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Internet of Things enabled real time cold chain monitoring in a container port

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Abstract

Purpose: Seaports are regarded as significant actors in global logistics and supply chains since a large part of the cargoes carried over the globe are being processed there. When the cold chain broken down during transport and storage in the ports, the humidity, nutrition, temperature and time conditions to be required for the growth of the bacteria occur, and rapid reproduction occurs and the properties of the products are rapidly deteriorating. It is imperative that especially medicines, some chemical substances and foodstuffs need to be transported without breaking the cold chain in the logistics. The monitoring and control of the temperature and humidity level is important in the time period between the loading of these containers in special areas in ports, the loading of freight in open areas, or the loading of freight on roads and railway carriages. For this reason, precise monitoring and control of the system is vital in the port logistics management.

Method: In this study, an IoT-enabled system is designed for Container Ports by developing software, interface and equipment that will enable remote monitoring of temperature, humidity and other necessary key status parameters.

Findings: The developed IoT-based system provides audible and visual warning, e-mail and SMS communication, similar to a monitoring screen such as a heart graph monitor, when the instant values of the refrigerated container are transmitted to the database, when the defined upper and lower values are approached. All these data and major change information are archived in the database and retrospective situation analysis and data analysis can be performed.

Conclusion: Using technologies such as Wireless Sensor Network (WSN) and RFID, an IoT-enabled Cold Chain Logistics system has been proposed that provides real-time monitoring of products in containers at ports, providing DS services to logistics providers and customers. In this context, it was explained how the ambient parameter values were collected in real time using WSN and IEEE 802.15.4, how the collected data was sent to the server via the GSM gateway. In the port scenario, activation devices such as IEEE 802.15.4 and RFID were modeled using the OPNET simulator. The developed model was carried out in accordance with the principles of EPCglobal Gen 2. With the proposed approach, smart solutions provide a smarter flow of information. The results show that IoT- enabled cold chain systems have a great potential for managing, monitoring, receiving and determining abnormal events related to temperature-sensitive products in real time.

Keywords: Container, Ports, Port logistics management, Cold Chain Logistics, Internet of Things, IoT enabled cooling system, RFID, Remote monitoring and controlling of containers

Introduction

Ports are areas where ships dock on the shore and have the necessary equipment for the transfer of cargo from ship to land, from land to ship. A port can be defined as an area where ships meet their other needs, such as loading, unloading, repairing, and where the necessary customs, warehouses, port organizations, and service facilities are located, as well as the possibility of full protection. They are the intersection of the sea and land and serve as logistics and distribution platforms. Ports are considered not only as the infrastructure of transport, but also as the basis of industrial activities.

Container ports are recognized as important actors in global logistics and supply chains with the fact that a large part of what is rising in the world is processed here. When the Cold Chain (CC) breaks down during transportation and storage in ports, moisture, nutrition, shelter and time-outs necessary for the production of furnaces occur and rapid production becomes a challenge and the properties of the products deteriorate rapidly. In logistics, especially the transportation of medicines, some chemicals and foodstuffs without breaking the CC is strong. It is important to monitor and control the humidity level and rise in the ports of these containers in special areas, rise in high open areas or rise in high road and railway cars during the time period. Therefore, a form of monitoring and control of the system is vital in port logistics management. In this study, an IoT- enabled system is being developed for software, decoupling and equipment development that will allow monitoring of temperature, humidity and other necessary key status parameters for ports 24/7 via remote control. The developed IoT-enabled system provides voice and visual warning, mail and SMS communication, similar to a monitoring screen such as a heart graph monitor, in the event that instantaneous values related to the refrigerated container are transmitted to the database, in close proximity to the introduced upper and lower values. The critical level is exceeded and the analysis data flow is stopped. All these data and big change information are archived in the database and return status analysis and data analysis can be performed.

The concept of smart ports can be defined as ports where port operations such as loading, evacuation, anchorage, etc., storage, maintenance-repair processes are provided by using wireless network or private network connections, and sharing and transferring necessary information for operation and operations. In other words, smart ports are fully automatic ports where all devices are connected via an Internet of Things based system. Today, the Ports of Rotterdam, Antwerp, Hamburg and Valencia are examples of ports that develop smart port applications (Li et al. 2018). It takes a lot of time and effort to get to a smart port. In order to achieve such a digital transformation, it is necessary to replace the traditional technologies that still exist at the ports with intelligent technologies and automate the processes within the scope of digitalization (Kamolov and Park 2018). Dong Xisong et al. (2013), they are developing a system of services for transportation in ports. Thus, services such as information collection, processing, publication, value determination and usage analysis are suggested to all logistics users.

For now, the tools used to manage goods flows in general are mostly based on information systems such as, Advanced Planning Systems, Enterprise Resource Planning, and Container Management Systems. Together with Industry 4.0, the medium output of the IoT, the related problem of information and event capture, processing, storage and payment has moved to a different dimension. In addition, for better cooperation in the supply chain management (SCM), the possibility of automatically notifying the relevant actors of each incident related to logistics flows is provided. In this article, a digitized port model using very relevant technologies for accommodation, promotion, communication, monitoring and data sharing is proposed.

Web technologies have a significant way in the transfer of information between the customer and the logistics provider. However, there are still problems obtaining real-time information between the logistics flow of goods and the flow of information. The Internet of Things (IoT) provides important support for monitoring the environment and decision making in the CC industry. This study provides decision support (DS) for monitoring the real time data of the CC and estimating the shelf life of products. The real-time data of the environment parameters are collected by the WSN and sent to a remote server by a gateway. The shelf life of these products can be estimated by the DS being designed. In the pilot application, a model study is being carried out with the Radio Frequency Identification (RFID) for perishable products contained in the CC.

In the rest of the article, a literature review is carried out in "Literature review" section. In "Port system analysis methods" section, the subtitles of Port System Analysis Methods, Basic Logistics Functions at Ports, and Port Operations and Operation Areas were presented under the "Port Systems and Analysis". In "Cold chain logistics" section, Cold Chain Management, IoT Enabled Cold Chain, IoT Enabling Technologies, Wireless Sensor Networks and Radio Frequency Identification sub-titles were presented in the main topic "Cold Chain Logistics". A Case Study of the study was explained in "Case study" section. Simulation Model of IoT-enabled CCL system, Simulation Scenario, Simulation Results and Decision Support System for Estimating the Shelf Life of Perishable Foods were discussed under the main title of "Modeling and Simulation" in "Modeling and simulation of the proposed system" section. Finally, the results of the study, the limitation of this article and recommendations for future research are discussed in "Conclusions" section.

Literature review

Literature review was conducted as a current literature such as Web of Science and Scopus. Today, digitization is at the beginning of the main trends of maritime transport and port development (Yau et al. 2020; Cil et al. 2022). Different areas of work of the ports are being carried out within the scope of digital transformation (Zolich et al. 2019; Cil et al. 2021a). Agatić and Kolanović work on improving the quality of quality of services and factors of quality on a daily basis to the analysis of digital technologies applied at ports (Agatić and Kolanović 2020). Although digitalization occurs in different ways in the literature, it is used in the form described by Gartner in this article (Gartner, Inc.2022). Within this framework, digitalization forces us to develop a new business model by changing the business model (Cil et al. 2021b). The components of Industry 4.0 are autonomous vehicles, robotics, artificial intelligence (AI), big data, IoT, digital security, and include important topics such as 3D printing (Cil et al. 2021c).Each of these new technologies will create significant changes in the activities of enterprises in the near future. There are few studies in this field so far, although there are some (Fruth and Teuteberg 2017). Sanchez-Gonzalez et al. verify the latest technology, as it is currently available for eight digital domains. In some studies (Sanchez-Gonzalez et al. 2019), important developments in the field of state-of-the-art autonomous naval vehicles and systems were reviewed. Kang et al. (2018) conducted analyses with big data techniques in maritime transport management. Fernandez et al. (2016) developed an application related to digital port management. Heilig et al. (2017) made an assessment about digital transformation technologies related to the digitalization of ports. Goudarzi et al. (2016) designed an IoT-enabled system related to better managing port warehouses. Shi et al. (2011) developed an application based on RFID at a container terminal. The Port of Rotterdam, the Port of Singapore and the Port of Hamburg are premier ports using various digital technologies for containers. The base technologies that are considered attractive from the major port sides are as follows: AI, cloud computing, block chain and the IoT (Anwar et al. 2019). The UK published its Maritime 2050 on navigating the future strategy and highlighted the importance of digitalization (Lesniewska et al. 2021).

