Decision making in cold chain logistics using data analytics

a literature review

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DECISION-MAKING IN COLD CHAIN LOGISTICS USING DATA ANALYTICS: A LITERATURE REVIEW

Structured Abstract

Purpose:

The purpose of the paper is to identify the multiple types of data that can be collected and analyzed by practitioners across the cold chain, the ICT infrastructure required to enable data capture and how to utilize the data for decision-making in cold chain logistics.

Design/methodology/approach:

Content analysis based literature review of 38 selected research articles, published between 2000 and 2016, was used to create an overview of data capture, technologies used for collection and sharing of data, and decision making that can be supported by the data, across the cold chain and for different types of perishable food products.

Findings:

There is a need to understand how continuous monitoring of conditions such as temperature, humidity, vibration can be translated to support real-time assessment of quality, determination of actual remaining shelf life of products and use of those for decision making in cold chains. Firms across the cold chain need to adopt appropriate technologies suited to the specific contexts to capture data across the cold chain. Analysis of such data over longer periods can also unearth patterns of product deterioration under different transportation conditions, which can lead to redesigning the transportation network to minimize quality loss or to take precautions to avoid the adverse transportation conditions.

Research limitations and implications:

The findings need to be validated through further empirical research and modeling. There are opportunities to identify all relevant parameters to capture product condition as well as transaction data across the cold chain processes for fish, meat and dairy products. Such data can then be used for supply chain planning and pricing products in the retail stores based on product conditions and traceability information. Addressing some of the above research gaps will call for multi-disciplinary research involving food science and engineering, information technologies, computer science and logistics and supply chain management scholars.

Practical implications:

The findings of this research can be beneficial for multiple players involved in the cold chain like food processing companies, logistics service providers, ports and wholesalers and retailers to understand how data can be effectively used for better decision-making in cold chain and to invest in the specific technologies which will suit the purpose. To ensure adoption of data analytics across the cold chain, it is also important to identify the player in the cold chain, which will drive and coordinate the effort.

Originality/value

This paper is one of the earliest to recognize the need for a comprehensive assessment for adoption and application of data analytics in cold chain management and provides directions for future research.

Keywords: Cold chain; logistics; data analytics; ICT infrastructure; content analysis based literature review

1. Introduction

A cold chain is a supply chain of perishable items, which protects a wide variety of food, pharmaceutical, and chemical products from degradation, improper exposure to temperature, humidity, light or particular contaminants to keep them frozen, chilled and fresh state (Bishara, 2006). The integrity of the cold chain must be preserved from the point of production or processing, through all phases of transportation i.e. loading, unloading, handling, and storage – and extend to storage at the consuming household or restaurant (Salin and Nayga Jr., 2003).

The freshness of food products handled in a cold chain is highly sensitive to temperature and other environmental conditions and, when deteriorated, can easily cause adverse effects on human health, product prices, and food availability. Lack of food safety has a huge impact on human health and causes economic losses for farmers and businesses (Marucheck et al. 2011). Food retailers experience missing revenue growth targets, poor operating margins and inventory performance due to the impact of multiple risks across the cold chain such as lack of traceability, transport delays and breakdowns, temperature abuse, cross-contamination in transport and storage (Srivastava et al. 2015). Moreover, it has been estimated that about 20-30% of perishable products are wasted at some point of the supply chain (SC) (Virtanen et al., 2014, Mena et al. 2014), excluding the waste in households, which is estimated to be 19% of all food purchased (Mena et al. 2014). Hence, to ensure food safety and quality across the cold chain and to improve performance of the cold chain, awareness and accessibility of *product (environment) data* from all stages of the cold chain has been emphasized (Kim et al., 2016). Such data capture about the condition of the food products enables real-time monitoring and traceability across the chain (Ringsberg, 2014; Kelepouris et al., 2007) and supports risk management (Kim et al., 2016). *Technologies for collection of digital data*, such as Radio Frequency IDentification (RFID) and Wireless Sensor Networks (WSN) have the potential to improve product traceability (Ringsberg, 2014, Raab et al., 2011) across the cold chain and to contribute effectively for risk control (Marucheck et al., 2011). Besides ensuring visibility, data capture and monitoring can bring additional benefits when combined with optimization models, for example to build optimal transportation plan (Wang et al. 2010) or storage plan (Raab et al., 2011) to reduce risks. Such application of *data analytics*, has received increasing attention in cold chain logistics due to its potential to improve flexibility, to effectively manage demand volatility, and handle cost fluctuations and thereby enable business organizations to make better decisions (Wang et al. 2010; Shi et al., 2010; Wang et al., 2012; Nakandala et al., 2016). For example, cold storage specialist Lineage Logistics uses data from sensors to adjust refrigeration systems, minimise temperature variability and ensure product integrity, transport lane optimisation and product tracking for recalls. This also helps Lineage Logistics to reduce energy consumption (Whelan, 2015).

However, the cold chain data have been underutilised, as it has been mainly used for evaluating the integrity of individual shipments (Joshi et al. 2012). Based on interviews with senior managers looking after logistics, food safety and quality, systems development and design of third party logistics service provider of temperature sensitive freight transportation, White and Cheong, 2012 conclude that it is not uncommon that food temperature is recorded but not transmitted in transit. Moreover, such data is only used at the destination to determine whether the freight is accepted or rejected (White and Cheong, 2012). Collaboration among supply chain members in terms of monitoring and control is often missing and even temperature data are mostly not exchanged within the cold chains (Raab et al., 2011). Moreover, most companies only perform a minimum level of temperature control in order to comply with food regulations (Stragas and Zeimpekis, 2011). In the context of meat supply chains, Raab et al. (2011) conclude that full implementation providing temperature control over the entire cold chain are mostly absent because the supply chain participants are often not aware of the characteristics of the different systems and the solution which fits their company's requirements best.

Similar concerns have been raised in a recent practitioner study, which mentions the current challenges in ensuring traceability across the cold chain. For example, the CEO of an US based provider of inventory and traceability software notes that the retailers' distribution and store systems were not ready to track the suppliers' traceability information from the distribution centre to the store or suppliers' direct-store-deliveries (DSDs) (Maras, 2016). While adoption of electronic traceability solutions is growing, there are still multiple challenges regarding data uniformity and standardization throughout the supply chain. The collection and transfer of data can vary greatly among supply chain partners. Challenges include learning automated collection process, the nuances between different electronic traceability vendors, and overcoming the legacy practices (Maras, 2016).

