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Adoption of Wireless Sensors in Supply Chains: A Process View Analysis of a Pharmaceutical Cold Chain

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Abstract

Real-time and continuous monitoring of high value goods can considerably improve the reliability and effectiveness of supply chains. Wireless Sensor Networks (WSN) offer technical capabilities for continuous sense and respond capabilities. WSN offer complementary advantages over the use of Radio Frequency Identification (RFID) in supply chains. Still, WSN have not been massively adopted. While some success stories on the use of RFID in supply chains have appeared, little research is available that studies the slow adoption of WSN. This paper presents results of a qualitative case study of the ongoing adoption of WSN in a Pharmaceutical Cold Chain to prevent loss of high value shipments. Based on interviews with various actors in the supply chain, benefits and barriers that impact the adoption process are identified. Using a process view and inter-organizational adoption model, the complex relationships between adoption factors are analyzed. The results show that WSN can effectively improve process quality and reduce waste in the cold chain. However, careful attention needs to be paid to managing the various interconnected factors that may support or hinder adoption. The study demonstrates that a process view contributes to understanding the adoption process. Moreover, an inter-organizational view to the adoption process is needed to successfully introduce WSN in the Pharmaceutical Cold Chain.

Keywords: Wireless sensor networks, WSN, RFID, Supply chain, Pharmaceutical cold chain, Inter-organizational systems adoption

1 Introduction

Supply chains need to be increasingly responsive to meet the needs of changing markets and customer demands. One of the key abilities required in responsive supply chains is real-time and continuous monitoring of shipments [12]. Wireless Sensor Networks can be implemented by the various actors in a supply chain to achieve this goal. WSN, consisting of small computing devices equipped with tiny sensors and wireless communication, battery-operated, can sense the world around them and can communicate with other devices wirelessly. WSN enable continuous measurement of environmental characteristics, e.g. temperature, location, and humidity, and to wirelessly collect and process these measurements into information systems, with the ultimate goal of gaining insight in the condition of objects and the progress of business processes. All WSN consist of the same three basic components: sensor-tags, readers, and middleware. Tags are compact, mobile hardware units equipped with sensors, and capable of collecting and transmitting measurements to readers. Readers are stationary hardware units equipped with antennae to receive the measurements transmitted by tags. Finally, middleware is software that collects the measurements from readers, and processes them into a form that is usable by existing organizational information systems [1]. The most defining characteristic of sensor technologies is their transmission *range*, the maximum distance between tags and readers that allows reliable transmission of sensor data. A longer range increases the probability of a tag being in range of a reader network, to communicate deviations as soon as they occur. A longer range also requires fewer readers to be installed, lowering infrastructure costs of an installation. A range longer than 3 meters does however require presence of a battery in the tag, to power transmission. This increases a tag’s cost, size and weight, and limits operational life. At higher frequencies, associated with longer range, transmission signals are more susceptible to reflection and absorption caused by metals and liquids [32]. WSN are viewed as a core component of the Internet of Things: “the pervasive presence around us of a variety of *things* or *objects* such as devices, sensors, actuators, and mobile phones, which, through unique addressing schemes, are able to interact with each other and cooperate with their neighboring *smart* components to reach common goals” [16]. WSN and Radio Frequency Identification are viewed among the core component of the envisaged Internet of Things that would provide ultimate support for responsive supply chains [26].

WSN are mainly distinguishable from RFID by the functionality that they support: WSN evolved separately from RFID, and whereas sensor-enabled RFID are sensors attached to existing RFID solutions, WSN have evolved from research into meshing networks, ubiquitous computing, and from wired sensor networks, allowing them capabilities that are not present in RFID, such as ad-hoc sensor discovery and dynamic network forming, storage of calibration records, actuating, and remote reprogramming of sensor thresholds [7], [21]. Sensor nodes in WSN can store statuses in memory and can connect to the internet to report status information [11]. WSN offer additional advantages over the use of RFID for supply chain management. In supply chains, RFID products have been primarily applied to reduce inventory inaccuracy, the bullwhip effect and their consequences, to limit shrinkage (theft and other loss during transport), increase supply chain visibility (real-time knowledge of product location and quantity, and process quality), and to reduce transaction errors and duration; [22], [30].

Finally, it should be stated that there is no single standard yet that covers all functions that are required for WSN. Unified standards are being worked on, but are not currently available, nor accepted by vendors [21]. Thus, multiple technologies and different approaches are suited to aid in wireless sensing in supply chain scenarios. Since a dominant standard is yet to emerge, a comprehensive framework should be ready to accept information from either of the technological sources, or multiple at once when objects traverse organizational and network boundaries, allowing adopters of the framework to make choices that best fit them.

While some success stories on the use of RFID in supply chains have appeared, little research is available that studies the slow adoption of WSN. Studies that address the adoption of RFID in supply chains find several challenges [3], [5]. In [30], a literature review of RFID research, it is noted that although *Enterprises generally conduct pilot projects to validate RFID technology in a limited environment*, there are *not many real supply chain applications yet*. Technical challenges include the speed and reliability of the RFID tags and networks, especially in harsh conditions e.g. in the presence of metal objects or liquids. Lack of standards, patent issues, low confidence in the technology and high impact on existing IT architecture and business processes can further impede implementation. Fear of privacy loss and labor redundancy can also raise barriers. High costs and unclear Returns on Investment (ROI) are also frequently mentioned as a reason for slow adoption of RFID and WSN. As shown in [4], cost and benefits of RFID implementation in a supply chain are not straightforward to determine and value obtained can differ among supply chains actors and can even be negative in some scenario’s. Also, factors of product value and demand uncertainty have a considerable influence on the expected benefits of RFID [35]. Furthermore, [5] notes that: “The coordination of supply chain players seems to be a major factor for influencing the speed and ease of the RFID introduction process.”. To benefit from RFID, sharing of information previously considered proprietary is needed and a shared view on performance information needs to be developed [3]. Complex inter-organizational factors have also been found to impact RFID adoption [23]. These include trade partner pressure, social support by customers, suppliers or government and power structure of the supply chain [34], [36].

