Real-time RFID-based item tracking using IoT & efficient inventory management using Machine Learning

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***Abstract*—Internet of Things (IoT) and Machine Learning (ML) based connected intelligence framework has become a technology enabler in various segments of supply chain like inventory management. In this paper, we have proposed an IoT-cloud architecture for passive RFID tag based real-time Stock Keeping Units (SKUs) tracking and ML algorithms for predictive stock analysis. The SKUs are fitted with RFID tags, those are scanned at entry and exit of the warehouse and this real-time data is sent to cloud server over internet. The acquired data is then processed using ML based software engine using techniques like classification, training and testing. We have considered, ABC Inventory Classification for the SKUs in warehouse and three ML algorithms as: Support Vector Machine (SVM), K-nearest neighbors (KNN) and Bayes for predictive analysis of SKUs in inventory. The result indicates SVM is outperforming with 84.8% accuracy. The accuracy of KNN is 83.6% and Bayes at 74%.**

Keywords— ABC Inventory Classification, Stock Keeping Units (SKUs), RFID, IoT, Support Vector Machine (SVM), K-nearest neighbors (KNN), Bayes

I. INTRODUCTION

In the recent pandemic scenario, most organizations have seen drastic effects on their Supply Chain Management systems. With disruptions in logistics to delayed manufacturing, companies all over the globe are facing challenges to keep up with these unprecedented times. The pandemic has created a major shift in the consumer preferences with spike of demand in various goods such as sanitizers, disinfectants to fall in demand for other non-essential goods. Rapid surge in demand has led to early stock outs and back orders whereas the unusual fall in the demand has increased the inventory holding costs. Kumar et al. [1] have given a detailed study of how pandemic has affected the operations management and how strategic stocking can help organization be more sustainable and resilient. The stock item classification schemes that are generally used by firms for stocking and reordering of item in warehouse is not effective in these unpredictable changes in demand. Firms generally use ABC (Always Better Control) classification scheme for classification and controlling of inventory items. A simple ABC classification technique is based on the cost of the item i.e. Class A items bear the highest expenses and Class C are items that are of low cost. This classification provides a generalized idea to control stocking of products that are of the highest value and improper stocking of such items would lead to increase in the overall costs. Nowadays firms are also employing complex ABC Classification based on various Multi-criteria decision making (MCDM) techniques such as Simple Additive Weighting (SAW) technique [2], [3] for a more holistic categorization.

In this paper, we are proposing a real-time Radio Frequency Identifier (RFID) based item tracking in warehouse using Internet of Things (IoT). The IoT framework is deployed for real-time data acquisition through internet data network infrastructure. Further this paper also focuses on developing predictive decision-making model to address the rapid changing demands for a more efficient multi-criteria ABC classification of SKUs in warehouse. The proposed model will make use of Machine Learning (ML) classifier algorithms to effectively predict and categorize items in inventory. We have used three Machine learning Classifier algorithms - Support Vector Machine (SVM), K-nearest neighbors (KNN) and Bayes Algorithm to classify stock goods and items based on multiple attributes. The trained ML model is then employed on for real time Stock Keeping Units (SKUs) classification for efficient inventory management, especially for unprecedented pandemic times where demand and supply is very dynamic.

The paper comprises of the following sections – Section II collates data from various related works, Section III describes the proposed system and architecture, Section IV describes the Machine Learning Model using three ML algorithms, Section V provides result and comparative analysis. Finally the paper has been concluded in Section VI.

II. RELATED WORK

Tejesh et al. [4] have proposed an IoT based warehouse inventory management system using open-source framework. They have used ESP8266-12e based NodeMCU for RFID reader em-18 interfacing and Raspberry Pi 3 as the cloud server. The inventory information is presented on a web based GUI. Passive RFID technology for item tracking using IoT is presented by Laxmi and Mishra [5]. They have proposed a Message Queue Telemetry Transport (MQTT) based protocols implementation over IEEE 802.11 network for transmission of RFID tag data over internet to the CloudMQTT based broker (Server) deployment. Alfian et al. [6] have proposed a RFID based traceability system for perishable food using IoT and machine learning. They have shown improvement in efficiency of the system to manage the inventory of perishable food which is a challenge for any stock-keeper.