Port systems and analysis

Container Ports cover the facilities where ships, sea transport vehicles can dock and connect to the docks or piers, or dock in water areas. A port can also be defined as a terminal or site that includes places where cargo is loaded onto ships or unloaded from ships, where ships are waiting for their turn, or where they are asked to wait or forced to wait. It is a restricted land and sea area with facilities for ship-to-shore, shore-to-ship and ship-to-ship cargo or people transportation, connecting, lifting or mooring ships, storing goods on land and at sea until delivery. It also provides integration between transportation modes having facilities for other forms of transportation (Deloitte Port Services - Smart Ports 2017).

Container ports also basically have two types of flow. These are the physical flow and the information flow. The purpose of the information flow is the realization of the entire bureaucratic flow of information about the ship and cargo. A physical flow is a flow that involves the handling of cargo in a port or terminal. These two basic flows mentioned are realized with three different subsystems at the ports. These are the transfer of information and cargo from ship to land, the transfer of information and cargo from land to ship, and finally the transfer of information and cargo from ship to ship.

Sea transportation, due to its reliability, carrying capacity and cost advantages, serves more than 80% of the imported and exported cargoes of world trade as the most preferred form of transportation. There is a lot of competition between port enterprises, the number of which reaches 250 worldwide (Sirimanne et al. 2019). The effective operation of the global supply chain and Turkish ports located at a critical sea transportation point is of critical importance for the port region and the Turkish economy. The most important criteria for taking part in maritime transport, the share of which is very high in the world economy, are the service, location and container handling capacities of ports. In this context, factors such as effective use of available capacity, use of port-appropriate equipment, planning of container placement area, deployment in accordance with geographical location come to the fore in the management of ports.

Ports should be integrated with commercial, supply and logistics channels. In this sense, ports are the points where many members of the supply channel meet; this interaction is emphasized in Fig. 1. The port can be involved in all kinds of distribution activities that include the flow of finished products coming out of the production line to the consumer. This distribution can be directed to the wholesaler, retailer or end consumer, and at each stage, the port can be located within this structure. In addition to transportation in physical distribution, storage is also an important activity. Nowadays, ports have also become capable of providing storage services.

Port system analysis methods

Systems can be studied by two basic methods, which are: (1) Examination on the real system and (2) Methods of studying the system by modeling. Solving system problems by trial and error is not possible for every system. However, if there is no significant cost loss in stopping the operation of the system, a direct examination of the actual systems can be performed. But it is important to note that the study of physically real systems should not significantly affect the costs of operating the system. On the other hand, the modeling of the system for performance monitoring purposes is divided into two main parts as physical and mathematical models in itself. Simulators, dam models, wind tunnels are examples of physical models. Mathematical models, on the other hand, are models that use linear programming, have objective and constraint functions, and they are divided into analytical models and simulation models in themselves.

Analytical solution uses solution methods such as linear programming, optimization model within the scope of operations research. Simulation, on the other hand, includes performance measurement models that measure the performance of the system. We cannot say that the results obtained from the simulation model are optimal, because by changing the parameters related to the system, the system performance is measured, and all system-related possibilities can be examined. In other words, simulation is not a tool that directly optimizes the system, but a tool that tries to optimize and find the system.

Port managers strive to make the lower and upper structures of the port optimal for ship operations, loading and unloading, temporary storage and in-port operations. For all these reasons, it has become a necessity for port or terminal managers to measure their performance to determine performance targets and achieve these targets.

The criteria for measuring the operational performance at ports are as shown in Fig. 2. These criteria are the main performance indicators adopted for ship-dock operations in all types of ports.

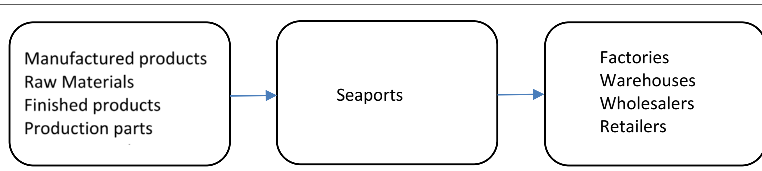
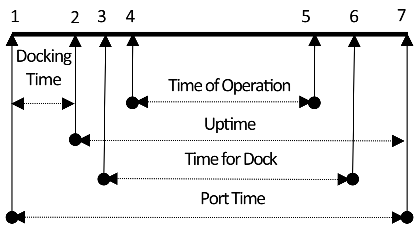


Fig. 1 Location of the port within the physical distribution (Clott and Hartman 2016)



Instructions	
1	Arrival of the Ship at the Port Mooring Site
2	Taking the pilot on board
3	Berthing of the ship at the dock
4	Start of loading/unloading operation
5	End of loading/unloading operation
6	Departure of the ship from the dock
7	Departure of the ship from the port

Fig. 2 Basic ship—dock performance indicators in ports

Based on the descriptions mentioned in Fig. 2, the following basic operational performance indicators can be identified:

- Time spent by the ship in the port = The time between the arrival and decommissioning of the ship in the port (7–1)
- Total time that the ship has been decommissioned = The time between the pilot's arrival on the ship and the ship's departure from the port to dock the ship (7–2)
- Time spent by the ship at the dock = The time between the ship's berth and decommissioning (6- 3)
- Loading time = The time between the start and end of loading/unloading operations (5–4)

Basic logistics functions at ports

There are basically three logistics functions in container terminals; these are the transportation of the container, its storage, and the handling of the container along with the cargo inside the container. The mentioned basic logistics functions are presented below:

Transportation function: three types of transportation modes carry out Arrival/departure of containers to the terminal area: sea, iron and road. Freight coming/going from the Sea railway is transferred by main and feeder lines. In general, seaway services are carried out periodically, and the volume of cargo they carry is much larger than in other modes. That is why the planning of sea transportation is a necessity. In the same way, rail transportation has less capacity than by sea, but more capacity than by road. It is also necessary to plan the rail transportation, which is carried out periodically. Road transport is a mode of transport that serves an individual cargo. Road transport has an irregular service structure, and there is no need for additional planning during loading/unloading hours. In particular, sea and rail transportation must be carried out within a certain period, and this period must be as short as possible. In addition to all, there is transportation activity within the port in accordance with the need to transport cargo within the port area.

Storage function: Time limits and irregularities in the modes of transport used in container terminals have led to the need to store cargo in container terminals. This situation coincides with inventory management in the logistics sense. It is very rare in practice that the container is loaded onto the ship by entering the port area directly or that the container evacuated from the ship is directed directly to the exit door. Ensuring the compatibility of all modes with each other and the departure of the container from the terminal site as soon as possible is the main goal of each container terminal operator. However, if there is not enough backfield, the cargo remaining in the port is reflected as successor income to the port. On the other hand, if the port provides logistics services, the cargo should not stay at the port site for longer periods. In general, in a technical term, it is necessary that the container's occupation rate (dwell time) at the site remains at the lowest possible level. Terminal sites are stacked on the site according to the characteristics of the container, taking into account the separation of export/import/empty/transit cargo. The fact that the port serves mostly import/export or transit cargo directly affects the terminal design.

Cargo handling function: Basically, the handling service provided at ports involves the transfer of cargo from ship to port, from port to ship, from port to land or from land to port. In addition, the handling of cargo in a container is a service performed at container freight stations (CFS) located at the terminal site. Accordingly, the loads are stacked in the container with the help of forklifts at the CFS site, or the loads in the evacuated containers are again unloaded at the CFS. The CFS service has started to be abandoned today, especially in terminals serving a significant amount of cargo. Terminals do not want to allocate their limited areas to CFS operations with relatively little revenue. Especially in the world's leading container ports such as Hamburg and Rotterdam, the CFS function is performed in logistics centers outside the port area. In addition, the cargo handling function plays an active role in the loading /unloading of cargo on the ship and its storage at the landfill.

