be a promising solution for quality monitoring and last-mile routing optimization problems. It is non-destructive, non-invasive, and cost-effective as it does not require any additional sensors besides a temperature and humidity sensor. For future work, some future upgrades may be added to improve versatility, e.g., accounting for the permeability of different types of plastic bags, tracking the levels of O2 to better predict the onset of anoxia, and the interaction effects between ethylene-generating and ethylene-sensitive products.

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