Advances in data analytics and Artificial Intelligence have led to a data driven automation of processes and

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development of Intelligent Enterprise Systems to streamline the Supply Chain Management (SCM) of an organization. Inventory Management is one such area of SCM where various studies related to effective classification of Stock Keeping Units (SKUs) by using Machine learning Classifier Algorithms have been developed by researchers. The proposed works in [7] has discussed various AI-based techniques and have developed ML models to perform efficient multi attribute Inventory management. The research paper has concluded that SVM Classifiers perform better classification than traditional multi attribute discriminant analysis. Works in [8] examines the classification performance of SVMs for a multi-criteria inventory analysis. The paper has employed supervised machine learning classifiers - support vector machines with Gaussian kernel (SVM) and deep neural networks (DNN) for multi-criteria inventory classification (MCIC). The proposed model is designed to address intermittent demand patterns that require forecasting approaches and probabilistic assumptions. The proposed model in [9] describes a hybrid methodology that integrates ML algorithms - Artificial Neural Network (ANN), SVM and Bayes, with multi-criteria decision making (MCDM) techniques such as SAW, Analytical Hierarchy process (AHP) to effectively perform a multi-attribute inventory analysis. Various other research papers have designed and developed Machine learning models to help in improvising Operation managements. [10], [11] research works have employed ML models to forecast backorders. The Classifiers used in [10] to predict probable back order cases are Distributed Random Forest (DRF) and Gradient Boosting Machine (GBM).

III. Proposed System

A. System Architechture

Fig.1 shows the proposed system for efficient management of inventory from real-time data acquired from passive RFID tags attached with the items using IoT. A machine learning computation engine is provisioned in the proposed system to provide necessary data analytics for accurate predictability of stock piling of goods in the warehouse. For analytics purpose we are using a well-established ABC classifier for goods & items classification in the inventory. We have used three machine learning algorithms SVM, Bayle's and KNN to present a comparative analysis of classification and prediction of items in to A, B & C class based on their priority.