Port operations and operation areas

Container ports consist of three main parts: ship loading and unloading areas, decommissioning areas and rear-internal stock areas. Coastal cranes are used for loading and unloading containers on board, and effective coastal crane scheduling is required for activities in this area. Various transfer vehicles are used to transport containers from the ship loading and unloading area to the stock area, and vehicle assignment and routing problems need to be solved effectively for activities in this area. Field cranes are used for handling such as transportation, storage and control of material activities in the inventory area and effective field crane scheduling is required to minimize time losses in the inventory area. Figure 3 shows the loading and unloading operations of ships at container terminals. Berth cranes are available at the ship loading and unloading sites and perform the operations of loading and unloading containers on board. The dock crane takes the container from the top of the ship and places it in the transport vehicles to take it to the stock areas, or it loads the container that comes from the stock area by the transport vehicle to the ship for transportation by ship. Multiple cranes at one berth can simultaneously carry out loading and unloading operations for a ship simultaneously. Operations in the field of stocking are more flexible than in the dock crane. Although field cranes, two-legged carriers and loaders are used in the stocking area, field cranes are widely used.

Stacking in ports is the most commonly used stocking method, and containers can be stacked up to 7 times in the stock area with the help of field cranes. The port stock area consists of classified hoarding blocks including export, import and empty containers.

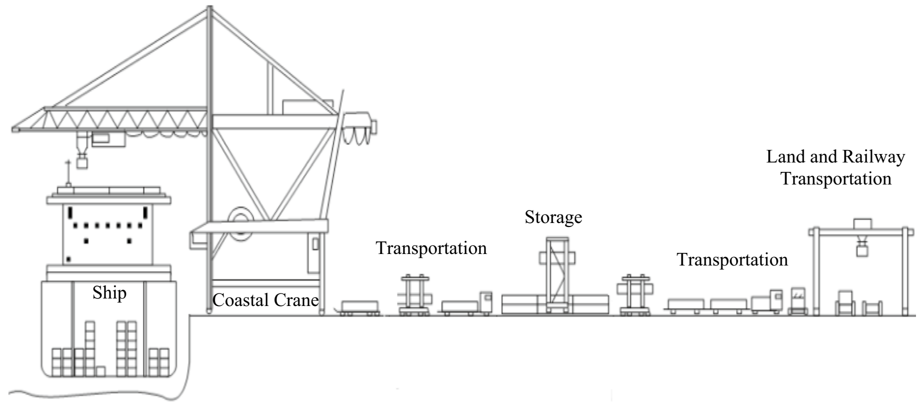


Fig. 3 Container port operations and operation areas (Vis and Koster 2003)

The area between the ship loading and decommissioning site and the stock area is the transport area and includes transport operations between the two specified areas. The vehicles used at the transport site are divided into two groups. The first of these are vehicles that are called passive and are not able to move containers in a vertical direction. There are single-trailer and multi-trailer vehicles in this group. The transportation vehicles that can move containers in both vertical and horizontal directions are large wheeled trucks, forklifts and stacking vehicles. Large wheeled trucks are the most important among them. Because these vehicles are capable of not only transporting containers, but also doing stacking work in the field. Vehicle traffic at the transport site should be well managed, as the effective use of the transport site affects the ship's stay at the dock.

How the Port Works can be sorted into steps as follows:

1. When the ship arrives at the port, the coastal cranes unload the containers.
2. These operations include the transportation of the container between the dock and the decommissioning site and the handling of the container within the scope of storage activities. Double-sided stacking and transportation vehicles (straddle carrier) stack loads by moving them to the transport area or the rear storage area
3. They are transported by container to the nearest gate of the port for shipment to their destination.
4. They are loaded and transported to external transportation vehicles and railway transportation systems throughout the country to be sent to non-local customers.
5. Containers are transported by trucks to be sent to regional distribution warehouses, Grocery stores/stores or factories. A summary of port operations are shown in Fig. 4.

Many authors have considered the processes in container terminals from different angles. The container terminal system consists of three main subsystems: the door, the container storage area and the dock. The main operations of container terminals are the loading, unloading, delivery and distribution operations that ensure the flow of containers in these three main subsystems mentioned. In addition, it is possible to divide container-handling operations into sea and land operations within the port.

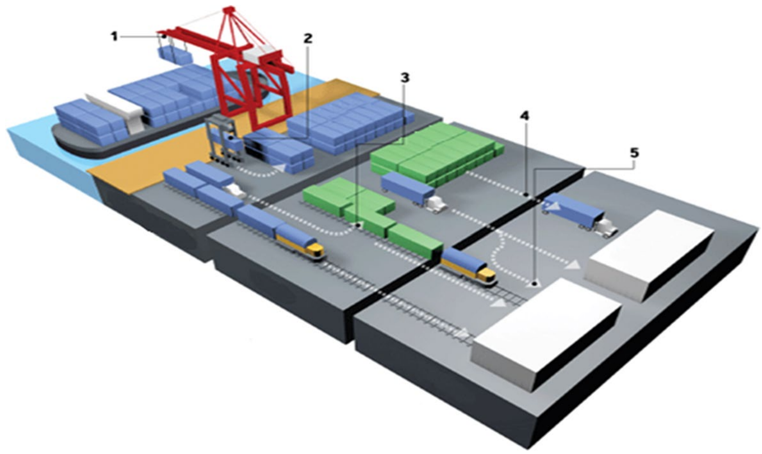


Fig. 4 Basic port operations (Lun et al. 2010; https://tr.pinterest.com/pin/366691594655389494/)

Fig. 5 Container models and equipment

Seaward operations: It includes container handling between the ship at the dock and the apron (the ship's decommissioning part of the port at sea). In addition, the lowering of the ship's hatch covers the apron and the handling to reach the container at the destination are within the scope of seaward operations. In this type of handling, a dock crane is usually used, but in practice, especially in small terminals, the ship's own cranes and mobile cranes can be used in dock operations. *Land-based operations:* It is basically a continuation of seaside operations. These operations include the transportation of the container between the dock and the decommissioning site and the handling of the container within the scope of storage activities.

These operations include the receipt of the container by the carrier or the delivery of the cargo to the receiving party. The container models used in the ports are shown in Fig. 5.

Cold chain logistics

Cold chain management

CCL affects every step of the way from the production of a temperature-sensitive product to its storage at the manufacturing facility, transport to the warehouse, and storage at the customer's facility. Different products have different temperature requirements. Monitoring the temperature in every environment requires special attention. Cargosense.com estimates that 20% of drugs are damaged due to CCL failure. BCG states that 1.6 billion tons of food is damaged or wasted every year, and this statistic is assumed to increase by 1.9% each year from 2018 to 2030 (BCG 2022).

IoT enabled cold chain

Web technologies have been successful in enabling communication between the customer and the logistics provider. However, there is always a gap between the product flow and the information flow, and this is a problematic in obtaining real time data about sensitive foods in logistics. This situation forces decision makers to use technologies that are more advanced in logistics management. IoT is recognized as a promising solution in the CCL industry that extends to imaging, management and decision-making. The system designed here is an IoT-based CCL that provides DS to all actors in the logistics chain, especially by estimating the shelf life of products sensitive to real time or temperature. The parameters of the real-time data environment can be remotely monitored through IEEE 802.15.4 based WSNs, and the shelf life can be estimated with the DSS. In this context, the system is modeled with RFID technology in the positioning of perishable products in the CCL.