This paper focuses on the limited adoption of WSN in supply chains. Given their specific features, WSN in supply chains are primarily aimed to monitor perishable and otherwise temperature sensitive cargo, e.g. [2], [6], [13], [37],

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[39]. Very few studies have addressed adoption of WSN. Moreover, given the high pace of the technological developments adoption drivers are frequently changing. As technological barriers are being addressed, the focus seems to shift to the organizational and inter-organizational factors. The costs of a lack of insight and limited ability to respond are high. For example, it is estimated that up to 30% of perishable products are estimated to become subject to spoilage at some point in the supply [6]. It is therefore remarkable that large efforts to implement WSN in supply chains are scarce and face slow uptake. Our research question therefore is: *How can the adoption of WSN in supply chains be explained?*. We address our research question using a process view adoption model and a case study of WSN adoption in a global pharmaceutical cold chain.

Existing theory may assist in identifying the individual factors that play a key role in WSN adoption. Prior research on inter-organizational (IOS) adoption identifies antecedents and factors that influence organizations and individuals in their decision to adopt or reject a technology, e.g. [28]-[29]. The dominant research approach in studying adoption of IOS is to identify the key factors that influence adoption. Such an approach has been applied to explain the adoption of various technologies such as ERP2.0 in [18], and RFID in e.g. [34]. However, researchers have noted that factors not only influence organizations in their adoption decision, but organizations may also modify these factors over time: Technology adoption by a network of organizations is rarely a single decision made by a single company. Rather, it is an ongoing process in which actions of individual organizations may influence the decisions of others. The process-view technology adoption model that Kurnia & Johnston propose [20] (hereafter: K&J model) supports this notion. In this model, K&J build upon the earlier work of e.g. [33] in that factors from technology, organization, and the environment influence organizational actions. However, the K&J model also acknowledges that organizational actions may modify these factors in return and affect adoption by the supply chain as a whole.

The slow WSN adoption in supply chains indeed suggests the influence of multiple opposing factors, and multiple actors are required for WSN to be adopted successfully. We apply the K&J model in a case study to conduct a comprehensive analysis of adoption of WSN in a pharmaceutical cold chain. Pharmaceuticals, for instance drugs and vaccines, suffer immediate quality deterioration if they are not kept within a certain temperature range. For this reason, pharmaceuticals are transported in a cold chain, that is, all organizations that together provide the transport guarantee that the product is kept within a specified temperature range, usually around 5 ºC. Despite the best efforts from logistical service providers (LSPs), carriers and trucking companies, pharmaceutical goods are incidentally exposed to temperatures that are either too high or too low, resulting in costly losses. For instance, in [24] it is estimated that 14% to 35% of international vaccine transports lead to irreparable damage of the vaccine. In pharmaceutical cold chains up to a third of all transported pharmaceuticals are exposed to temperature deviations so extreme that they perish, costing millions of euros. WSN may help prevent damage to sensitive pharmaceuticals by continuously measuring the temperature of the goods during their transport: By wirelessly reporting the collected measurements, supervisors may detect a cold chain problem while it is occurring and correct it before quality deterioration occurs. However, pharmaceuticals are distributed through a logistical value chain for temperature controlled transports, or cold chain. In the cold chain different stakeholders – shippers, carriers, forwarders – make up a complex whole through which pharmaceuticals are airlifted and shipped over the entire world. Adoption of WSN is therefore not straightforward. Using the K&J model, we aim to explain how the various adoption factors drive the adoption over time.

The paper is structured as follows. The next section presents the research method deployed. Section 3 presents the case study using data from the interviews with various actors in the supply chain, the archival study and observation at the sites. Section 4 presents the process analysis of the adoption factors using the K&J model. Finally, we present the conclusions and future research.

2 Research Method

In this section we elaborate how the research was conducted.

2.1 Multi-Actor Qualitative Case Study

The main objective of this research is to understand the factors in the adoption of WSN technology in supply chains. As we aim for a deep understanding of the role, the development over time and interplay of various adoption factors, we chose to conduct a qualitative case study of a particular cold chain following [9]. We study the adoption decisions and underlying factors of various actors in a cold chain: the Air Carrier (AC), the Forwarder (FR) and the Software and Sensor Technology Provider (TP). A qualitative case study allows the description and detailed understanding of a single occurrence of the phenomenon, at cost of the generalizability of the findings that can be achieved using a larger sample size. In this case study, three research instruments are used to collect measurements regarding the adoption: (semi-structured) interviews, (process) observation, and archival research. For instance, to understand the requirements for applying WSN to an existing process, firstly the current standard operation procedures have been consulted from the process manuals; secondly, the key process experts have been interviewed; and thirdly a single shift of the process has been observed in practice. Combining these data collection techniques increases validity and allows a more comprehensive understanding relative to the use of a single instrument, or multiple instruments on disparate variables.

2.2 A Process View on Wireless Sensor Network Adoption

The K&J model, an inter-organizational and process-view adoption model, was selected as a theoretical lens to analyze the case study findings. Figure 1 shows the Kurnia & Johnston [20] (K&J) Model. Note that organizations are not only subject to influence by external adoption factors, but may themselves also modify these factors, indirectly influencing the technology adoption outcome within a network of organizations. These influences may not occur instantly but happen over time. Therefore, a process view may be required to understand complex adoption processes of emerging technologies. The K&J model's dimensions (Figure 1) are based on a synthesis of earlier research. The Nature of Technology is based on [29], whose contributions to this research field have been mentioned above. The Capability of Organization borrows elements from [14] and [33]. By acknowledging that organizations may influence the factors, it becomes necessary to split up the External Environment dimension into Industry Environment (that an organization can influence) and External Factors (factors that an organization cannot influence, e.g. socio-economic conditions).