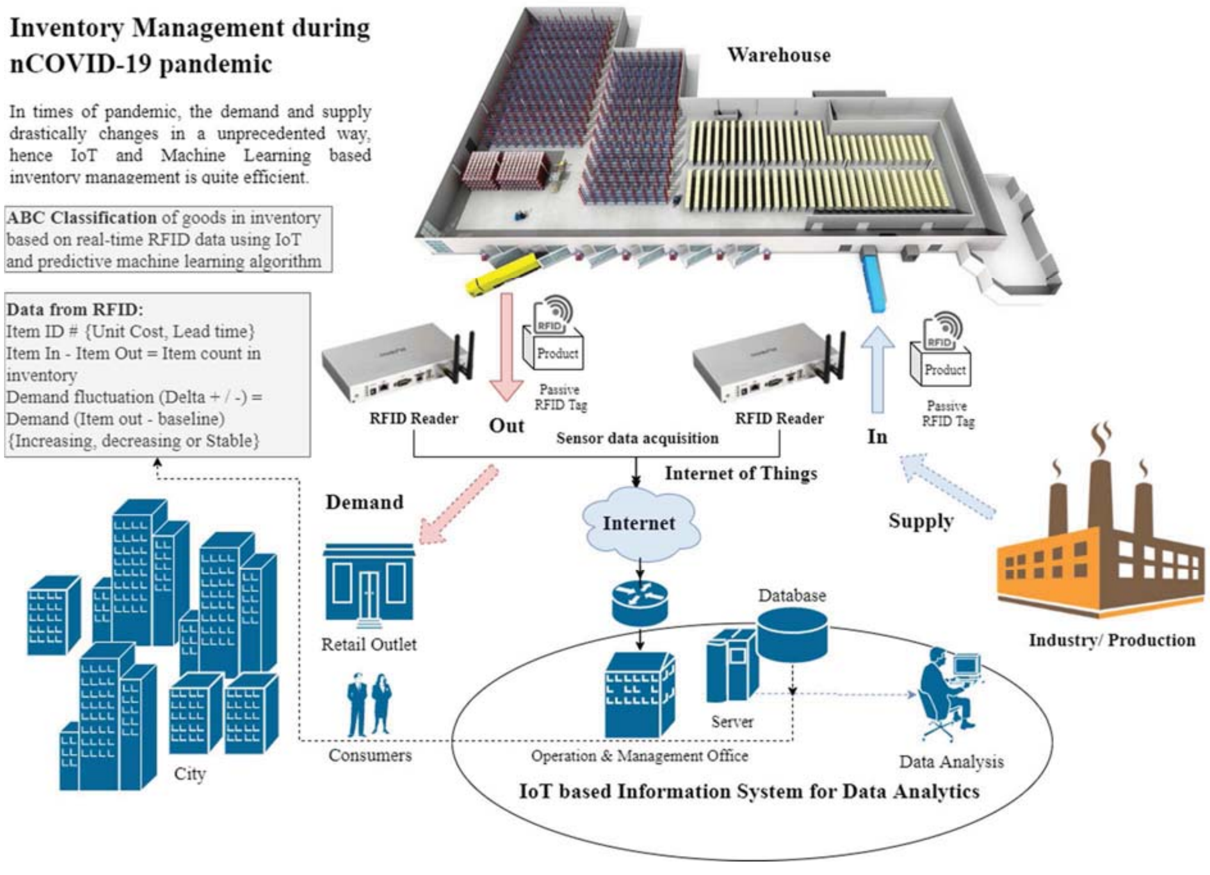

Fig. 1. Real-time RFID- based item tracking using IoT& efficient inventory management using Machine Learning

B. Real-time RFID- based item tracking using IoT

A passive RFID tag doesn't have any internal power source and hence takes power transmitted from a nearby RFID reader through electromagnetic energy. It is an ideal technology for supply chain and inventory management by providing precise item or shipment tracking. In our proposed system we make use of Internet as the backbone network to acquire this RFID data to the centralized cloud server using IoT. The data is then used in machine learning model to do the required classification and prediction. RFID tags are having its own low-power Microcontroller Unit (MCU) interfaced with programmable memory module. 865 - 960 MHz – Ultra High Frequency (UHF) RFID tags are having a typical range of 5-6 meters but can achieve a read range up to 30+ meters in ideal conditions. The RFID tag is pasted on the box of package of the item and the RFID can be read Electronics Product Code (EPC) typically 96 bits. EPC can be programmed for a unique ID of the item. However, some RFID has extended user memory up to 2 -4 Kilo-bytes for writing more product specific data on the memory. EPC is sufficient for an item tracking in a typical inventory management scenario. In the operator's database all the details regarding the item can be stored on the cloud server. Once tracked a unique EPC of any RFID tag the complete details of the item can be fetched from the database, hence need not has to be stored on the RFID chip memory. RFID reader has on board system clock which would provide a time-stamp for the read RFID tag hence a complete time-stamp based EPC tracking is viable using this technique.

In our proposed real-time RFID based item tracking system we have placed two dedicated RFID readers one at the entry point of warehouse and one at the exit. Both the RFID readers are connected to the internet (data network) to fetch all RFID real-time tracking to the company sever using a IoT-cloud architecture, where the RFID reader is working as a sensor module to fetch real-time sensor data to the centralized cloud server using internet infrastructure. Based on the tracking data from RFID reader at entry and exit point of warehouse detailed real-time inventory information of in and out flux of SKUs can be found and maintained in the database of cloud storage. For effective management of inventory many parameters can be derived through mathematical or logical computation from RFID scanning data like time-stamp and EPC at the entry and exit of warehouse. Table I gives the derived parameters computed using data received from RFID readers at both entry and exit point of warehouse.