The current literature has either fragmented focus on specific technology like RFID (Askin et al., 2010; Ruiz-Garcia et al., 2011; Butcher and Grant, 2012) or consider technology usage for specific food products, or cold chain member such as temperature monitoring in meat supply chains (Raab et al, 2011) , implementing temperature alerts in cod supply chains (Hafliðason et al., 2012), supply chain design for maintaining quality at minimal cost for fresh fruits. (Blackburn and Scudder, 2009). Similarly, data-driven decision making is considered from the perspective of a single cold chain member (Giannakourou and Taoukis, 2003 for distribution of frozen fruits, Bilgen et al., 2013 for production scheduling and distribution of dairy products). Among the literature review studies, Akkerman et al. (2010) consider quality, safety and sustainability only in food distribution, Zhang and Wilhelm (2011) provide an Operations Research/ Management Science decision support models for specialty crops industry. Shukla and Jharkharia (2013) provide a broad review of fresh produce supply chain but restricted only to fruits, flowers and vegetables. Thus, there is a lack of comprehensive review of data capture, digitalization technology, and analytics for enhanced decision making in different phases of the cold chain considering different product types. Such a review is needed for providing directions to future research to the growing but under-researched field, which has potentially high managerial implications. Hence, to fill this gap, we reviewed research papers to identify how data captured in cold chain can be used for decision-making and management. To answer the above research question, we also consider the sub- questions i.e. what data needs to be collected across the cold chain network and what are the appropriate technology and mechanisms which can be used for collecting and communicating the datacaptured in the cold chain. Lastly, we provide directions for future research to demonstrate how decision-making using such data can help improve overall performance of the cold chains.

2. Content analysis based literature review

In order to ensure replicability of the research and traceability of the findings based on literature review, we adopt content analysis method. Content analysis is any methodological measurement applied to text (Shapiro and Markoff, 1997, p. 14). It is a systematic, rule-governed, and theory-driven analysis of fixed communication (Mayring, 2008). Content analysis enables synthesis of a variety of topics (Rao and Goldsby, 2009), determining key ideas and themes in publications (Spens and Kovacs 2006), and offers a frame for conducting rigorous, systematic and reproducible literature review (Seuring and Gold, 2012).

In our study we follow the guidelines for conducting content analysis proposed by Seuring and Gold (2012), consisting of the following milestones:

(i) Material collection,

(ii) Descriptive analysis providing the background for subsequent content analysis

(iii) Category selection in which structural dimensions and related analytic categories are selected and applied to the collected material

(iv) Analysis of the material collected.

The application of the above four steps is elaborated in the following sub-sections.

2.1 Material collection

We choose not to restrict our review to a set of journals since our study is spread across different disciplines such as supply chain and logistics management, information system and technology management, food and agriculture. Based on the coverage of discipline, the authors decided to pick a powerful database that could include all the studies relevant to disciplines such as food science and technology, supply chain management, information management and operations research. ABI-Inform, which is a research database contains important journals in business, management, economics was suggested by the database experts to be the most relevant for our search category. Hence, ABI-Inform was used as the database for the searching the relevant studies.

We used the following search strings using ABI-Inform Global and ABI-Inform Collection (not including ABI-Inform Trade and Industry as the focus of the search is only scholarly journal articles published in English):

i. “Cold chain” OR ("temperature controlled chain" OR "Cold chain logistics") AND ("supply chain planning" OR "supply chain decision making") AND (food processing OR food retail) OR ("perishable food" OR "fresh produce") AND ("big data").

ii. (“decision making”) AND (data OR “big data”) AND (“Cold chain”) AND (“supply chain” OR logistics) AND food.

iii. Cold chain OR ("temperature controlled chain" OR "Cold chain logistics") AND ("infrastructure ") AND (“food processing” OR “food retail”) AND (data OR "big data")

The time period for the above searches was restricted between 1st of January 2000 to 30th of September, 2016.

The search strings were applied for search anywhere in the document i.e. title, abstract and main text.

The following restrictions were included to narrow down the search for the first search string

i. As the focus of the research is on cold chain for perishable food, we decided to leave out healthcare related subject areas using the ABI-Inform filter criteria i.e. vaccines, immunization, public health, poliomyelitis, world health, health services accessibility, healthcare industry, healthcare policy, biotechnology, pharmaceutical industry and poverty.

ii. ABI-Inform also includes classifications of the articles under different categories. We decided to leave out articles classified under the categories of pollution control, chemical industry, international trade and investment, pharmaceutical industry, politics and political behaviour.

The above search resulted in 182 hits. Two of the authors read the titles and abstracts of these 182 papers. Both authors agreed to include 31 papers and to exclude 145 papers based on initial judgment with respect to relevance in terms of data capture, technology or decision making in perishable food cold chain while there were disagreements about other 6 papers. This led to a Cohen’s kappa value of 0.89 with a 95% confidence interval from 0.85 to 0.93. After consultation with the other three authors, who read those 6 papers, 33 papers were finally selected from the first set of 182 papers.

For the second search, additional restrictions were used as follows:

i. Subject areas left out were healthcare, healthcare industry, electronic government, colleges and universities.

ii. Articles classified under the categories of healthcare industry, pharmaceuticals industry, chemical industry, electric, water and gas utilities, broadcasting and communications industry, publishing industry, insurance industry, health and life insurance, advertising, arts, entertainment and recreation, financial services industry, credit management, capital and debt management, politics and political behaviour, arts, entertainment and recreation were left out.

The above research resulted in 731 hits. The first 500 out of these were considered. The authors realised that being a broader search, it resulted in many irrelevant articles and hence it was decided to restrict reading the titles and abstracts to the first 500, which were read by another two authors. Both authors agreed to include 21 papers and to exclude 471 papers based on initial judgment of the authors with respect to relevance in terms of data capture, technology or decision making in perishable food cold chain while there were disagreements about other 8 papers. This led to a Cohen’s kappa value of 0.83 with a 95% confidence interval from 0.80 to 0.86. After consultation with other three authors, who read those 8 papers, 22 papers were finally selected from the second set of 500 papers.

For the third search, the restrictions used were as follows:

1. Subject areas excluded were vaccines, vaccination, immunization programmes, poliomyelitis, health facilities, pharmaceutical industry, health services accessibility, population services, poverty, infant, child, newborn.
2. Articles classified under the categories of pharmaceutical industry, politics and political behaviour, schools and educational services, social trends and culture, broadcasting and telecommunications industry, investment analysis and personal finance were left out.