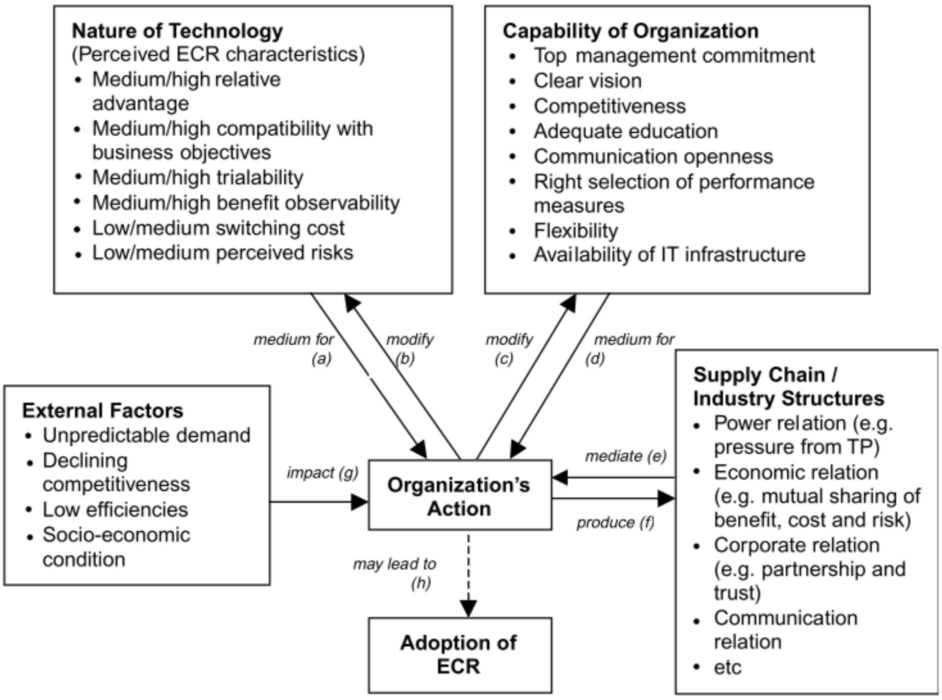

Figure 1: K&J model for studying IOS adoption [20]

2.3 Interviews

The interviews were held with key informants within all companies. These include business analysts, quality managers, warehouse operators, process monitors, process supervisors and process owners, who were invited for in-situ interviews. These interviews were mostly informal in nature and spread out over time, without preset appointments labeled as *interviews*. The reason to do so is to ensure that the key informants would give answers that are top-of-mind, not answers which were premeditated to fit this specific research. The cold chain actors studied are summarized in Table 1.

Table 1: Participating organizations, role, and technology adoption status

Id	*Role in value chain*	*Adoption status (2011-Q4 – 2012 Q2)*
A	Technology provider (TP)	N/A
B	Forwarder (FR)	Adopting
C	Air-carrier (AC)	Undecided / Not yet adopted

One researcher (one of the authors) was embedded for four months at AC, and for two-and-one-half days of interviews and observation at FR, in three visits. The visits to FR were distributed as one day before the embedding at AC, a half day during, and one day after. The embedding at the non-adopting AC allowed for nearly unrestricted access to the employees and internal processes, while the visits at FR were higher in intensity and more focused on acquiring specific information. The exception to this was FR, for which a journey abroad was necessary, and therefore the interviews had to be planned within a limited time frame. These appointments were set over a period of three days. In advance, a number of topics were agreed upon. These were: experience with the technology; trust in- and communication with partners; desires and perceived risks in sharing infrastructure with other forwarders; technical issues with WSN and possible solutions to any issues that were mentioned during the interviews. After the interviews, interviewees were given the chance to go over the reports and excerpts following the interviews and give their feedback.

The results from the interviews, process observation and archival research are mapped and combined using the K&J theoretical lens. To allow uncensored data collection, all case results are analyzed anonymously.

2.4 Process Observation

In order to fully grasp the process of handling and shipping pharmaceuticals in this specific cold chain, non-participant, non-intervening in situ observations have been held over the period of several months. In selecting the processes to observe at AC, the criterion was to look for processes that would be affected by the implementation of WSN. To this end, a full eight-hour shift of the department responsible for monitoring pharmaceutical shipments for deviations in the main hub was observed; a partial shift of a warehouse operations scheduler was observed. Further, the arrival and processing of a Envirotainer shipment and regular pharmaceutical parcel was observed. Cold chain stakeholders were observed in their natural context, in order to independently conclude what the main motivations would be to adopt or reject WSN throughout the organization. This prevented the organization to answer in a socially acceptable way (in this case, confirmation bias). Together, the observations covered a wide set of processes involved in handling pharmaceutical transports in the hub. At the WSN adopting FR, the loading process and physical association of sensor and shipment were observed.

2.5 Archival Research

In addition to observations and interviews, available data has been used in order to verify the results of the interviews and observations and further delve into the specific problem at hand: why pharmaceuticals perish due to temperature deviations, and at which specific moments these problems are most likely to occur. Log files of errors and claims investigations were used, and various process descriptions, i.e. International Air Transport Association (IATA) Cargo2000 process manual, World Health Organization’s (WHO) Good Distribution Practices (GDP) requirements documents [38] and AC’s standard operating procedures manuals.

3 Case Study: WSN Adoption in a Cold Chain

This section introduces the Cold Chain and opportunities for WSN adoption. Next, the K&J model is applied to analyze factors and actions per stakeholder. The findings are extracted from interviews held with the key players, archival results and process observation (as explained in section 2).