TABLE I. RFID TRACKING DERIVED PARAMETERS

Derived Parameters	**Computation Process/ Inventory database management**
Item ID/ SKU	Mapping of EPC in inventory database
Item Cost	Inventory database from product name item cost can be known
Lead time	From item unique product code the supplier details and it's lead time can be found from database
Item count in inventory	No. of item passed through entry point RFID reader - No. of item passed through exit point RFID reader (for a specific item type)
Demand fluctuation	From historical data company maintain a tread of demand of a particular type of data (Base-line). Current value of 'demand' Demand = (Out flow of item – Baseline)
(a) Increasing	Demand> + Threshold => 3
(b) Decreasing	Demand< - Threshold => 2
(c) Stable	+ Threshold < Demand < - Threshold =>1

C. System Implementation

The above derived parameters are the attributes that affect inventory decision making such as number of items to be stocked, reorder point etc. The historical dataset used for developing the Machine Learning Models will be making use of the same attributes and are discussed in detail in section IV. The trained machine learning model is then used for ABC classification of items in inventory from the real time data obtained. Fig.2 shows the block diagram of the data acquisition system based on real-time RFID based item tracking using IoT architecture and database management system (DBMS) for analytics.

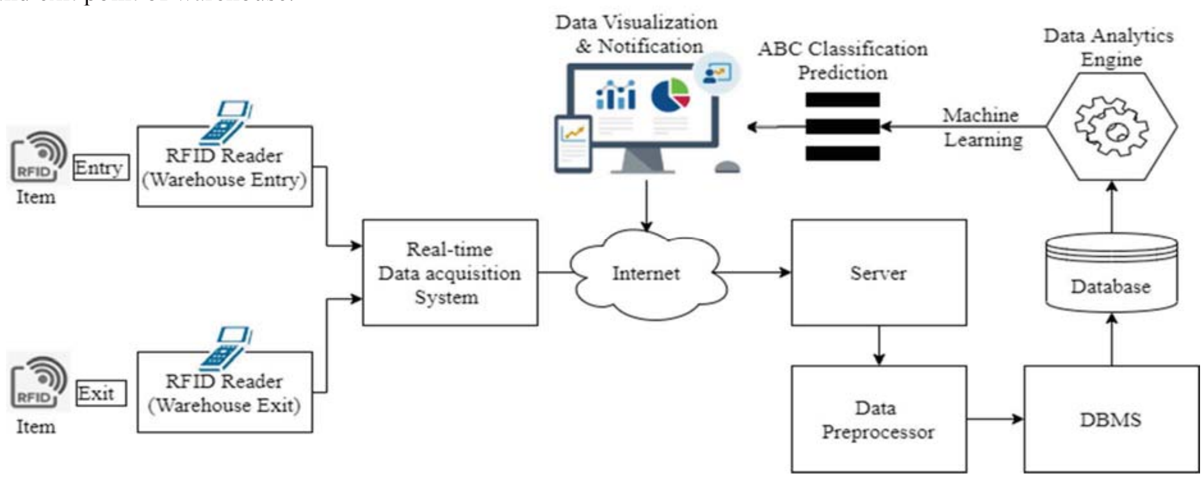

Fig. 2. Block diagram of real-time RFID based item tracking using IoT& DBMS for data analytics

D. Working & Algorithm

The system comprises of two RFID readers one at entry and one at exit of warehouse. The cumulative RFID data goes to the real-time data acquisition system. The system then sends the data to remote sever using Hyper-text Transfer Protocol (HTTP) or Massage Queue Telemetry Transport (MQTT) by establish a connection over an internet socket. The remote server after receiving the data carry out the data pre-processing then using a file handler-DBMS (PHP) it stores the data to a database (MySQL). The data stored in the server database is in the required format mentioned in Table. I. The data is then classified into ABC classification by Machine Learning Classifier Models.