The main purpose of IoT is to enable objects to communicate with each other, without any specific time and space constraints (Porkodi and Bhuvaneswari 2014). IoT allows the collection of real-time data on the determination of their location, humidity, temperature, vibration and noise about all living and inanimate beings. Therefore, IoT uses are altering the way of working and living by introducing a new approach by saving time and resources. By tracking IoT assets, it allows the necessary measures to be taken without human intervention, so that they can make a significant contribution to the provision of complex analysis and DS, resource allocation and optimization (Yan and Lee 2009). With these devices, it is possible to process these data by obtaining contextual information about the environment in which the objects are located. So far, companies in energy, manufacturing, automation, healthcare, logistics and other fields to improve their operation of different IoT devices have successfully used many different technologies, such as Bluetooth, Wi-Fi, RFID, SigFox, LoRa, NFC and the other sensor networks. Very few institutions have been used in the field of refrigeration, refrigerated packaging of perishable and temperature-sensitive products, transportation and storage of goods, in the CC area, which makes up a small part of the supply chain. Refrigerated train cars, refrigerated cargo ships, trucks, and air cargo (Rodrigue and Notteboom 2014) transport temperature-sensitive products. As it turns out, the contribution of the CC system to the global trade in perishable products and medical supplies is enormous. Especially because of the small CC system in developing countries, billions of tons of fresh food products are wasted every year and billions of dollars in losses are experienced. In the absence of IoT-based technology, a significant part of all food is thrown away without ever reaching the consumer. To solve this problem, the IoT-based CC system makes a very important contribution to the management, monitoring, and implementation of real-time data, especially from the production of temperature-sensitive products until they reach the customer. It will make an important contribution to the detection of ambient temperature of IoT-enabled devices and CC. Thanks to the developed IoT-enabled environment, the waste of perishable food products that have been lost and damaged will be significantly reduced. Therefore, the importance of this study is to monitor the status of products in containers at ports and to ensure that work schedules are prepared according to current data. It recommends using an IoT-enabled CC system with an emulator inside the truck during transportation to determine critical values with IoT devices. In this way, it will be ensured that the temperature sensitive goods are kept at the appropriate temperature and delivered to the customers on time (Al-Fuqaha et al. 2015).

The IoT enables cold supply chain equipment to transfer data and communicate independently. When it comes to IoT asset tracking solutions, there is no single positioning technology. There is a wide variety of technologies, each subject to different technological and operational requirements. Cost, size, power, coverage, accuracy, security, etc. The most suitable one should be determined according to the criteria. Commercial solutions for monitoring CCL rely on complex devices such as LoRa, SigFox, NCF, 3G/4G/5G, Wi-Fi and NB-IoT (Cil et al. 2022b). Other technologies such as RFID, which has a leading role in the supply chain, are more industry-oriented.

IoT enabling technologies

The IoT, a technology that connects things to the Internet, has become a new research field and many technological advances have been made. The IoT technology makes it possible to transmit data from the network to the Internet by providing easy access to observing. The performance of an IoT depends on the effective use of technologies that perform the basic IoT building blocks capable of deciphering, computing and communication between devices without human participation to perform a specific task. Real-time monitoring of the CCL, the framework of which is set here, is possible with the effective use of these technologies. RFID and IEEE dec02.15.4 wireless sensor components are briefly described below among the most important technological enablers for this purpose.

Wireless sensor networks

WSN is an emerging wireless network application that provides significant innovations in the design of embedded systems in medical systems, military systems, and industrial automation solutions. The WSNs are gaining great interest from researchers in almost every field. WSNs are typically portable embedded and multi-node computing structures interfaced with radio frequency and special converters for short distance communication. They can autonomously monitor, process and transmit various parameters at different locations for long periods of time, using very limited energy and generally without any maintenance during their lifetime (Lazarescu 2015). WSNs have coverage in multiple application areas such as healthcare monitoring, CCL, destination tracking, home automation, pollution control, traffic light management and machinery health monitoring (Sharma et al. 2019). In the study; we deploy IEEE 802.15.4 based WSN with a stellar topology (Fig. 6).

Radio frequency identification

RFID consists of a reader that listens to nearby active receivers or the control system via its antenna. By using RFID technology, the transitions are transmitted from the RFID tags to the reader. Generally, this attraction consists of the same identity of the tag in the eye to which the RFID tag is valid. It is also the method of an object

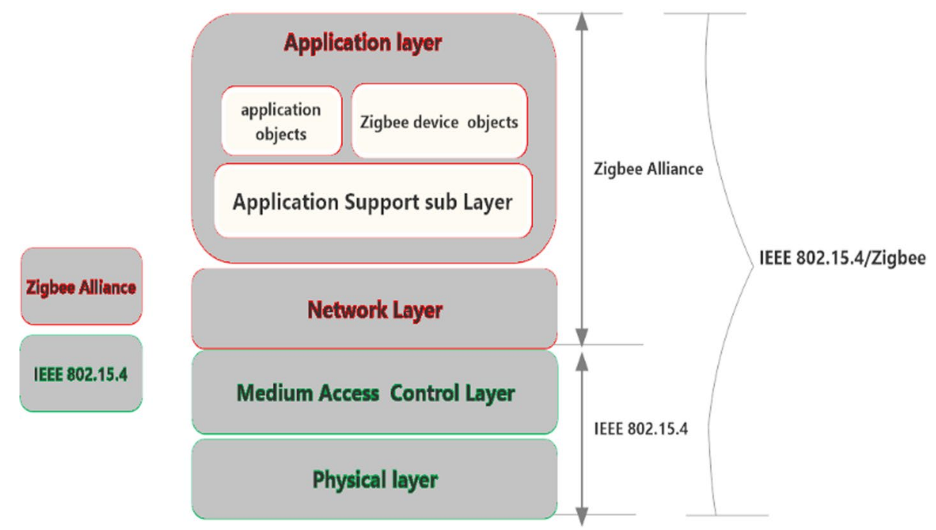


Fig. 6 ZigBee and IEEE 802.15.4 protocols

attaching an RFID tag as a master cell. This way makes use of sending from an RFID system, light beacons and the farthest readout. Although the means of transportation with RFID can be applied, the system simplicity maintenance, security and capacity, comprehensive about 1000 m and up to dimensions, applicable costs, preferred for use for application An application host, RFID installation system of Reader and Tag Reader and Tag are used for application for transportation divers are used, RFID provides subscriber data of application master customers. Products such as RFID, object recognition, moving and tracking the tagged object in real time are the prerequisite of IoT. This work is based on passive tags.

Case study

This section presents a monitoring system designed to monitor the CCL status of products in a container port in Istanbul in real time. The main purpose of this study is to verify how the IoT-enabled CC developed for real-time CCL monitoring of food and other temperature-sensitive containerized products can be implemented in a port. This system will provide real-time display of products throughout a logistics chain at any time in the movement of the CCL where the necessary infrastructure is available. Although this framework is designed to follow a wide range of CCL, we need to report here that this framework proposed in the study only covers the evaluations of container transactions in a port in Istanbul. In this scenario, CCL products arriving at or shipped from the port are accurately tracked and tracked. RFID and IoT sensor data are received and transmitted to the database in the cloud server. Finally, it is communicated to authorized users by a web-based software and DSS for users to monitor the real-time movement and environmental conditions of the labeled products.

Temperature, humidity, pressure etc. Information collected from the sensor node deployed in containers to collect physical or environmental conditions such as less memory, reusability, no need for human participation, possibility to read many tags at the same time compared to traditional traceability tools and currently used temperature data loggers and offers more significant advantages (Zhang and Liu 2019).

Real-time sensor data and static data are integrated into a cloud server. Data in the cloud is processed in real time and analyzed for alert management and further computation, business intelligence (BI) and decision support (DS). The results obtained are communicated to authorized users through various DS interfaces. Thus, real-time data monitoring and alert management can be realized. When environmental conditions violate specified limits, an alert is sent to administrators to assign follow-up actions.

The general framework of the IoT-based CCL monitoring system designed and still in progress for one of Turkey's leading container ports is shown in Fig. 7. The system includes cloud technology and internal and external mechanical hybrid positioning technologies. The developed system basically consists of the following components; (1) determining the status of various devices for the environment and various internal positioning devices and WSN gateway related to products in the container and in the port area and measuring the ambient temperature of the sender; (2) CCL in an RFID system for identification of sensitive goods; and (3) sending the collected data to the remote server WSN, RFID reader and hardware and software interfaces with the Global System for Mobile (GSM) communications gateway.