The third search resulted in 272 hits. Titles and abstracts of the above were read by two of the authors. Both authors agreed to include 14 papers and to exclude 253 papers based on initial judgment with respect to relevance in terms of data capture, technology or decision making in perishable food cold chain while there were disagreements about other 5 papers. This led to a Cohen’s kappa value of 0.84 with a 95% confidence interval from 0.80 to 0.87. After consultation with other three authors, who read those 5 papers, 16 papers were finally selected from the third set of 272 papers.

10 articles were common across the searches. This process resulted in 61 papers which were read by three of the authors. After reading the full papers, 23 papers were not considered in the review as those do not fulfil the criterion that a selected paper must have relevance in terms of answering at least one of the research questions, resulting in 38 papers, which meet the above criteria. This decision was made independently by the three authors who read the papers. All the authors agreed to include 34 papers but there were conflicts in terms of including four papers which were resolved after discussing with the remaining two authors who read those specific papers. Table 1 provides an overview of the 38 papers reviewed, identifying if certain food sector and stage of the cold chain was specified in the paper or not.

Table 1. Papers reviewed in this article

	Food Sector						Stage of the cold chain						
Papers	Fresh fruits and vegetables	Fish and marine products	Meat products	Dairy products	Other	NA	harvesting, sorting and pre processing	procurement	processing	Distribution and transportation	Storage	Retail	NA
Abad et al., 2009	√	√	√	√						√			
Aiello et al. 2012						√				√	√		
Aiello et al. 2015			√							√			
Akkerman et al., 2010						√				√	√	√	
Askin et al, 2010						√					√		
Bell et al., 2015	√									√			
Bilgen and Celebi, 2013				√					√				
Blackburn and Scudder, 2009	√						√			√	√		
Engelseth, 2009	√						√		√	√	√	√	
Gessner et al., 2007	√		√	√	√		√		√	√	√	√	
Giannakourou and Taoukis, 2003	√									√			
Hafliðason et al., 2012		√					√		√	√	√		
Higgins et al., 2010													
James and James, 2010	√											√	
Joshi et al., 2009	√			√									√
Kelepouris et al., 2007						√			√	√	√		

Kim et al., 2016						√				√			
Kumar et al., 2012				√				√					
Luo et al. 2016	√							√		√	√		
Lütjen et al., 2013	√				√	√				√	√		
Mai et al., 2010		√											√
Manzini and Accorsi, 2013		√					√		√	√	√	√	
Manzini et al., 2014					√					√			
Moccia, 2013							√		√	√	√		
Mohebi and Marquez, 2015			√										
Nakandala et al., 2016	√									√			
Pang et al., 2015	√				√				√	√	√	√	
Parreño-Marchante et al., 2014		√					√		√	√		√	
Prasad, 2015						√							√
Raab et al., 2011			√							√			√
Rijpkema et al. 2014	√						√		√	√	√		
Ringsberg , 2014						√							√
Ruiz-Garcia and Lunadei, 2011	√								√			√	
Sharma and Pai, 2015													
Shi et al., 2010			√		√					√			
Shukla and Jharkharia, 2013	√								√	√		√	
Thakur and Eskil, 2015	√												
Wang et al 2010					√	√			√	√	√	√	

2.2 Descriptive analysis

The journals with highest number of papers in our review are British Food Journal and Journal of Food Engineering (each with four papers), International Journal of Physical Distribution and Logistics Management, Computers and Electronics in Agriculture, Journal of Business & Industrial Marketing, and Industrial Management and Data Systems (each with two papers) representing 42 percent of the total number of papers reviewed. Out of the papers reviewed, 37 percent are from the discipline of Food Technology and Management, 21 percent are from Operations Management, Supply Chain and Logistics Management, 21 percent are from Information Systems and Technology, 13 percent from Operations Research and the remaining 8 percent are from miscellaneous disciplines like Business, Industrial Marketing.

Year-wise distribution of the papers show that among the papers selected for the review, seven are published in the year 2010, six each in the years 2013 and 2015, four in the year 2009, 3 each from the years 2012, 2014 and 2016, 2 each from 2007 and 2011 and one each from 2003 and 2005.

2.3 Analytic categories for analysing the content

The analytic categories chosen for the content analysis are food sector covered, stage of the cold chain process, methodology used, data captured, technology infrastructure and use of the data for decision-making. Within each of the above categories, the specific single categories were iteratively refined during the coding process. This two-step process of developing pattern of analytic categories follows the recommendations by Seuring and Gold, 2012. Finally it was decided to present the findings in terms of methodology used, data captured, technology infrastructure and use of the data for decision-making with respect to food sector covered and the stage of the cold chain process.

3. Findings from the content analysis based literature review

3.1 Data Capture in Cold Chains

Data capture involves several types of data, which corresponds to product and processes. Most systems aim to collect temperature or environment-related data. Others focus on transactional data such as inventory level, which is a typical supply chain measure, with a different consideration in cold chains though. This section firstly discusses the two types of data, i.e., environmental data, and the transactional data across cold chain. Furthermore, and overview is given of the literature which has reported the data which is collected across cold chain stage and in the specific sector of the food industry.

3.1.1 Environmental data

Tracing real-time data from the field is relevant to monitor the process of growth of crops or control environmental conditions in greenhouses, to make accurate planning of interventions and strategies by farmers for increased quality and productivity (Pang et al., 2015). Other than tracing, tracking the product during handling is a vital aspect, which improves the visibility of the product. In this concern, a study by Lütjen et al. (2013) proposed an intelligent container, which can provide necessary information about its location and the quality conditions of its loaded goods. Kumar et al. (2012) mention of capturing geographic information system (GIS) data related to district boundary, road network, road shape, latitude, longitude for identifying milk procurement potential.

In connection with process, the parameter that governs cold chain is temperature and has mentioned by multiple authors in our review (Giannakourou and Taoukis, 2003; Blackburn and Scudder, 2009; James and James, 2010; Raab et al. 2011; Aiello et al. 2012; Hafliðason et al., 2012; Lütjen et al., 2013; Thakur and Eskil, 2015; Kim et al., 2016; Luo et al., 2016). Efficient temperature monitoring and the effective management of temperature data is an important prerequisite for providing high quality and safe products and to avoid economic losses across the cold chain (Raab et al., 2011). Temperature data is often combined with time data and as such used to predict shelf-life. Hafliðason et al. (2012) constructed a wireless sensor network for cod supply chain to measure the ambient temperature and the temperature inside the packing. Based on an experiment, they concluded that simply measuring temperature and applying single criterion (e.g., when temperature falls below a threshold) may lead to "false alarm" and more sophisticated decision support or intelligent systems are required in order to fully utilise the value of the records. This is complicated by the fact that even within, for example, one container temperature profile is varying in different locations, different type of packaging used, and so (Mai, 2010; Manzini and Accorsi, 2013).