Predictions from ML Model can be send via notifications are displayed through data analytics visualization tool (graphical representation of data) for a holistic inventory management. Fig. 3 shows the flowchart of the algorithm running on the data acquisition system based on real-time RFID tracking using IoT and machine learning for classification & prediction for efficient inventory management.

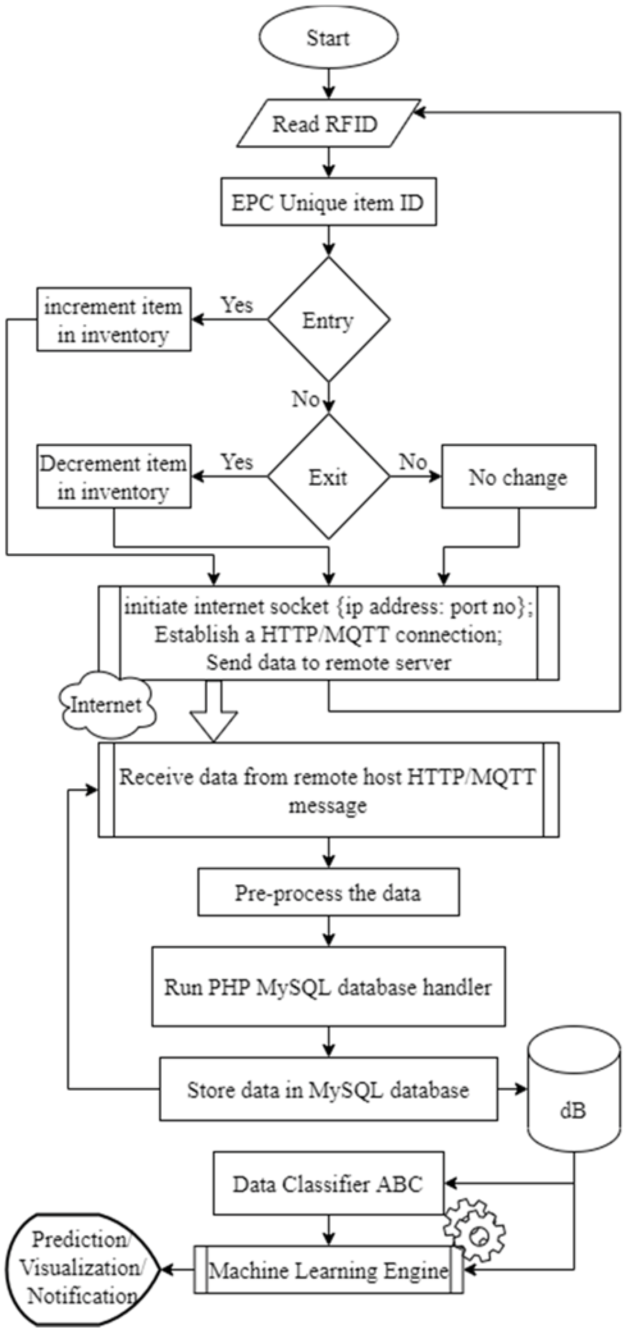

Fig. 3. Flow-chart of real-time RFID based inventory management system using IoT& Machine Learning

IV. Machine Learning Model

Real-time tracking of item through passive RFID tags using IoT is not sufficient for an inventory management rather an analytics engine is required for ABC classification of item. RFID is a sensing technique to track a particular SKU and from this data we can know the movement of items in & out of a warehouse. This method does not provide a holistic intelligence about status of the complete inventory. The objective of this research is to provide intelligence to inventory management through machine learning (ML) applied on the derived parameters from basic RFID in & out data. The various attributes of a specific SKU can be derived from the RFID readers and these are the average item count, the fluctuations in demand over a period of time, lead time of an item. The derived parameters from RFID tracking data are shown in detail in Table I of section III of the paper. The inventory dataset used in the paper for the ML model, has the same set of attributes i.e. Item Price, Lead time, Item count, demand fluctuation (1-Stable, 2-Decreasing, 3-Increasing). We have used 500 samples in our dataset for the ML Classifier Algorithm (split equally for train dataset and test dataset), out of that inventory dataset a subset of 5 samples are shown in Table II for visualization of dataset attributes. Each SKU in the historical data is classified by a SAW MCMD technique and grouped into 3 classes as per the ABC Classification. The ABC Classification is based on Pareto's 80/20 law which states that 20 percent of the items in inventory account for 80 percent of the total cost [12]. The data obtained after the initial ABC classification is then used for training and testing the ML Model.