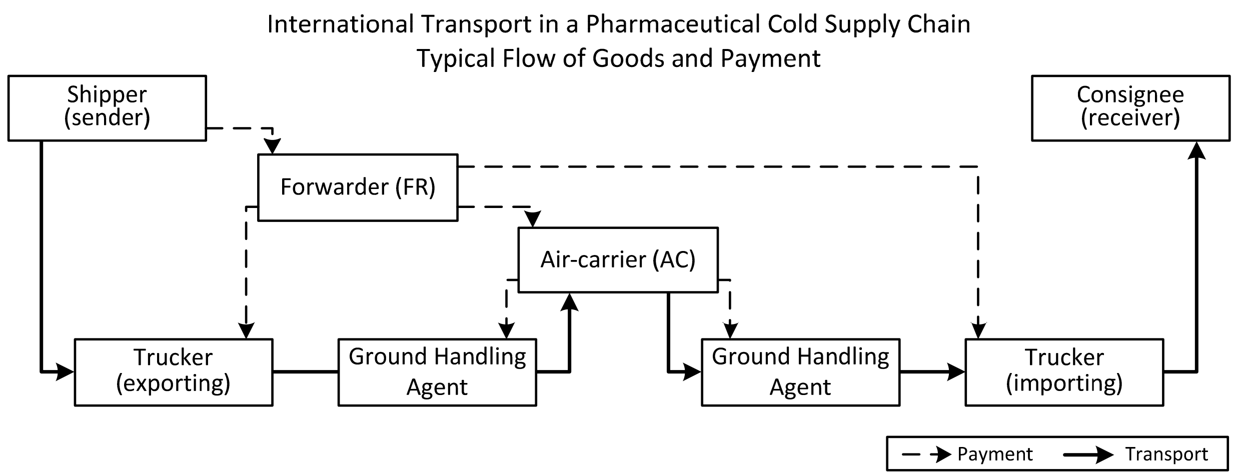

Figure 2: Actors in the cold chain

3.1 Pharmaceutical Logistics and the Cold Chain

Pharmaceutical transport differs from general cargo in that its parcels are valuable and sensitive. The high value comes from large quantities of regulated drugs and one-of-a-kind production batches for research and development. A shipment of pharmaceuticals therefore has a typical insurance value of several million US dollars. Unlike most cargo, pharmaceuticals are sensitive to temperatures: most drugs and other vaccines lose their effectiveness when exposed to ambient temperatures for too long. Moreover, pharmaceutical shipments are often subject to time constraints because of potential spoilage, therefore, they are most often airlifted over longer ranges – ocean freighting may take too long. In order to minimize losses, pharmaceuticals are transported in a cold chain. In cold chains, each operator provides cold storage at all parts of the journey. In cold storage every operator makes sure that temperature remains within a narrow range specified during the booking of the transport. These temperature regulations are most commonly low (2-5 degrees Celsius), but *room temperatures* (15-25 degrees Celsius) may also be requested. However, not every cold chain operator takes the same level of precautions on every transport to guarantee this specified temperature range, and in transfer between two operators, especially at peak volume of operations, parcels may be exposed to ambient temperatures.

The continuous guarding of shipment conditions is complicated as many actors are involved in handling shipments (Figure 2). The structure of a cold chain can be dynamic and sometimes complicated: Not all parties have the same decision power regarding the technology adoption. Ultimately, shippers pay for the transport. They hire (i.e. select and pay) a forwarder, and may select the carrier too. Typically, forwarders hire local truckers and a carrier. Ground Handling Agents (GHA) are then hired by carriers. In some cases, carriers may however hire truckers, and GHA may be hired by forwarders. Forwarders may also operate their own fleet of trucks, airplanes and/or warehouses. Since there is an open market, the hiring parties may request or demand compliance. Since forwarders and carriers may offer similar services, they may compete for the door-to-door transport of a shipment. Forwarders may integrate to some degree with shipper organizations, for instance by handling some part of the assembly or packaging of products, while also transporting the goods to an air- or seaport for a carrier to accept. Carriers may perform or orchestrate the retrieval of goods from shipper warehouses, but they are not likely to integrate directly to customer processes. A process scenario is defined in the Cargo2000 quality improvement initiative [15].

In spite of the agreements and coordination between the actors, frequently problems occur. Typical problems in the cold chain include [27], [31]:

- Storage at incorrect temperatures, for instance using a cooling truck when none is required.
- Facilities or material being unavailable, for instance cold storage being full.
- Envirotainers (temperature controlled air-freight containers) running out of battery power or dry ice.

While these problems can never by completely prevented, prompt corrective actions can minimize damages in most cases. WSN are a key technology to achieve this goal.

3.2 How Wireless Sensor Networks may Benefit the Cold Chain

Currently, pharmaceutical producers use passive sensors to add to shipments, i.e., a sensor which only logs temperatures but does not provide real time access to updates. This is the simplest solution to the monitoring requirements. These sensors show the temperatures logged during the journey, and help identify problems, but only after the sensor is read at the recipient (often another business unit of the pharmaceutical producer). In this case the sender may start a claims procedure and receive part of the value of their shipment reimbursed. With WSN, small sensors are attached to pharmaceutical shipments that continuously monitor the temperature. If within reach of a reader network, all collected temperature measurements are sent to a control center in real-time. The control center is alerted for any shipment that is (about to) exceed the temperature range that has been specified for it. The control center can then dispatch an intervention team to assess and correct the problem immediately, before damage is caused, or in case of damage, notify the shipper to ask for further instructions.

A WSN could improve a cold chain in three ways: Firstly, it may detect deviations for individual shipments in real-time, therefore allowing the recipient to alter business processes and/or cancel further transport if damage is detected and start resends immediately. Secondly, quality for censored shipments is expected to go up, because if problems are detected in real-time, they may also be correctable on the spot, or otherwise expose weak spots in the transfer process, allowing systematic quality improvement for future shipments; Thirdly, a WSN may create an audit trail for each individual shipment, thereby simplifying regulatory compliance, and claims process alike. For application in a pharmaceutical supply chain, the most significant indicator of quality during transport is the mean kinetic temperature (MKT), of the shipped pharmaceuticals [10], [25].

3.3 Air Carrier (AC) Adoption Factors and Actions

AC is piloting inter-organizational sensor technology. The pilot project is executed together with a partner that supplies the reading equipment for installation in AC’s warehouses.

3.3.1 Decrease of Value Offering Towards Shippers

Pharmaceutical air freight yields a high profit: the additional services required for cold storage for quality preservation is compensated by a high margin. Sensors offer upstream parties, i.e. forwarders, a chance to take over part of these services. This may occur when the primary control center, that receives and processes alerts directly from sensors, is provided to the forwarder. Carriers then become subservient to instructions from this center. This may lower the profit margin from pharmaceutical services for carriers. By enhancing business processes with sensors without any control over what is being collected, processed, and stored, and by whom, forwarders may gain control over the carriers. As a result, value that is currently added by individual air carriers to pharmaceutical transport shifts to forwarders. Interchangeable sensor networks implemented at competing air carriers allow competing carriers to offer similar services. AC fears that margins will vaporize similar to what happened with the commoditization of the trucking business.

3.3.2 Real-time Information Supply

Wireless sensors enable real-time warnings of shipment problems. This is perceived as an advantage, since in the current set-up with passive loggers, shippers learn about problems before carriers (and forwarders) do. Being able to inform customers of errors before the shipment is completed, shows a pro-active approach to manage process quality. If sensors are owned by forwarders, it is not certain that carriers will have access to alerts before forwarders and shippers do.