RFID technology has developed a lot in recent years and is now successfully used in the food industry to identify and monitor perishable foods. It is an alternative to existing barcode and other traditional systems and provides significant advantages in tracking CC products. In this context, a traceability system based on RFID and IoT sensors was developed for the port in Istanbul. Data is collected by standard wireless communication technologies such as RFID, GPS and ZigBee. Data can be synchronized, transferred and exchanged in various use cases. While RFID is used to track and trace the Foods in the port, IoT sensors are used during storage and transportation. The most basic component of this system consists of a smart tag and a commercial reader. Tags attached to cargoes with items to be tracked integrate light, temperature and humidity sensors, a microcontroller, a memory chip, low-power

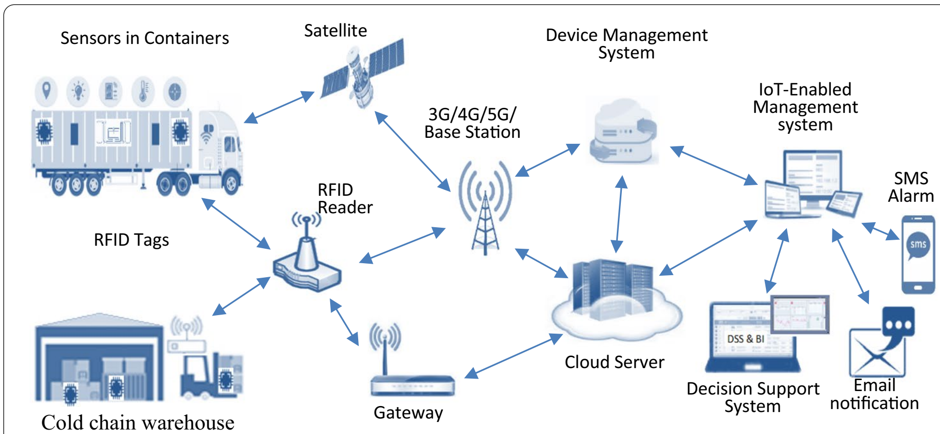


Fig. 7 IoT-enabled CCL system framework for container operations at a port

electronics, and an antenna for RFID communication. It consists of an RFID reader with close reading distance to read and write data on the smart tag.

The operation of the system designed in more detail will be as follows. The communication of the sensors can be achieved via satellite, cellular system or ZigBee3 IIEEE 802.15.4 radio-based Wireless Personal Area Network. IoT-enabled monitoring solutions, such as sensors embedded in containers, collect data on the condition of the products in the container and environmental conditions. The collected data is transmitted to the cloud server via 3G/4G/5G or LAN networks and, if necessary, sends instant alerts. From there, the aggregated data is forwarded to management systems that support a consistent monitoring network. The database that is suitable for processing big data applications in the designed system is MongoDB. The collected RFID and sensor data is received by a web service and transferred to the MongoDB database, and a JSON-based document is created. This sensor document includes event time, recording time, IoT device ID, and IoT device name, reading point, temperature and humidity. With appropriate information sharing between information systems, authorized users in the cold supply chain can be accessed. This platform allows real-time access and monitoring of containers by each authorized participant. This ensures full visibility of the relevant point of the cold supply chain. Compared to the traditional manual tracking system such as barcode, this system is relatively cost-effective, more effective and efficient.

Hardware requirement and cost

A summary evaluation of the hardware requirements and costs of the system is as follows. In the proposed system, reader hardware that can read/collect data with the RFID tag attached to each pallet will be required. A sensor card that can transmit data with the IoT module will be required. However, there is no average cost for RFID solutions here. Pricing can be made according to the label quantity, the memory on the label, the packaging of the label, the type of the label, where and how the label will be used. Features such as a special protective enclosure, extra-long battery life for active tags, and sensors can increase prices. The cost of RFID tags comes in numerous varieties, depending on their shape, size, and building materials. Generally speaking, active tags are $25 and up. Active tags with custom protective housing, extra-long battery life, or sensors can run $100 or more. The cost of deploying a passive 96-bit EPC ranges from 7 to 15 US cents. The price goes up to 15 cents and up if the label is embedded in a thermal transfer label that companies can print barcodes on. Low and high frequency tags cost slightly more. The cost of RFID readers and RFID label printers will again depend on the specific application Expect to pay between $3,000 and $5,000 for an industrial device if you use durable labels. The cost of the software will depend on the type of installation and will vary depending on the number of devices connected and the location covered. The hardware price indicated in Table 1 is approximate and will vary according to the required service type and the type of location to be installed (Miragliotta et al. 2007).

Benefits of the proposed model to the container terminal

There are some challenges that the container logistics industry is currently facing. The lack of visibility will be eliminated by monitoring the status of the CCL products in the container. Documentation errors due to manual switching of container

Table 1 Approximate price of hardware in the recommended model

Hardware	Approximate price of hardware ($)
RFID Printer	5,000,00
UHF RFID Reader	2.100.00
UHF Antenna	280.00
RFID Tag (Passive)	0.20
RFID Tag (Passive) IP65 Boxed	5.00
Integration Software	50,000.00

control movements are eliminated. Insecurity in service causes an increase in operational costs due to incorrect schedules prepared without considering shelf lives; with this model, negativities can be eliminated. In other words, temperature changes during shipping are a common and costly threat to pharmaceutical and food logistics. Positioning technologies combine wireless communication and secure data services with comprehensive detection, contributing to the precise identification and mitigation of weaknesses in the CCL. Deteriorated products and drugs can be detected and withdrawn from circulation. This system can help shippers and manufacturers identify when and where a problem occurs. This information can make it easier to identify which products may deteriorate and, in the event of product damage, to identify failure. It provides visibility into the state of products in the container and the ability to quickly react to inefficiencies and remediate adverse situations, streamline field operations, reduce delay costs, and improve customer service levels. It offers monitoring of reliability and condition of products and peace of mind and efficiency. The proposed system ensures that perishable products such as long-distance foods, seafood, chemicals, and frozen foods are delivered with guaranteed freshness and quality and reach the target within their shelf life. This knowledge can help make logistics operations much more efficient, making it much easier for CCL managers to reduce waste and deterioration. Using RFID tags to monitor the CCL status of products in containers will improve the overall data quality and therefore the efficiency of the entire operation. This gives managers the most up-to-date picture of activities, allowing them to respond in a timely manner to evolving situations. Asset tracking and CCL tracking make a great contribution to meeting delivery dates, quality levels and customer expectations of products. Instant, complete and accurate data is automatically provided in cold supply chain processes. Depending on its integration with other systems used in the terminal, effective data flow is provided between units. Reduction in incorrect handling, shipping and loss of containers. Increasing operational efficiency. The advantage of effective planning for the future in the light of the quality and correct data provided. Reducing waiting times, minimizing human errors and increasing port security with its effective use in gate operations. Increasing competitiveness due to faster and higher quality service With the addition of location sensors, terminal activities and all people, vehicles and loads in the activity can be tracked, and effective management of the other processes (activity planning, resource allocation, instantaneous problems etc.) depending on obtaining the necessary information.

Modeling and simulation of the proposed system

The simulation model and evaluation of the system are discussed in this section. With simulation, a real system is modeled, tested, visualized and analyzed without using expensive hardware infrastructures. The simulation is not a real application, but an imitation of the real system (Bungartz and Schäfer 2014). In real-time scenarios, WSN is subject to severe limitations such as restricted power supply, short communication range, less bandwidth availability, and small memory storage. WSNs consist of multiple sensor nodes deployed in an area to collect data. Simulation is critical to assess their form. Simulation is a cost-effective way. The simulation model enables the performance of WSNs to be evaluated. OPNET, NS-2, TOSSIM, EmStar, OMNeT++, J-Sim, ATEMU and Avrora are commonly used simulation platforms (Monika and Shekhar 2014). Of these, OPNET (OPtimized Network Engineering Tool) is a commercial modeling and simulation tool for analyzing communication networks, which is a very suitable tool for simulating the behavior of those networks. The OPNET user graphically specifies the topology of his network consisting of nodes and connections. The constraints on the node mobility of ZigBee WSN models are modeled with the OPNET simulator. A network layer model compatible with ZigBee protocols based on the ZigBee MAC layer model and an advanced routing algorithm were developed in OPNET Modeler.