The three ML algorithms used for classification are – Bayes, KNN, SVM are discussed in detail.

A. Naive Bayes Algorithm

Bayes Theorem gives the probability of an event occurring, given the probability of another event has already occurred i.e. conditional probability. Bayes' theorem is mathematically represented as,

$$P(X|Y) = \frac{P(X).P(Y|X)}{P(Y)}$$

Where,
P(X) = probability of event X
P(Y) = probability of event Y
P(X|Y) = probability of event X given event Y has occurred
P(Y|X) = probability of event Y given event X has occurred

We have used Gaussian Classifier which is a type of Naïve Bayes that follows Gaussian normal distribution. From sklearn library we have imported Gaussian NB Classifier to develop a predictive ML Model.

B. K-nearest neighbours(KNN)

KNN algorithm gives predictions based on how closely it matches its neighboring data in the training dataset. The data point that is located at the minimum distance from the test point is classified under the same class. To calculate the distance between data points KNN uses the simple Euclidean Distance formula that is mathematically represented as below,

$$d(p,q) = d(q,p) = \sqrt{\sum_{i=1}^{n}(q_i - p_i)^2}$$

Where,

n = number of dimensions

We have imported K-Neighbors Classifier from sklearn to develop the KNN ML model.

C. Support Vector Machine (SVM)

SVM is coordinate geometry based learning algorithm, which puts the data on to a 2D plane or 3D space to constitute hyper-planes. The idea is to get maximum separation between the supports vectors associates with the data points belonging to the hyper-plane. SVM is classifiers which creates distinct clusters of data-sets as maximum separation possible between the support vectors.

SVM equations are given as below:

$$y_i(w^T.x_i + b) \geq +1 \, for \, i = 1,2, \ldots m$$

$$y_i(w^T.x_i + b) \geq +1 \, for \, i = 1,2, \ldots m$$

Combined equation is as follows:

$$y_i(w^T.x_i + b) \geq \pm 1$$

Based on the above equation, min & max can be found using Langrage multipliers and kernel function can be deduced. The detail analysis of SVM can be found [13].

Derived parameters (Item Price, Lead time, Item count, demand fluctuation) and SAW MCMD based ABC classification of inventory would contribute in predictive data analysis. Hence, we have applied SVM, KNN and Bayes algorithms for inventory ABC classification. This would be useful for preemptive measures in inventory management based on real-time movement of items in the supply chain and would lead to better manageability, optimum utilization of man, machine and space by minimizing bottlenecks and wastage in the supply chain. The accuracy of all three classifier algorithm are obtained. Result and the comparative analysis are discussed in next section.

TABLE II. SAMPLE LIST OF INVENTORY DATASET #

SKUs	Item_Price	Lead_Time	Item_Count	Demand_Fluctuation	Class
100	244.8	29	130	3	A
101	188.02	15	163	3	A
102	274.75	6	108	2	B
103	423.95	3	68	1	C
104	289	8	81	2	B

Only few Sample are provided in the above table

V. RESULT AND ANALYSIS

Fig. 4 provides the comparative analysis of actual vs. predicted A, B and C Classification of SKUs using the ML algorithms. The actual ABC classification is derived from the SAW and MCMD techniques and is in line with the Pareto's principle i.e. approximately 20 percent of the SKUs are in class A and rest in class B and C. The predicted classes are also similar to the actual values. The classification report and accuracy of each ML Algorithm is summarized in Table III. It can be concluded that SVM Classifier provides the highest accuracy and can be used for inventory classification under real time demand fluctuations.

