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RFID Technologies for Cold Chain Applications

4th Informatory Note on Refrigeration and Food

Introduction

Much has been written about the need for temperature monitoring of the cold chain for environmentally sensitive goods.[1-4] The emphasis on this issue stems from the critical role that temperature has on the social, economic and environmental performance of food supply chains:

- in a social context, food safety is an important driver of quality assurance systems in chilled and frozen goods. Temperature is second on the list of factors causing foodborne illness, surpassed only by the initial microflora present in foods.[1,5] Additionally, vaccines, temperature-sensitive pharmaceuticals and other health products also require temperature-controlled logistics;
- in an economic context, the profitability of fresh supply chains is highly reliant on the reduction of product shrinkage. The IIR figures indicate that about 300 million tonnes of produce are wasted annually through deficient refrigeration worldwide.[6] The wastage problem is not particular to developing nations; for example, in the US, the food industry annually discards USD 35 billion worth of spoiled goods;[7]
- in an environmental context, both food wastage and the wastage of resources used to grow the unused products need to be highlighted.

Radio Frequency Identification (RFID) technologies are said to improve the performance of perishable supply chains through the following uses:

a) as a means to track the geographical position of individual packages, pallets, shipping containers, or trucks, which can be stationary or in movement during distribution;

b) as a means to identify items through a unique electronic product code (EPC) or other barcode alternatives;

c) as a means to store real-time environmental data (including temperature) and transmit this information in near real-time, allowing corrective actions to be taken before products are irrevocably damaged.

Although there is a scarcity of published studies that report the specific benefits of RFID on perishable supply chains, case studies in the retail industry[8] suggest potential benefits at a retail level, such as an increase in sales, shrinkage reduction, labour cost reduction and improved transparency in the supply chain.

These potential benefits have attracted industry interest. However, between 2004 and 2006, optimism turned to scepticism about the technology and its benefits.[9] A significant proportion of RFID deployments remain exploratory: companies are not taking for granted the potential benefits described by RFID vendors and are assessing the results in their own chains with pilot projects. Often, companies undertake RFID pilot trials to fulfil retailers' requests and to comply with food safety regulations, but fail to demonstrate a return on investment that justifies the use of the technology.

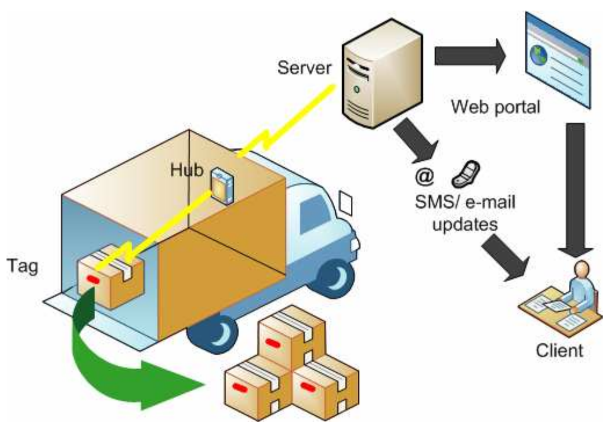

Figure 1. Conceptualization of an RFID system for monitoring cargo and air temperatures in a refrigerated transport system

This informatory note aims to explain the principles, advantages and disadvantages of RFID-based monitoring technologies for the cold chain of perishables.

Principles of RFID technologies for cold chain applications

An RFID system for cold chain purposes generally encompasses a sensor, a tag and a reader, that communicate with each other by means of radio transmission. RFID tags can store an EPC for logistics management purposes, and, if equipped with the appropriate sensor and battery power, a limited number of temperature readings. RFID tags can be separated into the following categories[10]:

1. **Passive RFID tags.** These tags rely on the power supplied by the reader. When radio waves from the reader are encountered by a passive RFID tag, the coiled antenna within the tag forms a magnetic field. The tag draws power from it, energizing the circuits in the tag. The tag then sends the information encoded in the tag's memory. The lack of an integrated power supply means that passive tags can be very small. Therefore, passive tags can be embedded in stickers and other similarly flat presentations.

2. **Active RFID systems are battery-powered.** The reliability of active tags is typically higher than passive tags due to the ability for active tags to conduct a "session" with a reader. Active tags also transmit at higher power levels than passive tags, allowing them to be more effective in environments commonly found during food distribution. Examples of these situations could be the transmission of information in crowded enclosures (e.g. humans, cattle); data transmission from tags attached to boxes, which may be placed in the middle of a tightly packed container of fruit, meat or other products with high moisture contents; transmission through metallic walls (e.g. shipping containers, trucks), or transmission from long distances (e.g. containers in transit).

3. **Semi-passive tags.** These systems are also battery-powered. However, they use the passive RFID interface, thus allowing wireless access to the device without using the internal power source. The battery size is therefore smaller than in the active tags.