Food quality deteriorates as a consequence of bacterial growth, which is directly related to the increase in storage temperature. Unfortunately, the relationship between food quality and temperature is not simple because bacterial growth is a function of not only temperature but many other factors, such as humidity, light intensity for some products (especially liquid).

Besides temperature, light, humidity and other environmental conditions does matters. Hence, these data can indicate if the product has been treated under optimal conditions or if there is potential for damage or decrease of quality (Manzini et al. 2014, Abad et al. 2009). For capturing chemical data, different gas and bio-sensors can help identifying if certain microbiological growth has emerged. Manzini et al., 2014 mention capturing free acidity, sensory assessment, gross calorific value CO_2 equivalent which can be used to control the quality of the product. Aiello et al. (2015) indicated use of relative humidity, solar irradiation, atmosphere composition, at regular time interval.

Records of environmental conditions could also be provided to the customer to achieve sales premium (Pang et al. 2015). During transportation it is essential to capture some of the environmental characteristics where Pang et al. (2015) reports the results of a field trial in which sensors were used to track the conditions while transporting Brazilian honeydew melons to Sweden via Netherlands. Throughout the whole transportation chain, the sensor node measured conditions in the environment including oxygen, carbon dioxide, ethylene, temperature, humidity, and mechanical stress like vibrations, tilts and shocks. The measurements were transmitted through the GSM network upon request or saved in a local storage if the network is unavailable. The backend software system monitored the environmental and mechanical conditions (Pang et al., 2015).

A system which has not been implemented on a large scale in the meat supply chains so far are time-temperature indicators (TTIs). Members in the meat supply chain are not aware of the specific effect of non-isothermal temperature conditions on different products and the linkage between temperature data and product characteristics. This can lead to an under- or overestimation of remaining shelf life of the products, thus resulting in health risks and also wastage and economic losses (Raab et al., 2011).

3.1.2 Transactional data

Transactional data for supply chain or logistics management, such as inventory profile, sales volume, transported quantity, and so on, are always important parameters in traditional supply chain studies Similar data can also be captured in cold chain to facilitate better decision making. For example, Engelseth (2009) study traceability of Corona strawberries in Norway and finds that a paper label identifies the producer and the product which is visible to both those handling the strawberries and the consumer. Comparing the production location with transport records in the wholesaler's information system may help identify the actual transport route. If additional information regarding production modes is requested, the farmer must be contacted usually by phone. Blackburn and Scudder (2009) mention about collection of data related to picking rate, batch transfer time, time from picking to cooling shed i.e. initial cooling to transfer to retail to design a supply chain for watermelons. Bilgen and Celebi (2013) mention about capturing shelf life, percentage of maximum shelf life remaining, production cost, changeover cost, inventory cost, transportation cost while Rijpkema et al. (2014) mention about using inventory cost and cost of product that fail at distributor.

3.1.3 Data captured across cold chain and product types

Using previous studies this subsection summarizes the data that has been captured across the cold chain stages and the type of product. Table 2 indicates the data corresponding to cold chain process and the perishable products.

Table 2: Data captured in cold chains

Cold chain process	Fresh fruits and vegetables	Fish and marine products	Meat	Dairy products	Others or not specified
Harvesting or catching	Field temperature, picking rate, batch transfer time	Pallet temperature both ambient and product, time duration across multiple stages, accumulated temperature over period of time	None exist		
Procurement	Inventory cost, cost of product that fail at distributor	None exist		District boundary, road network, road shape, latitude, longitude, cow and buffalo population	None exist
Processing and manufacturing	Temperature, relative humidity, solar irradiation, atmosphere composition Co_2, O_2, ethylene at regular time interval	Pallet temperature both ambient and product, time duration across multiple stages, accumulated temperature over period of time	None exist	Shelf life, percentage of maximum shelf life, production cost, changeover cost, inventory cost, transportation cost	Increase in external temperature
Distribution	Time from initial cooling to transfer to retail, conditions in the environment including oxygen, carbon dioxide,	Pallet temperature both ambient and product, time duration across multiple stages, accumulated temperature over period of time	Time-temperature indicators, temperature at regular intervals	Temperature at regular intervals	Real time temperature, humidity and physical position, increase in

	ethylene, temperature, humidity, and mechanical stress like vibrations, tilts and shocks, place Country of origin, product number, product type designation, color, texture, information regarding product orders, deliveries from producers and customer orders				external temperature
Storage	time from packing to cooling	pallet temperature both ambient and product, time duration across multiple stages ,accumulated temperature over period of time	None exist	None exist	Environmental conditions, real time temperature, humidity and physical position, temperature, increase in external temperature
Retail	Time-temperature data	None exist			increase in external temperature

The literature reviewed identified cases of data capturing for each stage of the cold chain for the fresh fruits and vegetables, mostly environment related data (temperature, humidity, vibrations.), and some transactional data (inventory cost, place of origin, time.). Data related to fish and marine products was scarcer, covering only temperature and time data. Research addressing specifically data in the meat cold chain has been most infrequent, while diary data has been mostly related to transactional (different costs, road network.) and temperature data. Regarding the stage in the cold chain, most of the research addressed the distribution, followed by processing and manufacturing, and storage, and least addressed were harvesting/catching, procurement and retail phases.

Thus, the literature mentions multiple types of environmental data as well as some transaction data capture for fresh fruits and vegetables, but predominantly temperature data for fish, marine products and meat products. Both temperature and transaction data have also been captured for dairy products. Thus, there may be opportunities to explore capturing of other relevant environmental and transaction data for fish, marine products and meat products.