3.3.3 Sensor Radio Interference with Aircraft Electronics

Wireless sensors use radio signals to send measurement data to base stations. These radio signals may interfere with sensitive electronics aboard aircraft, and cause unsafe conditions, especially when cargo is added to passenger flights. Approval of sensors is a time consuming and fragmented process: aircraft manufacturers provide guidelines for the conditions under which signals are allowed aboard aircraft, but stricter rules may be required and enforced by local government, an air carrier's department of aircraft maintenance, and insurance organizations. Switching the sensor radio off during flight is a safe and location-independent solution to this. However, this requires that a sensor is able to accurately detect when flights are about to start and to reactivate when flights have ended. Although there are several methods to do this, none of these are universally recognized as robust and safe. Government authorities, carriers and insurance organizations therefore require testing and separate approval for every sensor product. AC's engineering department is yet to give their permission for usage of these kinds of sensors. However, this barrier may slowly disappear as several other air carriers are already flying with such sensors. Also within AC, small scale tests were conducted in the sensor pilot project with the forwarder.

3.3.4 Validity of Sensor Data

The data collected from sensors may not accurately reflect the condition of the product. This is dependent on the number of sensors compared to the volume of the parcel, but also on the placement of sensors. Sensors may be placed on the inside of a parcel, measuring the temperature of air directly surrounding the product or alternatively on the outside of the parcel, measuring the air temperature surrounding the parcel, or ambient temperature. The ambient temperature is not a robust predictor for the product temperature, because the insulating effects of the parcel are unknown, and ambient temperature sensors are more susceptible to placement errors. The temperature measured from a parcel's shady side may widely differ from that measured in direct sun [17] (Both these extremes may not provide a valid measure for the ambient temperature, to be useful for in quality calculations such as the MKT.

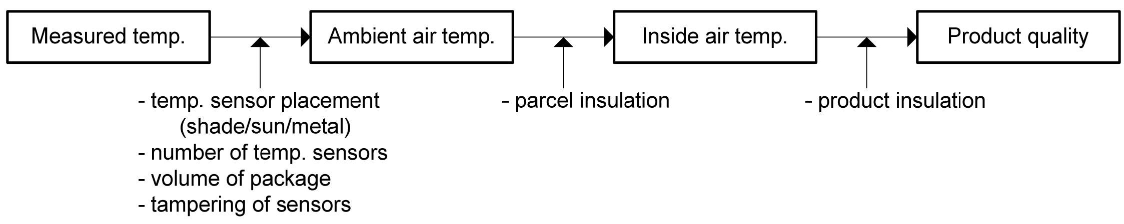

Figure 3: Relation between sensor measurements and product quality: Observable phenomena and modifiers

Measuring the in-parcel temperature is not trivial either (Figure 3). Sensor network signals are weaker from inside parcels, limiting the transmit range. Further, sensors need to be added to the product by the original sender before sending, due to (customs) restrictions. These include regulations such as who may open a sealed box of pharmaceuticals, even if only to add or extract sensors. This requires that one uniform sensor type be used that is readable throughout the network consisting of multiple organizations. The application of wireless sensors such that it provides valid measurements, affects the reliability of detection and the rate of false positives and negatives. Measurement errors may negatively influence operating margins and the customer's quality perception and brand image once the temperature measurements are shared.

3.3.5 Data Ownership

AC expresses concerns over who will own the data collected by the sensor. Data ownership helps control risks of liability, validity issues, and the load on customer service. Data ownership involves the authority to decide what measured details will be shared with whom, and under what terms. This authority may be (partially) claimed by either of the parties that provide the sensors, own or operate the reader infrastructure, own or operate the building, warehouse or vehicle that is measured within, the parties that provide the data collection and processing service, provide part of the process that is monitored, or any parties that pay for any of these activities. The data owner may apply or require constraints on the use of data. For instance, for any party it shares data with, the data owner may choose to disclose less detailed data, e.g. only the alert state for a shipment (under control / out of control) instead of current temperature. Furthermore, a data owner may choose to delay data sharing by 30 minutes instead of sharing in real-time, or release data only on a premise that it is not suitable for legal reasons. AC prefers to share data directly with the shipper without involving the forwarder.

3.3.6 Technology Stability

Sensor technology is continuously evolving. Sensors are progressing to lower cost, lower power-consumption, and interface standardization. Research and development efforts are aimed at addressing problems in applications in aircrafts. However, no dominant and integrative set of standards has emerged. Sensors are still too expensive for one-time use so re-use is a necessity. This may be hard to achieve. It is arguably better to defer investment until the next generation of sensors to prevent buy-in in a soon outdated technology. The interviewees in AC differ in their view on this. One business analyst states that there will always be a better technology just around the corner and if there would only exist a positive business case, large scale implementation be rolled out.

3.3.7 Increased Load on Customer Service

AC expects that sharing of sensor data (i.e. shipment quality) with customers will cause a significant increase in customer service inquiries. This requires allocation of resources to service centers that are possibly not compensated as these inquiries are currently not billed to customers.

3.3.8 Return Logistics

AC has indicated concerns regarding return logistics, i.e. the organization involved in collecting and transporting sensors back to origin for re-use. From experience AC has with return logistics of Envirotainers (large refrigerating standardized air-freight containers), this requires a significant coordination effort.

3.3.9 Organization of Detection and Intervention

AC currently cannot detect every temperature-deviation on pharmaceutical shipments. It does not currently monitor all pharmaceutical shipments. Monitoring requires some manual action and may therefore be intermittent. Monitoring is based on parcel location instead of parcel temperature while location is sometimes misreported and monitoring only occurs in the hub location. Full implementation of sensor networks allows automatic continuous monitoring of any shipment based on temperature, in real-time if within range. When fully implemented, it is likely that the availability of sensor data will cause an increase of detected (temperature) deviations.

The quality norms that AC uses within its hub require placement of pharmaceutical cargo in the correct temperature-controlled storage area within 5 hours of flight arrival and to keep it there till 3 hours or less before flight departure. During extreme outside temperatures of above 25 C or below 2 C, both limits are lowered to 1 hour. Note that these quality norms are based on location, not on temperature. If a shipment does not meet the standard and this is detected, the incident is reported in a weekly management summary. During December 2011 and April 2012, the number of detected incidents varied between 30 to 80 per week. AC estimates this is 2% to 5% of cold chain shipments. Only a few claims per month are filed for pharmaceutical shipments. This ratio of claims to incidents suggests that the intermittent monitoring by shipment location is sufficient for guaranteeing its quality, assuming that all shippers file claims if errors were detected. If AC fully implements sensor technology and shares measurements in real-time, it is obligated to address any detected temperature deviation equally in real-time. Assuming the intervention capability remains unchanged but the detection volume increases with the use of sensors, this is likely to negatively affect customer's quality perception.