The preferred RFID embodiments for environmental monitoring of food supply chains are semi-passive or active tags coupled with sensors. Tags can collect a wide range of information,[11] such as temperature, humidity, shock/vibration, light, radiation, and concentration of gases (e.g. ethylene). The information collected by the tags is "harvested" by a gateway or hub, which then transmits the data to a server, though the use of digital mobile telephony (GSM) or local area networks, which can be wireless (WLAN) or with wired Ethernet connection (LAN). Data collected in the server can then be stored and analysed, allowing the automatic generation of notifications and events. A Webportal may display historic temperature data, frequency data and may trigger alerts for the users, transmitted via SMS messages or e-mails. Given that the information is in real-time, or near real-time, sudden situations that endanger the integrity of the goods can be addressed promptly, as opposed to traditional monitoring techniques that only allow analysis of past temperatures and events.

Figure 2. An RFID tag. Courtesy of Mark Lohmann, CHILL-ON project

Limitations of cold chain monitoring systems based on RFID

A number of concerns have been raised in regards to the use of RFID technologies. Some of these are general issues related to all RFID applications (e.g. security and privacy concerns, legislative concerns, intellectual property right issues and health risks linked to RFID frequencies). We emphasize in the following paragraphs specific issues detected in cold chain applications:

- **Reliability.** For example, readers failing to register tagged pallets or that boxes still exist, due to the harsh conditions in which tags have to operate (e.g. exposure to direct forklift impacts, excessive vibration, high humidity environments, multiple tag orientations and distances with respect to readers).

- **Lack of uniformity in global standards.** Numerous standards and regulations on frequencies and radio spectrum have been adopted in different countries, which in turn have inhibited development of a global standard for RFID. The two main global organizations undertaking work on RFID standards are EPCglobal and the International Organization for Standardization, and efforts to unify the standards of both organizations are well underway.[12]

- **Difficulty of establishing a return on investment (ROI).** The "cost" of this technology has been cited frequently as a reason for the slow uptake.[13] However, in the case of cold chain applications, the actual information may be much more valuable than the cost of the tags. Rather than cost alone, the failure to accurately undertake a calculation of ROI, including tangible and intangible benefits has been highlighted as a significant factor for the slow growth of RFID-based cold chain monitoring.[14] Efforts carried out to investigate the economic impact of monitoring temperature during the distribution of perishables and the associated quality loss have been published.[15-16] However, the impact of depreciation, insurance premiums, labour added or taken out of the chain due to RFID monitoring, costs of pilot trials and the distribution of RFID advantages to supply chain players has not been fully integrated in published case studies.

- **Troubleshooting and data-driven decision-making tools.** Active-RFID monitoring can potentially generate large amounts of temperature data, and its interpretation can be overwhelming. Therefore, the full potential value of RFID is limited by the structures and processes that companies have in place to take advantage of that potential.[17] In current RFID applications, the tools to interpret real-time temperature information and provide practical steps to correct temperature deviations or to plan the next stages for product distribution are underdeveloped.

- **Accuracy.** For most cold chain applications, a sensor accuracy of ±0.5 °C or better is expected. However, mass production of RFID tags requires a calibration method that is simple and inexpensive, yet reliable enough to ensure the desired accuracy in all active tags manufactured. Calibration procedures may be different between manufacturers and models.

- **Placement of RFID sensors and representation of spatial variation of cargo temperatures.** A company may decide to instrument only a percentage of the total number of boxes moved through the supply chain with temperature monitoring RFID sensors. In this case, care must be taken in placing these sensors in enough numbers and in locations that are representative of the entire load. The thermal behaviour of transport and storage systems varies significantly depending on the type of product, stowage practices, packaging and many other factors. Therefore, some experimental trials or the use of models will be necessary to select adequate locations for the RFID sensors.

- **Lack of collaboration in the supply chain.** Inevitably, the use of RFID sensors will disclose information that, although beneficial, can challenge beliefs and operations of growers, manufacturers, logistics providers or retailers involved in the supply chain monitored. Therefore, an RFID strategy needs to account for the reaction of supply chain partners to the information collected. These reactions will be driven by group and individual interests, personalities and the level of cooperation in the chain. Obtaining the required level of trust and cooperation across the supply chain is probably one of the greatest challenges for the successful adoption of RFID technologies.

- **Consumer adoption of RFID.** This topic involves a large number of issues, including concerns about the disclosure of private information (such as shopping habits) and health concerns. However, another obstacle is the lack of apparent benefit for consumers from RFID monitoring. After all, many consumers take food safety and quality for granted and consumers trust that their favourite products and brands will be available every time they go to the supermarket. Therefore, the supply chain benefits of RFID may need to be more evident for consumers. One option is the RFID-enabled domestic refrigerator. Several prototypes of RFID-enabled refrigerators have been developed by appliance manufacturers with functions such as sending a shopping list to the owner's cellphone or directly to the supermarket. So far, the uptake of these refrigerators has failed to motivate manufacturers to scale up production.