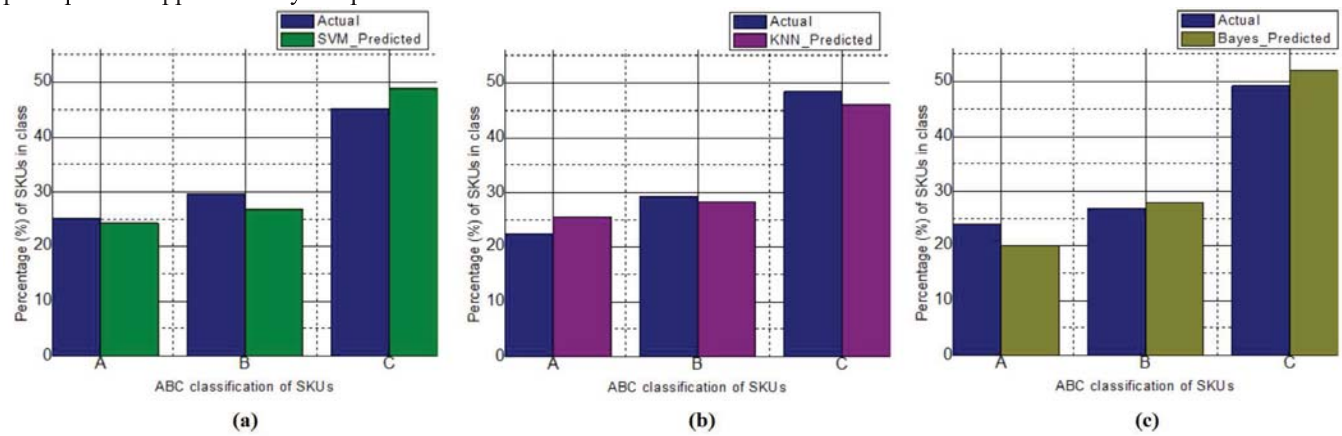

Fig. 4. Comparative analysis of actual and predicted A,B & C classification of SKUs using ML algorithms (a) SVM (b) KNN (c) Bayes

TABLE III. PERFORMANCE ANALYSIS OF VARIOUS MACHINE LEARNING ALGORITHMS IN ABC CLASSIFICATION

ML Algorithm	Class	Precision	Recall	f1-Score	Support	Accuracy (%)
SVM	A	0.87	0.82	0.85	67	84.8
	B	0.73	0.78	0.75	72	
	C	0.92	0.91	0.91	111	
	Summary	0.85	0.85	0.85	250	
KNN	A	0.93	0.81	0.87	70	83.6
	B	0.71	0.71	0.71	70	
	C	0.86	0.93	0.89	110	
	Summary	0.84	0.84	0.84	250	
Bayes	A	0.75	0.64	0.69	56	74.0
	B	0.53	0.54	0.53	65	
	C	0.84	0.88	0.86	129	
	Summary	0.74	0.74	0.74	250	

VI. CONCLUSION

An effective demand forecasting is crucial for efficient operations management in any organization. Improvisation of inventory management strategy by predicting real-time market demand is the key to optimize supply chain. The randomness in supply and demand during a pandemic situation can be alleviated by the use of technology like IoT and Machine Learning in inventory management. Inefficient inventory management would lead to bottleneck in operation management of an organization. Lack of optimum utilization of warehouse space would drastically affect the business during uncertainty such as rapid fall or surge in demand of a specific item or goods. Disruption in production units, logistic during pandemic times also create uncertainty in lead time for acquiring stock from the supplier hence increase a extra layer of complexity in inventory management. In this paper, we have proposed an IoT and machine learning based system for efficient inventory management using the real-time data received from passive RFID tags. Hence our system would be completely adaptive to the fluctuations in demand and supply. Furthermore, predictive SKU classification can be instrumental in a pre-emptive recognition of anomalies in supply and demand. This work can be extended using a various other machine perception techniques to see the viability of improvement of predictability of fluctuation in supply and demand for a optimizing the inventory management process of any supply chain.