The capability to intervene is not trivial to improve as it is constrained by operational issues. For example, both operational and quality control departments have indicated that the incident list is currently not actively used to improve processes. The most commonly reported causes are parcel congestions, cold room scarcity and lack of room for Envirotainers. It also occurs that it is unclear if a temperature deviation actually took place, due to problems with information quality. Understaffing appears to prompt these causes, along with data quality errors, confusion about operating procedures, and functional thinking by departments (not-my-job attitude). Solving these issues is not straightforward (e.g. understaffing is caused by forecasting inaccuracy and economic climate) or requires changes within both the department for monitoring and intervention, and the operational departments that process deviant parcels. These changes may be too large to be warranted solely by the benefits of using sensors.

3.3.10 System Integration

The IT architecture of AC is not easily extended to handle processing, storage, and real-time dissemination of sensor data. AC employs two large, custom-developed legacy information systems that are both optimized for a single function: one for shipment administration support, and one for warehouse handling. Among interaction with other systems, the implementation of sensors and intervention processes requires data to be exchanged between both legacy systems. However, inconsistent data in these two systems is currently known to cause conflicts. Both these systems are based on mainframe technology, and originate from before 1980. Development is outsourced to a large enterprise software developer and all modifications require extensive testing. Therefore, even minor changes take significant financial resources and time. For example, instead of extending the existing system with a new screen to support a (temporary) warehouse function, AC considered it faster and cheaper to develop in-house a separate application that uses screen-scraping of the legacy systems. An enterprise service bus architecture is under development that will allow different systems to exchange data more efficiently. Unfortunately the bus architecture is not expected to be production-ready in time to affect the adoption of sensor network technology. Furthermore, in-house development of support for processing large streams of sensor data is not trivial. The investments required to update the IT-architecture to support WSN and intervention require financial resources and substantial time before systems are production ready.

3.4 Forwarder Adoption Factors and Actions

FR is actively adopting inter-organizational sensor technology. The project is executed together with several subcontractors and a Technology Provider that supplies the sensors, sensor network and software systems for installation in AC's warehouses. The interviews revealed the following adoption factors and organizational actions:

3.4.1 Forwarder's Evolution of Support for Wireless Sensors

At around 2008, 2009, FR's healthcare division set the goal to match the quality level requirements that its customers were facing: FR's cargo handling was to comply with the pharmaceutical industry standard Good Distribution Practices: GDP. At that point, FR was unclear on how to guarantee GDP service levels, but it started looking into this, and began to adapt processes and training to an *every-packet-counts* mindset. It became clear that a system was needed to support the new processes, to help monitor the conditions of shipments in real-time. This system was found to be based on wireless sensor networks. TP was selected and became partner in further development of the technology. Customers were welcoming the initiative and started to express a need to extend the use of sensor technology at other stations than the initial two hubs in Europe and the United States. The management of FR became aware that sensor technology was positively received in the market and dedicated broadened funding the project. The view of management was that sensor technology yields traction in a high margin market. To further improve the processes that are to ensure GDP standards of quality, the web based sensor monitoring system provided by TP is being integrated with the legacy systems at FR.

3.4.2 Evolution of the Technology

After recognizing the need for continuous monitoring of shipments, FR selected sensor technology and the services by TP because the solution offered by TP was the only technology that allowed monitoring in a continuous stretch regardless of how far a parcel would travel, using a pro-active approach to damage prevention. The TP software was initially sensor-oriented. Temperature progression was recorded and reported on a sensor by sensor basis, ignoring that multiple sensors may be attached to one or more parcels, and that sensors may be attached to different parcels over time. Working closely together with TP, the sensor network solution at FR gradually evolved into a shipment-oriented approach. Shipment numbers are now associated with sensors for the entire duration of the journey. Feedback from customers helped in guiding other developments. For instance the alerting of temperature deviations, and reporting for journey audits. FR considers the state of the technology mature. A possible improvement is mentioned to be a USB uplink, allowing stations that are without reader infrastructure to retrieve measurement data upon receipt of the parcel. FR currently works on having the sensor to recognize where it is, and based on that automatically alerting the right people at the right time.

3.4.3 Convincing Subcontractors to Join in the Technology

FR is dependent on other logistical service providers in the value chain to guarantee temperature integrity during an entire transport. The quality of the transport is largely determined by the weakest service provider. FR works together with air carriers, truckers and ground handling agents. FR started to work with one of its air carriers and gained permission to do anything necessary to test the technology. FR has an exclusive contract for use of two of their Boeing 747s including Aircraft, Crew, Maintenance and Insurance. After researching and compliance with Federal Aviation Administration (FAA) regulation for the placement of sensors, FR started using wireless sensors on flights. The sub-contractor did perform its own technical testing to ensure that everything was ok. Since then FR and its subcontractor learned how to ensure cargo safety from practice.

The wireless sensor partnership with another subcontractor started with difficulties. Despite having a long-standing relationship with FR since 1973, the subcontractor expressed its concerns for the safety of sensors aboard their

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aircraft. They also perceived the technology as a strategy by FR for making them liable. It took around 12 months of lobbying by FR and various technical tests by the subcontractor's technical department to convince the carrier to allow wireless sensors on board. Several elements may have helped. FR clearly defined service level agreements and standards that the carrier is to adhere to. FR and the subcontractor met with IATA representatives to convince IATA to start with regulation of the procedures that are required to place wireless sensors aboard aircraft. This would free the carrier from technical concerns regarding the correctness of their sensor implementation. IATA also published an update of their Perishable Cargo Regulations, holding all IATA-adhering carriers responsible for the correct handling of temperature sensitive products and (more) liable in case of damages, starting from July 1st 2012. Most importantly, FR treats the carrier as a partner in the improvement of processes as opposed to creating a hostile, controlling environment in the cold chain. It is important that all stakeholders uphold a culture of excellence, in which each stakeholder tries their utmost to help each other reach high standards. Finally, the four eyes principle is vital: every step in the cold chain should be monitored by at least two stakeholders in the cold chain in order to ensure that every stakeholder tries their best. This implies that responsibility is shared and therefore information will be shared more easily and technology implementation will be accepted more readily throughout the cold chain.

FR provides training of GDP requirements to employees and management of its subcontractors. Because FR considers itself exemplary when it comes to standards, FR does not fear sharing information on internal procedures via training; instead, they hope that these training sessions will raise the bar for other stakeholders in the cold chain.