Applications and benefits of RFID-based cold chain monitoring

There is no shortage of published examples of RFID applications in the food and pharmaceutical industries. However, it is difficult to discern from the information publicly available which trials have evolved from pilot studies into full commercial implementations. Furthermore, updated information about the outcomes of past commercial pilot trials is sensitive and mostly unavailable to the general public.

Many examples of commercial pilot trials of RFID for cold chain monitoring are available.[18] For example:

- **Delivery and logistics:**

Companies such as Envirotainer and DHL use RFID to track shipments of temperature sensitive goods. Through the uptake of RFID, these companies aim to increase their competitive advantage and to improve their customers' confidence in their quality assurance systems.

- **Distribution and retail:**

Case studies in the retail industry suggest the following potential savings:[8]

  - an increase in sales of 1-2% due to reduced out-of-stock;
  - shrinkage reduction of 10%;
  - labour cost reductions of 20% in warehouses;
  - 20-30% reduction in inventory due to lower safety stock;
  - improved return on investment;
  - transformation to a demand-driven enterprise;
  - improvement of visibility and transparency in the supply chain.

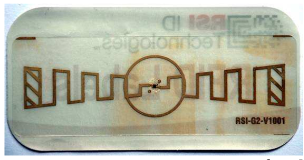

Figure 3. An RFID tag. Courtesy of Behnam Jamali, The University of Adelaide

Ballantine tracks fresh fruit shipments from packing house to retail display cabinets in order to possess a competitive advantage. Unilever tracks ice cream temperatures from manufacture to retail display cabinets in order to ensure quality assurance throughout the cold chain. Manor monitors supermarket freezers and refrigerators. In these cases, the aim of RFID tracking is to decrease shrinkage due to food spoilage and to have a faster response to equipment failures. Wal-Mart stores, and more recently Carrefour and Metro have adopted (and asked suppliers to adopt) digital-tagging technologies, including RFID. Nevertheless, at this stage Wal-Mart has not required temperature tracking of perishable goods. The third largest retailer in the US, Kroger Co. (Kroger supermarket chain), has trialled RFID temperature monitoring with their suppliers. However, the business case for RFID remains to be proven, as stated by a Kroger spokesperson[19]: "We continue to execute internal pilots with our supplier partners where we see the potential for compelling business process and operating improvements".

Looking into the future of RFID for cold chain applications

New developments include:

(a) The combination of RFID technology and time-temperature indicators (TTI). This opens up the possibility of tracking the shelf life of chilled and frozen products remotely. In Europe, a prototype of an electronic component that allows the connection of chemically based TTI to RFID transponders has been designed. This development is part of an umbrella project ("CHILL-ON"), funded by the European Commission. A consortium of 27 companies is backing the project.[20]

(b) Wireless technologies that allow gathering of data and exchange of real-time information with supply chain partners. An example is the wireless 'mesh' network technology.[21]

(c) Multi-sensing RFID nanosensors. The development of the smart sensor is being funded through the EU's GoodFood programme and involves researchers and industry in Italy, Spain, and Germany. The sensor will incorporate ultra-low-power gas sensors along with a thin film battery, allowing data acquisition and storage when no reader is present. This design allows the user to access both the traceability and sensor information even when the on-board battery is exhausted.[22]

(d) Temperature sensors integrated to RFID tags require continuous power, which is usually supplied by the battery on the tag. The extra power required not only significantly increases the cost of the hardware and makes it heavy and bulky, but also limits a tag's lifetime. Researchers at the Auto-ID Lab (St Gallen, Switzerland) have proposed an ambient energy scavenging system as a method to power sensors on battery-free RFID tags for continuous temperature monitoring. Work on this innovation continues.[23]

Figure 4. One of the objectives of the "CHILL-ON" project, an European initiative, is the development of a tracking system that integrates RFID and TTI principles. This hybrid technology has significant potential to enhance safety and quality in food supply chains. Photo on the left: courtesy of Mark Lohmann, CHILL-ON project

Conclusion

RFID is a promising technology that can provide numerous benefits in temperature monitoring and performance of perishable supply chains. The main limitations are: (a) a relatively high cost; (b) difficulties in calculating a ROI; and (c) reliability and accuracy, which should be further improved for cold chain applications.

IIR Recommendations

- A temperature-controlled supply chain is very important to ensure that the consumer receives high quality and safe perishable products (e.g. food, vaccines or pharmaceutical products). The use of RFID technologies and similar wireless monitoring systems to achieve these benefits should be further explored.

- Research and development should focus on: (a) further cost reductions; (b) sound methodology for the calculation of ROI; and (c) improvements in reliability and accuracy of RFID monitoring systems tested under realistic cold chain scenarios.

- The development of a global RFID standard would improve the uptake of the technology and would also help to decrease the confusion around the required frequencies and radio spectra in each country.

- Transparency and collaboration across the supply chain are the greatest challenges for the successful adoption of RFID technologies. The role of the IIR is to facilitate collaboration between the relevant supply chain partners, through the dissemination of scientific information and the development of forums attended by academic and industry experts worldwide.

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