3.2 Technology Infrastructure for Capturing Data

There are a number of studies concerning cold chain using intelligent or advanced information technologies to collect data. One typical example is RFID technique (e.g. Shi et al., 2010; Hafliðason et al., 2012; Manzini and Accorsi, 2013). This section will discuss the current state-of-the-art regarding the infrastructure to collect data. A technology solution can be represented in a way in which it covers one or more of the following three layers: *connectivity*, *middleware* and *application*. Connectivity refers to the devices and protocols for collecting the data and can be based on passive devices (RFID), battery-powered devices (WSN or active RFIDs) or a combination thereof. Middleware refers to solution for collecting the data offered by the connectivity solution and storing or processing data to represent it in a form that is suitable for the application. The application layer refers to the services and interfaces that offer insights into the collected data and facilitate decisions. In the following, we structure the reviewed papers according to their dominant focus.

Connectivity and middleware. Technologies like RFID Device along with sensors have been suggested to improve traceability (Kelepouris et al., 2007; Parreño-Marchante et al., 2014) and enable risk management in cold chains (Kim et al., 2016). By applying RFID tags on the cases or pallets of each lot, all chain partners can use the Electronic Product Code (EPC) for identification without any data inconsistency and need of data synchronization. RFID can also help link supply chain partners, thus significantly facilitating forward traceability. One barrier for implementing traceability across the cold chain is that each partner in the supply chain needs to implement traceability internally and then share information with the rest of supply chain partners for forward traceability to be enabled. Abad et al. (2009) validate a RFID smart tag attached to a fish product integrating light, temperature and humidity sensors. Key aspect of the proposed RFID system is that the data can be read-out at any time of the logistic chain without opening the boxes containing the fish and the tags. Hafliðason et al. (2012) demonstrate application of wireless sensor network (WSN) made for stationary and mobile monitoring considering both temperature abuse and the severity of the abuse to develop temperature alerts in cod liver supply chains. Besides WSN, they have also used data loggers as temperature sensors. In general, WSN have been used in agri-food sector for: environmental monitoring, precision agriculture, cold chain control and traceability (Prasad, 2015). Pang et al. (2015) propose a procedure to derive sensor portfolios related to shelf-life prediction, precision agriculture, and sales premium (providing consumers with records of handling and environmental conditions). Type of sensor used will depend on the requirement and compatibility. Electrical temperature sensors can be thermistors, thermocouple or resistance thermometers. The choice of device is made based on the technical requirements of the system (Sharma and Pai, 2015). Virtanen et al. (2014) develop passive wireless temperature tag based on ultra-high frequency (UHF) RFID technology and a dual port sensing concept. Their solution should increase the accuracy of the sensor readout in environments with interference, reduce the user-created errors and the measurement time, and requires reader units with less strict hardware capabilities. Mohebi and Marqez (2015), based on literature, review and propose indicators and sensors for meat spoilage and evaluate them according to economic aspects and usability in packaging. One of the technologies, so called electronic nose, consists of sensor, signal processing and pattern recognition subsystems. The different sensors reviewed were: chemical, optoelectronic, colorimetric, enzyme and oxygen sensors. They also identified different indicators such as: time-temperature, gas and freshness indicators. Ruiz-Garcia and Lunadei (2011) established a framework linking different factors such as huge amount of data, harsh environments, reading range, fault detection and isolation, physical limitations, standards, level of granularity, cost, lack of skilled personnel, information sharing, integration with chemical sensors and recycling issues which limit the use of RFID in traceability of cold food products. Thus, the above factors need to be considered before choosing the right technological solution for traceability.

Application. A conceptual framework for tracking information from data is achieved by integrating Internet of Things (IoTs) with tracking technology in a cold chain environment (Luo et al., 2016). Li et al. (2012) propose and discuss the architecture of a cloud platform for cold chain logistics. Cloud computing could on one hand meet the changing requirements of enterprises and on the other hand decrease IT investment. This is also of interest for small/medium cold chain logistic companies to achieve high-quality IT service with minimal investment (Jede and Teuteberg, 2015). Cloud computing brings better cooperation between cold chain logistics and customers, realizes co-control of product sales information, accelerates the speed of cold chain logistics and maximizes the interests of all parties (Li et al., 2012). Bell et al. (2015) proposed infrastructure framework for investment in Fish Aggregating Devices (FAD) during processing stage for capturing fisheries in improving food security of Pacific Island Countries and Territories (PICT).

All three layers. Kelepouris et al. (2007) suggest an architecture that simplifies many of the tasks required by the supply chain partners, thus resulting in significant cost reduction and elimination of major barriers. The system follows a hybrid approach consisting of distributed elements and a centralized information system which can either hold all needed traceability information or only information regarding traceable unit linkage. All partners of the chain can access information in the central information system using a simple personal computer and a web browser (Kelepouris et al. 2007). Pang et al. (2015) design and pilot-test a value-centric business-technology joint design framework. As part of the framework they propose a three-tier information fusion architecture that could be used for shelf-life prediction and real-time supply chain re-planning. Parreño-Marchante et al. (2014) develop a traceability system architecture based on web services by integrating traceability data captured through RFID systems with environmental data collected with WSN infrastructure and pilot it in two aquaculture supply chains. Their proposed system consists of four components: (i) RFID readers, sensors and data input devices, (ii) set of capture and query applications that act as a connector to the traceability repository of the physical data received from the hardware devices, (iii) traceability repository used to store the relevant traceability data generated during the company operations and (iv) set of web services which provide the product information to the customer through a web browser or a mobile application. The above system demonstrates that several technologies can be integrated and different industry standards can be used to improve traceability in fish farm industries. Luo et al. (2016) propose an intelligent tracking system consisting of sensing layer, network layer, and application layer. The sensing layer collects real-time data about temperature and humidity status and physical position of goods in cold storages and during refrigerated transport. When data are transmitted to remote monitoring centres via mobile telecommunication networks, servers located in remote monitoring centres process it first and display the real-time status of goods on liquid crystal displays (LCDs). Personnel in remote monitoring centres can easily track the status of goods on LCDs and if the status of goods is not as per requirements, alerts can be generated by applications installed in servers so that remote monitoring centres can notify on-site personnel to take actions immediately (Luo et al., 2016). Aiello et al. (2015) realized expected value of traceability information through optimal configuration of traceability system in accordance with optimal granularity level i.e. estimating economic traceability lot using stochastic programming.