3.4.4 Sharing Infrastructure with other Forwarders

FR was asked by another forwarder for access to their airport reader infrastructure of Smartpoints provided by TP. After considering this request, FR decided to deny this. FR had invested considerably over the years in the growth of technological advantage over the competition: FR considers its current state of the art in wireless sensor network to be one of the unique selling points in their pharmaceutical transport offering. However, even if the technology would be shared or (eventually) copied, FR will not lose its position as technology market leader. The true advantage is that of the process that wields the technology, not the technology itself. Quality is more than having the right technology. Only if crews act in a consistently accurate manner upon the data that is provided by the technology, quality of the process improves. For instance, FR itself has the exact same technology installed in different stations, yet the results differ per station because of the way the individual station's handling crews manage to respond upon the data. Therefore, FR ascribes the potential success of the system as an exponent of corporate (or divisional) culture. Getting the awareness, the culture into the company is bigger than getting the network installed. Technically, FR considers it feasible, in the future, to use non-FR/TP sensors to gather data: for as long as there are standards for data exchange, safety checks, and barriers against corporate espionage and as long as the information is rendered consistently and uniformly in FR's system, FR is ok with using externally provided data.

3.5 Technology Provider Adoption Factors and Actions

In this section we describe the dynamics and variety of factors that underlie the adoption of wireless sensor networks by actors in a pharmaceutical logistical chain.

3.5.1 Need for WSN in the Cold Chain

TP focuses its efforts primarily on forwarders and shippers, and less on carriers. Forwarders can improve their added value to shippers and also see other forwarders starting to use sensor networks, increasing competitive pressure. Forwarders are considering, if not adopting, wireless sensor networks to better serve the needs of pharmaceutical producers. Real-time monitoring of valuable shipments increases value and creates a unique seller proposition. Of course, if all forwarders do this, the uniqueness diminishes, but the technology will still improve operational processes for adopters. FR used the technology to improve their own internal processes first. A practical barrier to adoption currently for non-adopting forwarders is that they do not own most of the warehouses that require installation of readers. Some forwarders do own the warehouses for their trade-lanes. For FR, it was easy to install sensor networks at eight sites as they owned these warehouses. Other forwarders require negotiation for the installation of reader networks with dozens of warehouse owners, and see this as an obstacle.

3.5.2 Cost of Sensors

Shippers themselves currently have budgets for passive data loggers of up to $60 per single-use logger. TP aims to redirect this spending towards wireless sensor networks and services (wireless sensors are $20 a piece and prices are dropping). Shippers are hesitant to adopt new technology since they are subject to regulation. Their aim for sensor networks is to prove the quality of the product to the consignee. The loggers they currently use have their hardware and software certified (by shipper and consignee). This takes over half a year and increases the switching costs, also allowing the large margin by producers of the data loggers. A *medium size* pharmaceutical shipper explained to TP that its yearly volume is around 200.000 data loggers. Eventually, TP hopes that pharmaceutical companies will demand the monitoring service that early adopting forwarders offer. This will convince non-adopting forwarders to adopt sensor networks as well.

3.5.3 Adoption by Carriers

Carriers show much more of a wait-and-see attitude towards the technology. Some carriers started Request for Information Procedures recently. One of their concerns is safety; In an meeting, with IATA, TP and FR and one of its subcontractors announced that they had to *reinvent the wheel* concerning how to evaluate wireless sensors. Recent and future IATA regulation may help with this. TP considers it beneficial if independent bodies operating on behalf of IATA and the flight authorities European Aviation Safety Agency (EASA) or FAA were to be able to certify sensors such that any air-carrier would be able to accept them without further checks. This would free the decision authority from air-carriers. This however will take years, and air-carriers are not supportive in this. Carriers are in a different position than forwarders in the logistical value chain. They provide airport-to-airport transport rather than door-to-door services. Forwarders have better access to shippers. However, forwarders are each implementing their individual choice from unstandardized and incompatible technologies. This makes it hard for carriers to choose which technologies to support as carriers usually work for multiple forwarders.

3.5.4 The Role of Forwarders

Several forwarders play an active role in advancing wireless sensoring. Competing forwarders may install multiple competing and incompatible sensor networks at the same warehouse site. In one warehouse at a major European hub probably a third reader network may be installed in a single warehouse facility. This may be an issue for, the owner of the warehouse, who over time may have seven different networks for seven different forwarders installed, and possibly for other warehouse owners too. An important requirement to successful adoption, according to TP, is the understanding and acceptance by Logistics Service Providers of the responsibility that they have in pharmaceutical transport. Pharmaceutical transport is very different to that of general cargo; once they understand and accept the increased responsibility, they will also use wireless sensor technology correctly. At FR, a decentralized organization, this is apparent. Not all sites have equally progressed. TP finds that the number of actors in a logistical supply chain complicates the adoption considerably. In the case of FR, not all transports are currently monitored. FR started out in its own warehouse where it has complete control over operational processes. FR rolled out its sensor network from there. Hopefully, other forwarders and logistics service providers can follow the same route.

3.5.5 Technology Evolution

FR chose the hardware of TP's sensor supplier because it had characteristics that allowed it to perform both wireless sensors on shipments, and on cold rooms. Other forwarders still use passive RFID. This allows them to monitor their shipments, although not in real-time. Some forwarders exclusively owns a monitoring solution/network for Ocean Freight. TP tries to facilitate exchange between the technical solutions in use by major forwarders. This trend is also being picked up by other technology providers. The actual roll-out of a reader network is quite easy and cost-efficient It takes about a day to equip a warehouse, and all that is needed are power sockets. The reader networks then organize themselves. However, if each forwarder requires its own network, this creates a complex situation for warehouse owners.

Software development is fully driven by requests from customers. Since the software was sensor oriented at first, TP developed the concepts of shipments and locations, including alerts for deviations on shipment and location level, instead of alerts based on sensors status. Currently, the most important development is the full integration of Smartview, TP's web based sensor platform, with FR's existing IT system architecture. FR also finances some of the development. Other customers for Smartview, focusing primarily on cold room monitoring, ask for new features such as the addition of hardware warning lights, making temperature deviations visible inside the warehouse too, instead of only per sms or e-mail.