Simulation model of IoT-enabled CCL system

In this section, the simulation model of IoT-enabled CCL system created using OPNET Modeler software is discussed. The original OPNET was developed by the IPP-HURRAY Research Group (Al-Fuqaha et al. 2015). The model was revised and some functions were include the model such as GSM-gateway and RFID-reader. The Sensor node (SN) node component of the simulation model consists of a physical level with a transmitter and wireless radio receiver. The model operates in the 2.4 GHZ frequency band using the Quad Phase Shift Switching (QPSK) modulation technique. The Media Access Control layer of SNS synchronizes the Slotted CSMA/CA mechanism and the nodes associated with the PAN coordinator. The battery module is used to find the consumed energy of the WSN. OPNET process models use the EPC-global Gen 2 and the Finite State Machine (Abdurrahman, 2016). The IoT-enabled CCL model was developed in accordance with the EPCglobal Gen 2 and IEE 802.15.4, and consists of WSN and RFID sub-models. Process models were developed based on the EPCglobal Gen 2 specification (Figs. 8, 9). The node model includes RFID reader and Tag MAC layer operating in the 860 MHz-960 MHz frequency range, and physical layer with wireless radio receiver (rx) and transmitter (tx). Details of RFID protocols can be found at Kim et al. (2010). In the Gen 2 protocol, a reader uses three basic processes to manage the tag population: Selection is the process of selecting the surrounding tag population for inventory and access purposes. The Reader sends a select command that enables the tags to be powered on, the SL flag confirmed or removed, and the inventory flag set, which prepares the tag for the next state, Inventory is the process of defining tags using the query, query repeat, and query set commands. Access is the process of accessing (writing/reading) defined tags.

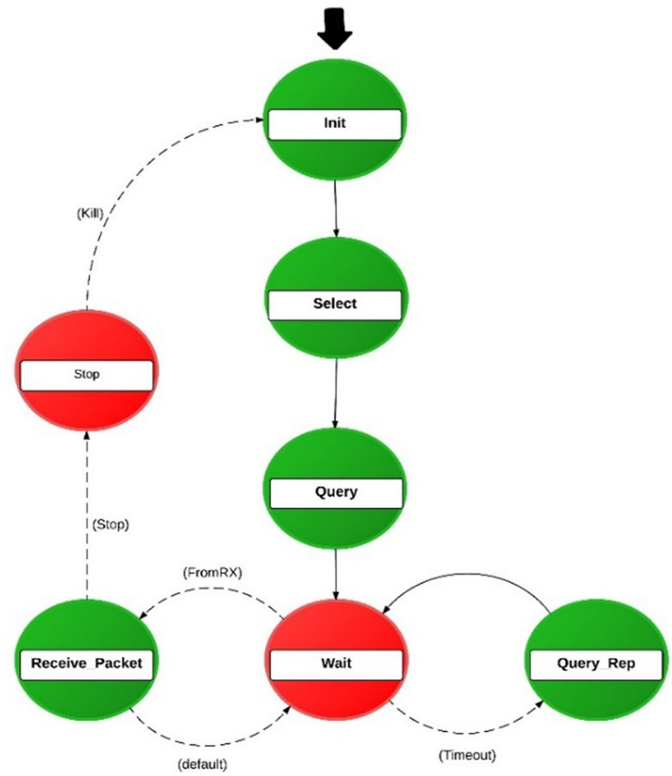


Fig. 8 OPNET Simulation model of RFID reader

Simulation scenario

The IoT-enabled CCL simulation scenario includes WSN and RFID models developed according toEPCglobal Gen 2 standards and IEE 802.15.4. The simulation parameters are given in Table 2.

Our aim in simulation is to feasibility of collecting and monitoring real-time data of the proposed IOT-enabled CC system with IEEE 802.15.4 and RFID. There are many similarities between these two structures. As shown in Fig. 10 in the simulation model, there is basically a Server and a GSM network. The simulation model includes a Sensor Node (SN) and a PAN Coordinator. The main function of SN is to detect the temperatures and transfer them to RFID interfaces and GSM (Abdurrahman, 2016; Kim et al. 2010).

In the simulation scenario for WSN, network activities are controlled by a computer. The simulation model performs such functions as receiving and sending data from the GSM and sensing information from RFID tags. In the simulation scenario, the server is used to admission data of the proposed IoT based CC. The main purpose of using the simulation is to study the feasibility of organizing RFID and IEEE 802.15.4 to collect real-time data and monitor products in IoT-based CCL system. Therefore, the simulation model focuses on some significant fragments of CCL system. Since food products begin to deteriorate with the start of production, it is important to keep the temperature at the optimum level without breaking the CCL. Shelf life is a key factor in determining freshness of product throughout the entire life cycle of goods,

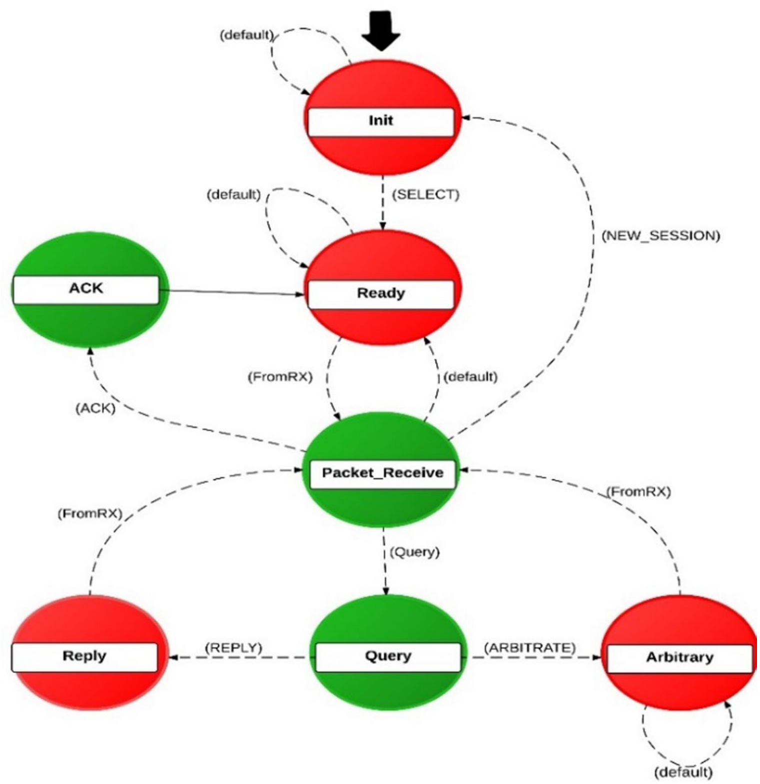


Fig. 9 OPNET Simulation model of RFID tag

Table 2 Simulation parameters

Parameter	Value
GTS	Enabled
Beacon	Enabled
Frequency band	2.4 MHz
Simulation time	60 s
Packet Interval Time(seconds)	Exponential (1.0)
Packet Size (bites)	Constant (500)
Data rate(bps)	250,000
Beacon order	15
Super frame order	15
Initial energy	2 AA Batteries (1.5 V, 1600 mAh)
Maximum Back off Number	4
Minimum Back off Exponent	3

and it refers to the storage time of a perishable product before it becomes suitable for human use. In order to assessment the shelf life of a perishable goods by developing a mathematical model, different experimental tests are performed on the parameters of a particular perishable product. The shelf life of a product is determined by