Table 3 summarizes the IT infrastructure across the product sector as well as the cold chain stage. One observation is that most of the articles cover several stages of the cold chain, implying that the main focus is on technologies that can support the entire cold chain. Those articles that focus on particular segment of the cold chain mainly focus on distribution and storage. There were no articles focusing solely on IT application in the earlier stages of the cold chain, which may also imply lack of data from the earlier stages i.e post-harvesting and processing, thereby adding to the challenges of traceability. The main developments in technology infrastructure have been reported for the fish and marine products industry. But, a large number of articles do not specify a sector, implying that the developed solutions are quite generic and can be applied across sectors and for different processes. Future research needs to focus on identifying and adopting the appropriate technologies in specific contexts and across the chain. Especially there is a lack of research in dairy sector.

Table 3: IT infrastructure for capturing cold chain data

<table>
<tr><th>Cold chain process</th><th>Fresh fruits and vegetables</th><th>Fish and marine products</th><th>Meat</th><th>Dairy products</th><th>Others or not specified</th></tr>
<tr><td>Distribution</td><td colspan="2">None exist</td><td>RFID and sensors, GPS, wireless communication technology</td><td>None exist</td><td>RFID tags with sensors, logistical systems (ERP, WMS, MES); RFID and data loggers; wireless sensor network built on Zigbee, IoT</td></tr>
<tr><td>Storage</td><td colspan="4">None exist</td><td>RFID tags with temperature sensors; wireless sensor network built on Zigbee, IoT</td></tr>
<tr><td>Not specified</td><td colspan="4">None exist</td><td>ZigBee-based WSN and semi-passive and active radio frequency identification</td></tr>
<tr><td>Several stages/SC perspective</td><td>RFID, WSN; EDI for purchase and for distribution (to be replaced by ERP), fax, internet, sms</td><td>temperature sensors (data loggers and wireless sensor network monitoring system made for stationary and mobile monitoring); RFID hardware and middleware, WSN infrastructure, web services; RFID based system (smart tag and a commercial reader/writer), light, temperature, humidity sensors; RFID and TTIs</td><td>TTI, freshness indicators, oxygen indicators, fluorescence-base (oxygen), RFID tags; different temperature monitoring systems</td><td>Geographic Information System (GIS)</td><td>RFID based system architecture, web browser; RFID tag, ERP</td></tr>
</table>

3.3 Data Analytics and Decision-making

Out of 17 papers discussing the use of data, 2 do not refer to any specific food sector, 2 refer to diary, 7 refer to fresh fruits and vegetables, 1 corresponds to fish, and 2 are related to meat sector respectively, while 3 papers addresses jointly several products. Regarding cold chain stage, 3 articles do not specify it, while most of the remaining refers to several stages (2 articles refer to harvesting, and food processing respectively, while 5 refer to distribution and transportation, and to storage respectively). Raab et al. (2011) emphasised capturing temperature monitoring in meat supply chains and identify the applications that vary according to the parameters, which are to be measured, such as the control of environmental, surface or core temperature of the products. They also observe that some applications support the temperature control at a company level (entrance control, process control, final inspection) while other solutions focus on control of the temperature across the entire supply chain from production to the retailer or end consumer. However, the actual implementation in practice is lagging because of different intra- and inter-organizational challenges which Raab et al (2011) pointed out. We also find empirical evidence that explains the utilization of temperature tracking methods in the detection of decomposition processes, their origin and fluctuations (Ringsberg, 2014). The studies that discussed the importance of decision-making are further summarized according to various stages of cold chain.

Harvesting

There are existing systems that trace grapes reception, mixtures, laboratory analyses, during the harvest season. However, the data are mainly used by the finance and accounting departments and not much by oenologists as they are distant from their workflow, mainly based on conventional methods of data recording such as blackboards, pencil and paper (Moccia, 2013). To aid decision-making of oenologists, Moccia (2013) proposed a decision support system prototype that are helpful to deal with grape harvesting. Using field temperature, picking rate and batch transfer time, Blackburn and Scudder (2009) determined optimal transfer batch size from field to cooling shed to maximize value of the product.

Optimizing procurement

Implementation of IT tools like geographical information system (GIS) will be a strategic decision for a growing dairy firm which is looking to optimize procurement expenditure, identifying new procurement areas and also for diversifying the business in terms of providing input services, rural marketing of milk and milk products (Kumar et al,2012). There are few attempts in the past to use GIS and IT tools to assess the milk procurement potential of bulk milk chilling units from different villages and help in taking business decisions like tapping new villages as procurement centers. Milk procurement in different bulk milk chilling units follows a specific seasonality pattern. Maintaining the balanced supply of raw milk to processing plant will be a challenge for private dairy firms (Kumar et al., 2012). What if analysis have been used by Rijpkema et al., (2014) to understand the trade-off between transportation costs, shortage costs, inventory costs, product waste, and expected shelf life losses and to determine the sourcing strategy for perishable food products. Interestingly we didn't find any study that uses real time data or subjective/qualitative data to optimize or prioritize procurement decision.

Maximizing quality and value across the cold chain

Collection of temperature data along the cold chain from farm to the store will help in estimating the rate of decay of the product using suitable decay functions as suggested by Blackburn and Scudder (2009) and Nakandala et al. (2016). Analyzing such data over longer periods will help in estimating the cost of product devalue due to temperature variations along the cold chain. Such estimation will be needed to create the business case for not only temperature monitoring but also point out the value of improved decision-making using the data. For example, the analysis of temperature data and estimation of product devaluation can help in redesigning the cold chain network by separating the responsive and efficient part of the cold chain which will help in ensuring product quality at the minimum cost (Blackburn and Scudder, 2009), to take specific actions to reduce human interference and mishandling (Pang et al., 2015).

Recent research in cold chains have focused on developing decision models for predicting food quality and remaining shelf life based on microbiological growth, which in turn depends on temperature conditions. Time-Temperature-Indicators (TTI) have been considered as useful decision-support tools for optimizing inventory and improve consumers' acceptability by reducing losses (Aiello et al. 2012). The accuracy and the size of available data and further refinements of the proposed management system could potentially improve substantially the quality of the final products (Giannakourou and Taoukis, 2003). More specifically, Askin et al. (2010) develop decision models that use RFID environment conditions data and consider remaining shelf life for determining dynamic assignment of perishable items in warehouses to maximize the total value of the items. Simulation for evaluating market power of products delivered based on expected consumed/remaining shelf life and fraction of products above or below acceptance thresholds resulted in identifying performance characteristics for perishable products (Aiello et al., 2015). Wang et al. (2010) developed a decision support system to forecast the parameters that reduce losses.