REFERENCES

[1] Aalok Kumar, Sunil Luthra, Sachin Kumar Mangla, YiğitKazançoğlu, COVID-19 impact on sustainable production and operations management,Sustainable Operations and Computers, Volume 1, 2020, Pages 1-7,https://doi.org/10.1016/j.susoc.2020.06.001

[2] Manisha Ketkar, Omkarprasad S.Vaidya, Developing ordering policy based on multiple inventory classification schemes, Procedia - Social and Behavioral Sciences, Volume 133, 15 May 2014, Pages 180-188, https://doi.org/10.1016/j.sbspro.2014.04.183

[3] L. Abdullah, C. Adawiyah, Simple Additive Weighting Methods of Multi criteria Decision Making and Applications: A Decade Review, nternational Journal of Information Processing and Management 5 (2014): 39-49.

[4] B. Sai Subrahmanya Tejesh, S. Neeraja, Warehouse inventory management system using IoT and open source framework, Alexandria Engineering Journal, Volume 57, Issue 4, 2018, Pages 3817-3823, ISSN 1110-0168, https://doi.org/10.1016/j.aej.2018.02.003.

[5] A. R. Laxmi and A. Mishra, "RFID based Logistic Management System using Internet of Things (IoT)," 2018 Second International Conference on Electronics, Communication and Aerospace Technology (ICECA), Coimbatore, 2018, pp. 556-559, doi: 10.1109/ICECA.2018.8474721.M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.

[6] G. Alfian, M. Syafrudin, U. Farooq, M. R. Ma'arif, M. A. Syaekhoni, N. L. Fitriyani, J. Lee, J. Rhee, Improving efficiency of RFID-based traceability system for perishable food by utilizing IoT sensors and machine learning model, Food Control, Volume 110, 2020, 107016, ISSN 0956-7135, https://doi.org/10.1016/j.foodcont.2019.107016.

[7] Min-ChunYu, Multi-criteria ABC analysis using artificial-intelligence-based classification techniques, Expert Systems with ApplicationsVolume 38, Issue 4, April 2011, Pages 3416-3421, https://doi.org/10.1016/j.eswa.2010.08.127

[8] Lolli Francesco, Balugani Elia, Ishizaka Alessio, Gamberini Rita, Rimini Bianca, Regattieri Alberto, Machine learning for multi-criteria inventory classification applied to intermittent demand, Journal Production Planning & Control The Management of Operations, Volume 30, 2019 - Issue 1, https://doi.org/10.1080/09537287.2018.1525506.

[9] Hasan Kartal, Asil Oztekin, Angappa Gunasekaran, Ferhan Cebi, An integrated decision analytic framework of machine learning with multi-criteria decision making for multi-attribute inventory classification, Computers & Industrial Engineering, Volume 101, November 2016, Pages 599-613, https://doi.org/10.1016/j.cie.2016.06.004

[10] Samiul Islam & Saman Hassanzadeh Amin, Prediction of probable backorder scenarios in the supply chain using Distributed Random Forest and Gradient Boosting Machine learning techniques, J Big Data 7, 65 (2020). https://doi.org/10.1186/s40537-020-00345-2

[11] R. B. de Santis, E. P. de Aguiar and L. Goliatt, "Predicting material backorders in inventory management using machine learning," 2017 IEEE Latin American Conference on Computational Intelligence (LA-CCI), Arequipa, 2017, pp. 1-6, doi: 10.1109/LA-CCI.2017.8285684.

[12] Handanhal Ravinder and Ram B. Misra, ABC Analysis For Inventory Management:Bridging The Gap Between Research And Classroom,American Journal Of Business Education – Third Quarter 2014 Volume 7, Number 3

[13] Hasan Basri Kartal and Ferhan Cebi , Support Vector Machines for Multi-Attribute ABC Analysis, International Journal of Machine Learning and Computing, Vol. 3, No. 1, February 2013.