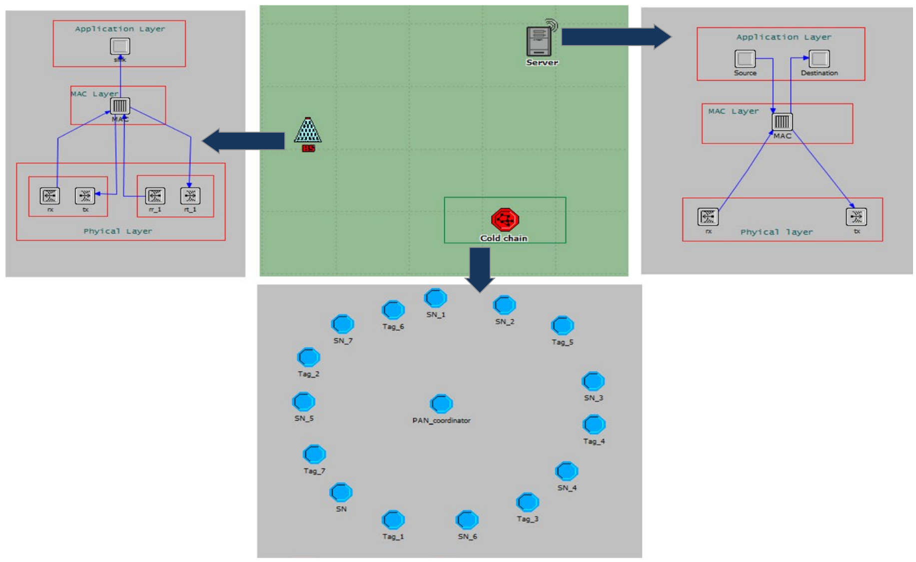


Fig. 10 IOT-enabled OPNET network model in CCL

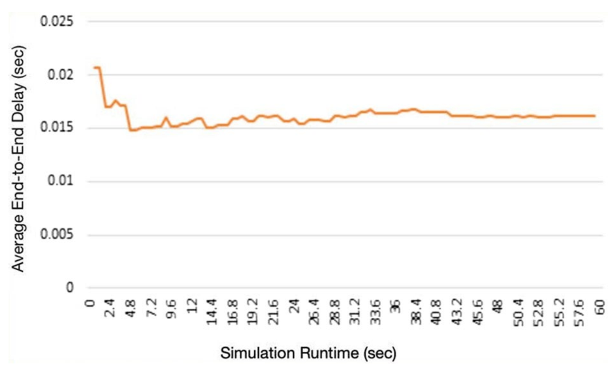


Fig. 11 Average End-to-End latency result

environmental factors such as the structure of the product, temperature, light and humidity that are effective in its deterioration.

Simulation results

The results seen in Fig. 11 show the time it takes to send any data packet from an SN to a PC. Also, local statistics of the WSN model are displayed by measuring the end-to-end delay of data transmission. The figure shows that the end-to-end value stabilizes in about 0.015 s. It is a good result expected for the designed scenario. The size of the network load is very light. The capacity is sufficient for the transfer of all packets generated in the network.

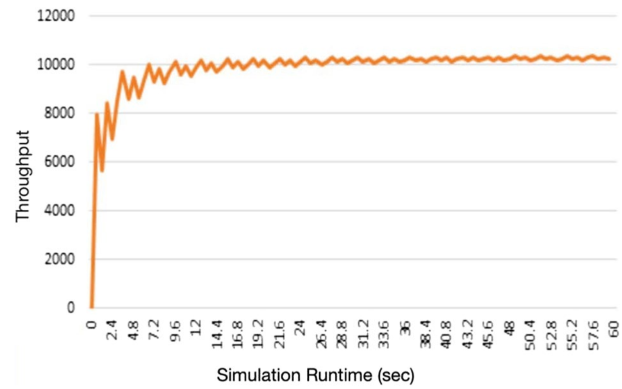


Fig. 12 Network output load

The entire network egress load of the WSN in our model of IoT-enabled CCLs is given in Fig. 12. The average network throughput value is about 10 Kbps at steady state. As the figure shows, the network can easily transmit all measured data, as the maximum bandwidth value, i.e. 250 Kbps, is never reached.

Decision support system for estimating the shelf life of perishable foods

In this section, the DSS that determines the shelf life of perishable foods, which is an important component of the model, is explained. Ports are places that require the use of analytical methods to support the decision-making process of the management of logistics and supply chain operations in supply chains. To facilitate these necessary calculations and to provide DS to managers, these analytical methods were embedded in technological platforms as Decision Support Systems (DSS) and the results were combined with graphs, pivot tables and visual elements of BI (Mar-Ortiz et al. 2018).

Experimental tests are performed based on the chemical, physical, and microbiological parameters of the product to predict the shelf life of a product that has a tendency to spoil with a mathematical model. Based on these tests, standards are set (Torres-Sanchez et al. 2020). When evaluating the shelf life of a product, the characteristics of the product, the structure of the product and environmental conditions, such as temperature, humidity and light, are effective on the product. Different methods are used for this purpose. Accelerated Shelf Life Test (ASLT), one of these tests, is a method that quickly calculates the shelf life of products. In our study, we used the ASLT method to estimate the real-time shelf life of perishable products. In the ASLT method, every 10 °C decrease or increase in the temperature of a process causes a 1/2 × or 2 × change in the chemical reaction rate, respectively. This chemical reaction rate is represented by Q10 = 2 (Boekel 2008; Labuza 1984). Keeping this theorem in mind, the shelf life of a perishable product can be determined using Eqs. 1 and 2.

$$Q10 = \left(\frac{Shelf - lifeatelevated\,T}{Shelf - lifeClaimed} \right)^{\frac{10}{elevated\,T(^{\circ}C) - \mathrm{optimal\ T}(^{\circ}C)}} \tag{1}$$

$$shelf - lifeatelevatedT = \frac{Shelf - lifeClaimed}{2^{\left(\frac{elevatedT(^\circ C) - \text{optimal T}(^\circ C)}{10}\right)}} \quad (2)$$

Using the Accelerated Shelf Life Test (ASLT), the shelf life of products is quickly calculated. The real-time shelf life of perishable products is determined using ASLT (Labuza 1984).

In the simulation model, Shelf life is calculated using the following algorithm:

1. The "Claimed Shelf Life" related to the standard shelf-life of the item for consumption is stored as the optimum Temperature (℃) and a definite "threshold".
2. The value of the “upstretched Temperature (℃)" of the CCL is taken from the WSN.
3. Using ASLT, the "shelf life in raised Temperature” of the product is calculated.
4. If the "high Temperature -value shelf life" of the food is standard, it is continued to monitor the shelf life for a certain period.
5. If the measured "shelf life at high Temperature” is under a defined threshold, an alarm is sent to the CC. This procedure is repeated within the specified time.

In the developed system, it helps to create an efficient supply chain operations environment with cold supply temperature threshold and other information by using BI. It enables intelligent decision-making and leverages the power of intuitive rich visuals and reports. Interactive dashboards provide a consolidated view of data from multiple sources. It helps to manage multiple items in containers through a unified dashboard view to understand the damage and loss that has occurred. Insights into food distribution events are provided that help identify the pattern of temperature threshold

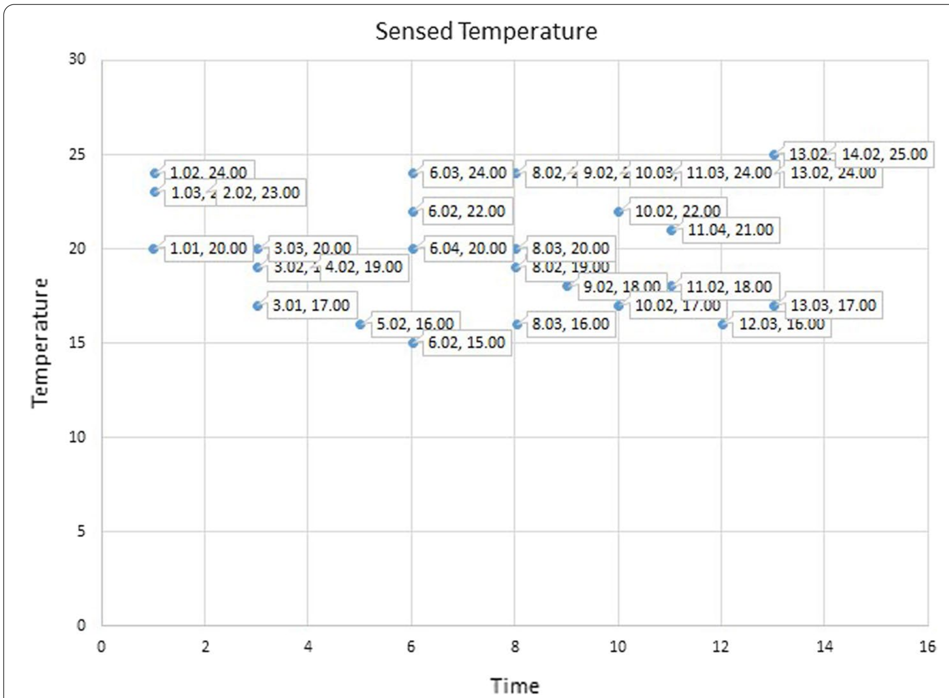


Fig. 13 Ambient temperature of CCL products

exceedances to minimize the risk of goods being returned. The IoT base system that developed in the simulation scenario provides real-time environmental data and monitoring of the CCL to its authorized users in the port. The temperature results of the data collected with WSN technology are stored on the server. The real-time ambient temperatures of the data collected instantly using WSN during the testing phase, where the evaluations of the system are made, are shown in Fig. 13.