At the *manufacturer/processor stage* there is a possibility to implement ERP systems that are based upon electronic record movement mirroring business processes and tracking manufacturing operations, finished products, quality control, regulatory compliance, food safety, supplier management, financials and regulatory management. More specifically, by automatically tracking product ingredients, a system can create regulations compliant labels, saving time and money while reducing errors. Key benefit is to be gained through implementation of manufacturing execution systems (MES) to increase the ability to identify quality failures, and isolate them when they occur prior to being passed onto the public (Gessner et al., 2007).

In *transportation*, since proof-of-delivery paperwork is required to complete the transfer, each time the transportation mode changes, RFID-tagging can help automate this process and assist in meeting regulatory requirements. Specific to food, RFID-tagging can assist in reducing food losses due to spoilage by tracking and monitoring the temperature and conditions inside the vehicles to watch for heavy shaking and temperature changes (Gessner et al., 2007). For livestock tracking through RFID tag, an electronic record can track the specific animal to the specific piece of meat, its defect information, grading data, hotscale weight and finished weight as it continues to move through the supply chain (Gessner et al., 2007).

Optimizing production, distribution, logistics and storage planning

Bilgen and Celebi (2013) developed optimal production scheduling considering minimal residual shelf life requirements to maximize benefits from higher shelf life. Mocchia et al. (2013) developed decision-making tool for press and value added tax (VAT) assignments to avoid bottlenecks, and inventory control and allocation of unlabeled wine. To minimize overall cost of cold chain network, Shi et al. (2010) developed a multistage planning model to optimize distribution plans using a real-time monitoring solution for cold chain distribution by integrating radio frequency identification (RFID), sensor, and wireless communication technologies. Real-time monitoring enhanced visibility of product flow and quality information and minimized the overall cost. Frequent update of product quality information during distribution allows the distribution decision to be adjusted at sequential stages to optimally preserve the product value and meet demand. The continuous monitoring of temperature and product devaluation can also help in deciding the optimal route, the speed of the transportation and optimal temperature to be maintained to ensure high product quality at the lowest cost (Nakandala et al., 2016).

Lütjen et al. (2013) recommended quality driven customer order decoupling point, which ensures a quality-driven distribution of perishable goods. Thus, in cases of changes in the product quality, a new allocation of goods to customer orders can take place. The rapid calculation of the remaining shelf life and risk assessment based on the temperature history allows the optimization of storage management from the FIFO concept (First In – First Out) to the LSFO concept (Least Shelf – Life First Out) (Koutsoumanis and Taoukis, 2005). At the distributor/retailer phase of the cold chain there are significant benefits of utilizing RFID by reducing handling at the receiving end and by reducing storage expenses. The tagging is still limited to cases and pallets through to the final consumer due to privacy issues. Most companies are not taking full advantage of RFID-tagging and associated information capabilities, as they are employing a "slap-and-ship' tag application method at the end of the distribution line (Gessner et al., 2007).

Risk Management

Using pallet temperature both ambient and product, time duration across multiple stages, accumulated temperature over period of time, Hafliðason (2012) developed criteria for developing alerts. Collecting temperature data along the cold chain can also be used for identification of sensitive spots where variations occurred, setting up alarms and reporting date and time (Pang et al., 2015). Kim et al. (2016) suggest an intelligent risk management framework which can accommodate various types of risk situations by introducing the notion of context-aware real-time risk management using RFID tags and sensors by defining rules for risk management functions, context identification, risk detection, and response action judgment in semantic ontologies. Thus, the proposed approach could help in real time monitoring of risks and enhance ability to respond to those risks. Tracking vegetables (for example by RFID) *at the farm* to loading on truck and through the processor can assist in food recalls and product quality efforts by identifying the precise location in the field (Gessner et al., 2007). Gessner et al. (2007) explained the potential of electronic record creation and movement through the food supply chain with an emphasis on RFID and ERP systems.

Thus, the review shows that the advantages from use of real-time tracking and tracing have been:

- Reduction of costs for logistic operations, receiving and handling expenses
- Minimization of product value loss and maximization of total value of items
- Supporting decision-making related to optimal production, distribution planning and storage
- Reduction of costs for logistic operations, receiving and handling expenses
- Identification and isolation of quality failures, identification of risks and taking real time actions to mitigate such risks.

Table 4 provides a summary on the usage of data for decision-making in cold chain. It showed that previous studies have primarily focused on distribution and transportation and to certain extent in processing and storage. But, surprisingly our review did not reveal any studies which addressed data driven decision-making based on the condition of the products or packaging in the retail stores. Moreover, the majority of the applications of data-driven decision-making corresponds to fresh fruits and vegetables, followed by dairy products, and to a limited extent few studies discussed fish and marine, and meat products.

Table 4: Usage of data for decision-making in cold chains

Cold chain process	Fresh fruits and vegetables	Fish and marine products	Meat	Dairy products	Others or not Specified
Harvesting or catching	Optimal transfer batch size from field to cooling shed to maximize value of the product	None exist			
Procurement	Procurement optimization (determine sourcing strategy considering multiple trade-offs)	None exist		Assessing milk procurement potential	None exist
Processing and manufacturing	None exist			Optimal production scheduling to maximize benefits from higher shelf life, improve ability to identify quality failures	Risk management (improve ability to identify quality failures), optimal press or vat assignments to avoid bottlenecks
Distribution	Risk management (sms alarms and reporting, identification of sensitive spots, identifying areas to	Risk management (establish alerts in	Optimal arrangement of product flow in cold	improve ability to identify quality failures	Optimizing distribution planning (dynamic

	minimize human interferance and handling, context identification, risk detection and response) Optimizing distribution planning to minimize product quality loss (optimal shipping quantity from cooling shed to retail, quality driven distribution, minimizing cost while maintaining quality)	decision support systems)	chain network		assignment of the products to locations)
Storage	Maximizing quality and value (Improving acceptable quality and minimization of rejection using Least Shelf Life, First Out distribution and stock rotation)	None exist			Assess impact of external temperature increase on quality
Retail	Quality information to choose market i.e. either primary or secondary market	None exist			

3.4 Use of research methods

Our review shows that most of the research methods such as mathematical modelling, experiments, review and case study are used with respect to fruits and vegetables, as well as dairy products, by previous studies. For meat products literature review is a dominating method, while for fish products experiments have mainly been used. Overall usage of research methods with respect to cold chain stages and product is summarized in Table 5. This shows that there are possibilities to use several other methods for fish and meat, and for dairy products especially in the harvesting, procurement and retail stages of the cold chain.

Table 5: Research methods used in cold chain research

Cold chain process	Fresh fruits and vegetables	Fish and marine products	Meat	Dairy products	Others or not available
Harvesting or catching	Mathematical modeling Experiments Review Case study	Experiments	Review	Review	Review
Procurement	Mathematical modeling Case study	None exist		Case study	None exist
Processing and manufacturing	Review Mathematical modeling	Experiments	Review	Mathematical modeling Review	Review Conceptual
Distribution	Mathematical modeling Experiments Review	Experiments Mathematical modeling	Review Mathematical modeling	Review Mathematical modeling Experiments	Review Mathematical modeling Conceptual

	Case study				
Storage	Mathematical modeling Experiments Review Case study	None exist	Review	Review Conceptual Case study	Review Mathematical modeling Conceptual
Retail	Review Mathematical modeling Simulation Case study	None exist	Review	Review	Review Conceptual
Others or not available	None exist	Case study Empirical	Review	None exist	Review

4. Discussions and Conclusions

Most of the papers reviewed are related to fresh fruits and vegetables and focused on the distribution stage. Overall data capture and decision-making in distribution process within cold chain have been well studied by researchers using multiple methods for different types of products. Interestingly few studies have been used to understand the data capture and analysis for the procurement and retail stages. This conveys that there is scope for future research to understand data capture and use it for decision making not just for distribution but across the cold chain from post-harvest to processing, distribution and retail. Irrespective of stages of the cold chain, there are few studies, which discuss the potential of data capture and decision-making for fish and marine, and meat products. Thus, overall we can conclude that there is limited literature on how data captured can be effectively used for decision-making in cold chains and particularly for fish and marine and meat products.

From the point of view of methodology, literature review is quite popular for analyzing challenges related to processing and manufacturing stage for all types of products. There are very few studies, which used mathematical models or case studies to illustrate the data capture and subsequent analysis for decision-making. In contrast, mathematical modeling has been used by researchers to identify decisions for fresh fruits, vegetables and dairy products. For storage of fresh fruits and vegetables, a wide variety of methods ranging from mathematical modelling, simulation, case studies and review have been used. Fresh fruits and vegetables have received due attention from researchers in using multiple methods and there is a potential for data driven decision making in cold chains for other types of products like fish and meat.

Our review shows that the data that are useful for cold chains are not only the more traditional environmental conditions such as temperature, but also other environmental conditions such as humidity, vibrations as well as specific transactional and process related data such as picking rate, transfer time from field to cooling unit, transportation costs. The review also indicates that the adoption of electronic traceability systems in order to improve the food supply chain has not been as fast as expected (Parreño-Marchante et al., 2014). Development of systems for monitoring temperature and ensuring traceability across the supply chain will be needed before data captured through such systems can be monitored and analysed on a real time basis for improved decision-making in the cold chain. There is a need to identify appropriate technology solutions for connectivity, middleware and applications, which can be used across specific cold chains for example in the dairy sector, which has limited research on technology infrastructure needed for data capture across the cold chain. Suitable technological solutions also need to be implemented to capture data from earlier stages of the cold chain i.e. post-harvesting and processing to ensure traceability. It is also an imperative to understand how continuous monitoring of temperature and other environmental conditions can be translated to real-time assessment of quality of products, determination of actual remaining shelf -life for fish, meat and dairy products and use of those for decision making in cold chains such as rerouting of products. Analysis of such data over longer periods can also unearth patterns of product deterioration under different transportation conditions, which can lead to redesigning the transportation network to minimize quality loss or take precautions to avoid the adverse transportation conditions. Moreover, there is limited discussion of how such analytics capability may impact overall cold chain performance in terms of responsiveness, cost efficiency, environment footprint, flexibility. There are opportunities to identify all relevant parameters to capture product condition as well as transaction data across the cold chain processes for fish, meat and dairy products and use those for optimising procurement planning, processing and production planning, transportation and storage planning and also pricing of those products in the retail stores based on product conditions and traceability information. Addressing some of the above research gaps will call for multi-disciplinary research involving food science and engineering, information technologies and computer science and logistics and supply chain management scholars.

This paper is one of the earliest to recognize the need for a comprehensive analysis for adoption and application of data analytics in cold chain management and to provide directions for future research. This research is based on a content analysis based systematic literature review. A thorough understanding of the challenges faced by players in cold chain both regarding decision-making and adoption of technology will be needed to improve adoption of data driven decision-making in cold chains. The findings of this research can be beneficial for multiple players involved in the cold chain like food processing companies, logistics service providers, ports and wholesalers and retailers to understand how data can be effectively used for better decision-making in cold chain and to invest in the specific technologies which will suit the purpose. To ensure adoption of data analytics across the cold chain, it is also important to identify the player in the cold chain which will drive and coordinate the effort. Future research should also focus on identifying that player in the cold chain and possibly explore contracting mechanisms to ensure compliance across the cold chain.

Sharma and Pai (2015) suggest using temperature monitoring systems, traceability, infrastructure, electronics and information technology, standardization, ability of handlers, quality of communication, transaction costs and government policies to measure the effectiveness of cold chain. There are opportunities to thoroughly assess the impact of data analytics on the cold chain performance measures. Future research should both empirically validate those as well as demonstrate the true benefits using modelling or simulations of specific cold chains.

Recent developments in blockchain technology, which is a distributed ledger system where multiple copies of the same database, stored across computers online can communicate with each other, allows new entries to a database to be shared with all stakeholders with real-time cross-checking. This ensures the integrity of existing entries and thus, food products can be digitally tracked from suppliers to store shelves, and ultimately to consumers, with suppliers uploading farm origination details, batch numbers, factory and processing data, expiration dates, storage temperatures and shipping details (Craik, 2017). It is already pilot tested by Walmart for pork supply chain in China (Craik, 2017). None of the papers in our review assessed the impact of blockchain technology on cold chain performance. There will be opportunities in future to analyse the implications of blockchain technology for ensuring quality, safety and traceability in cold chains.

Finally, the information about the efficiency, quality, traceability, environmental sustainability of manufacturing, consolidation and distribution processes should play a crucial role in influencing the purchasing habits and prices of perishable food products (Wang and Li, 2012;

Manzini et al., 2014). Future research may also be directed to estimate the value of data analytics in cold chains on consumer perceptions and buying behavior if such information and particularly traceability is shared with consumers.

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