One of the important advantages of IoT is the analysis of the collected data and providing the right DS with useful results. Ambient temperature and other important CC parameters can be managed and monitored in real time. As an example, it is possible to determine the remaining shelf life of the products in the study or to understand them by measurement. A sample of the calculated shelf life of sensitive products obtained from the test data was prepared. Using the test data, the calculated results regarding the remaining shelf life of items during their stay in the port are shown in Fig. 14. Shelf life is determined using the algorithm above. Because the performance of temperature sensitive products is dependent on temperature and shelf life, these real-time results provide important DS in responding appropriately to ensure the safety of products.

IoT-enabled CCL monitoring brings comprehensive and effective visibility into ports. Real-time CCL monitoring service offers visibility leading to optimized, efficient supply chains. In CCL, necessary information such as humidity fluctuations, shock detection, temperature fluctuations, geographic location, route and shipment performance reports, intrusion detection, and door opening status can be monitored and actionable insights, DS and warnings can be obtained.

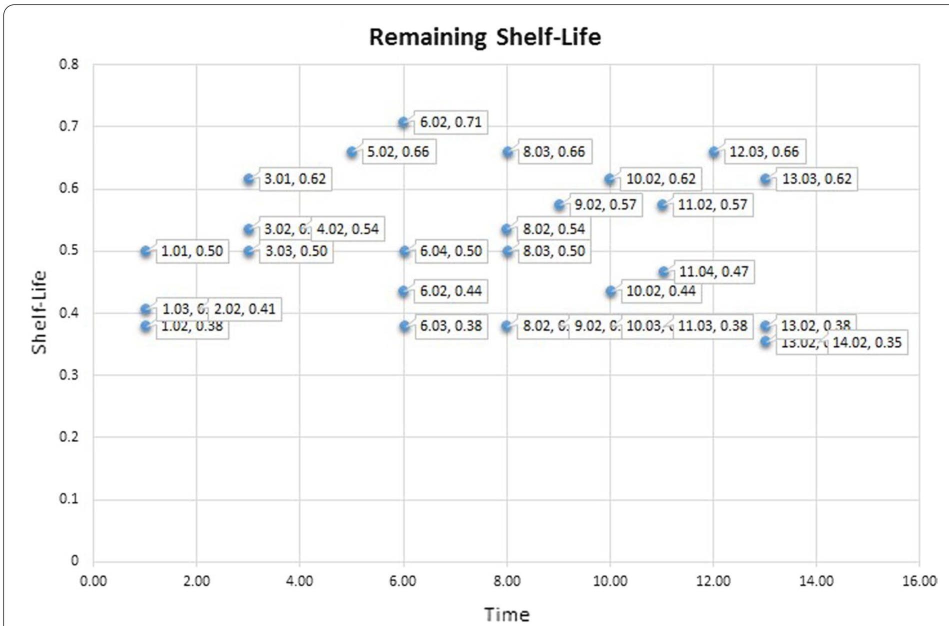


Fig. 14 Remaining shelf life of products

Conclusions

In this article, an evaluation of the WSN system, which is designed for monitoring and DS of CCL processes of products in a container port, was carried out with a simulation model. Although current research shows that there are significant technological advances in this direction, it shows that the real applications of IoT based systems that meet these requirements are not used in all container ports as of today. A comprehensive IoT-based framework was designed by determining the system requirements of a port in Turkey. Then, the efficiency of the proposed system was evaluated by simulation. It has been verified that the results of the created simulation model exhibit favorable and adequate parsing. Implementation of the proposed system will be show several advantages for the port. BI, DS and monitoring are embedded in a cloud server with core collaborative services. The system can simultaneously acquire, process, transmit and analyze data enabling real-time decision making in the CCL. In this study, an IoT-enabled CCL system that can monitor and analyze the ambient temperature of perishable products and calculate the remaining shelf life in real time was introduced. The IoT-based cold logistics monitoring system has been developed to provide DS to logistics providers and customers by providing real-time monitoring of food products in containers at ports using IoT enabled technologies such as WSN and RFID. An access point has been developed that includes WSN, GSM and RFID reader interfaces. An RFID system related to the identification of perishable products in the CCL has also been modeled. In addition, the remaining shelf life based on ASLT was integrated into the proposed system into the prediction algorithm. The results show that IoT-enabled CCL systems have a great potential for managing, monitoring, receiving and determining abnormal events related to temperature-sensitive products in real time. The status and unusual values of the products in the container are transmitted to the responsible logistics actors via RFID, the corresponding interface software and the cloud server. The basic services and the actual status of port logistics can be monitored using IoT-enabled technology. In this context, IoT-enabled CCL is introduced, which describes how the values of the environment parameters are collected in real time using IEEE 802.15.4 WSN and how the collected data is sent to the server via the GSM gateway. In the port scenario, activation devices such as IEEE 802.15.4 and RFID were modeled using the OPNET simulator. The developed model was carried out in accordance with the principles of EPCglobal Gen 2. With the proposed approach, smart solutions provide a smarter flow of information. Monitoring objects in the port environment and collecting instant data about them improve processes and provide better decision-making.

The limitation of the article is that a proposed conceptual model and framework with process concepts has been validated by simulation for only one port. This framework and model is not validated in the field with real data within a wider CCL network. Future works may try to validate the entire model or adapt it in the field. This study is devoted to the traceability of the cold supply chain only in the port area, where waiting and handling processes are intense. However, since CCL covers a very wide intermodal transportation system, future studies should be evaluated to cover all of the supply chain bounce CCL rings. Considering the shelf life of the CCL products, minimizing the transportation and unloading time, keeping the waiting times at the ports taking into account the shelf life of the products and protecting the integrity of the shipment were the key points, only the port point was considered in the first place. Due to the long wait for CCL products at the port considered in the case study, a single port level evaluation was carried out primarily. If we talk about future studies, first of all, with the implementation of the system evaluated by simulation in this study, more comprehensive results can be presented with studies to be conducted with real data. AI and big data can make a significant contribution to further enabling CCL. Thus, the risks can be further reduced. The best performance can be achieved with various parameters such as temperature ranges, routes, and transportation modes. By looking at its performance according to the situation, it may be possible to evaluate how it will perform under a certain set of parameters. Weak links can be strengthened by making evaluations not only at one point but at every stage of the CCL.

Abbreviations

AI: Artificial Intelligence; ASLT: Accelerated Shelf Life Test; BI: Business Intelligence; CC: Cold Chain; CCL: Cold Chain Logistics; CFS: Container Freight Stations; DS: Decision Support; DSS: Decision Support Systems; GSM: Global System for Mobile; IoT: Internet of Things; OPNET: OPtimized Network Engineering Tool; RFID: Radio Frequency Identification Systems; SCM: Supply Chain Management; SN: Sensor Node; QPSK: Quad Phase Shift Switching; WSN: Wireless Sensor Network.

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Ahmet Yunus Cil and Dini Abdurrahman are young researchers who are carrying out practical studies and projects in the field of digitalization software and hardware. Ibrahim Cil is a researcher with academic experience who has been working on lean production and smart production systems for more than 30 years as a professor.

Author contributions

AYC: Concept Design, Data Collection or Processing, Analysis or Interpretation and Writing, Reviewing and Editing. DA: Data Collection or Processing and Analysis or Interpretation. IC: Concept Design, Analysis or Interpretation, Literature Review and Writing, Reviewing and Editing. All authors read and approved the final manuscript.

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Declaration

Competing interests

The authors declare that they have no competing interests.

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