Future development may include a USB interface to wireless sensors. This may help in retrieving data where no reader network has been installed, e.g. at dozens of delivery locations. In that scenario, reader infrastructure would be deployed at key locations in transport, and the USB could be used at the outset stations. TP relay these requests to its hardware supplier, but such innovations require several wireless sensor hardware manufacturers and manufacturers of data loggers to make changes to their existing product range.

4 Process Analysis of the WSN Adoption Process

In the previous section, the dynamics and variety of factors that underlie the adoption of wireless sensor networks by actors in a pharmaceutical logistical chain have been described. This section explains how these dynamics may be attributed to various adoption factors in the K&J model [20] discussed in section 3. The K&J process model of adoption identifies eight causal links between adoption factors and organizational action, rendered in Figure 4:

- Compliant with traditional factor-based models, there exist Adoption Factors that influence Organizational Actions. These factors can be grouped into those related to the Nature of Technology, the Capability of Organizations, and the organization's External Environment (links *a*, *d* and *g*).

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- Unlike traditional factor-based models, the process model recognizes that Organizational Actions may also modify the Adoption Factors in return (links *b* and *c*).

- However, organizations may not influence factors that are truly external, such as socio-economic conditions (there exists no reverse to link *g*); instead, every organization may influence its immediate environment and is influenced by it – its industry and/or supply chain (links *e* and *f*).

- The compound of organizational actions over time may lead to adoption (link *h*)

We will use the process adoption model by K&J as a lens to organize the findings from the interviews presented in the previous section. Following the analysis of case study data in [20], we label the data from the interview into the categories listed above and identify the causal relationships that may be at play (*a* to *h).* As advocated by the process view of adoption, we are sensitive for time delays in the effects that have impact on adoptions. For example, if capabilities of an organization are low regarding sensor technology (*d*) this will hinder adoption. If the organization conducts pilot projects with sensor technology including training sessions, this will increase its capabilities (*c*). Similarly, if supply chain partners and regulators agree on procedures for on-board use of sensors (*g* and *e*), this will have an impact (with some delay) on sensor technology (*b)* and with considerable delay on the supply chain and industry structure (*f).* Similarly, we analyzed the interviews presented in the previous section with the actors in the pharmaceutical cold chain. We derive the following relationships framed in the K&J model:

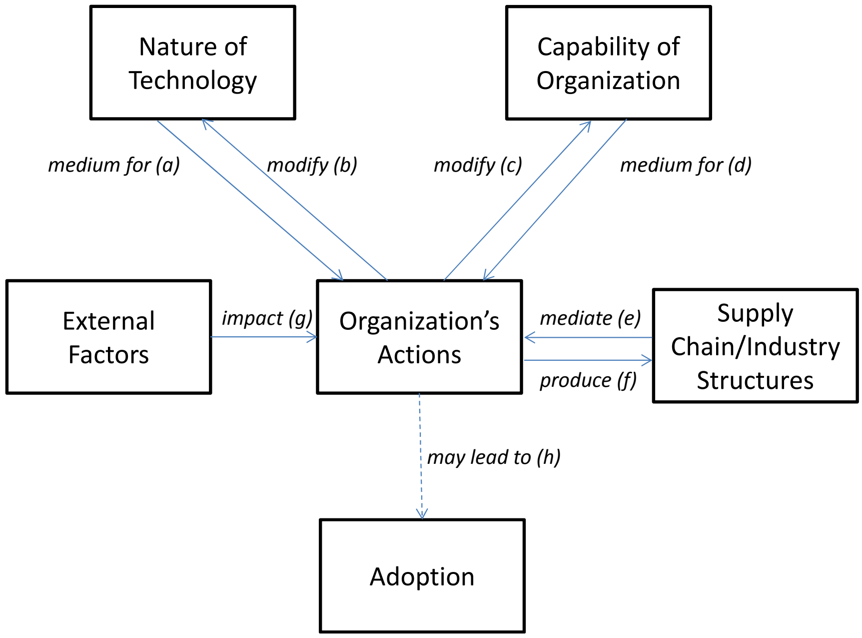

Figure 4: Causal links *a* - *h* in the Kurnia and Johnston adoption process model

4.1 Direct Links

Our analysis of the interviews with the various actors in the pharma cold chain revealed the following relationships that have and impact on adoption of sensor networks (*h*):

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Table 2: Evidence for direct links in figure 4

Link(s)	*Supporting evidence*
d	FR has a very capable process for eradication of all temperature deviations. This technology, and the acceptance thereof shows this relative advantage to potential clients, aligning it with strategic initiatives
c, e	FR is more responsible/involved in the pick-up of transport of freight from shippers than AC, allowing FR easier access to placement of sensors at the initial pick-up. This affects FR to be more interested in the technology than AC
a, c, b	By use of wireless sensors, FR's processes have improved. This increases the perceived benefit of the technology: the technology demonstrates the improved performance of FR
a, c	Real-time sensor networks allows AC to experiment with the technology and get data on its shipments
a, h-	Sensors may not accurately predict the quality of the product (false positives, false negatives). Sensor data, valid or invalid, may affect brand image when published
a, h-	AC perceives sensor technology as relatively unstandardized and undergoing fast development
a, h-	AC perceives sensors too expensive to not re-use, requiring effort in tracking sensors for return
a, h-	AC sees considerable risk that Radio signals from the sensors may interfere with sensitive aircraft electronics, causing severe safety issues
a, h-	AC uses fully passive data loggers which fulfill most shippers' immediate auditing needs. With an acceptable alternative available, AC is not pressured into immediate adoption
b, h+	TP started development of support for a cheaper, more standardized class of sensors, in an effort to appeal to a broader group of logistics service providers

4.2 Direct and Reverse Links

The K&J model explicitly takes reverse relationships into account. These are clearly at play in the case study:

Table 3: Evidence for reverse links in figure 4

Link(s)	*Supporting evidence*
b, e	After FR chose to conform to GDP requirements, they perceived wireless sensor technology better fitting
b, c, d	FR puts effort in integrating the web based sensor management software of TP to its existing IT systems. This creates a more integrated IT architecture and more sense of ownership. As a result the project received more funding within FR.
b, c, d	FR puts effort in integrating the web based sensor management software of TP to its existing IT systems. This creates a more integrated IT architecture and more sense of ownership. As a result the project received more funding within FR
a, c, d	AC's operational process require significant investment to support ad-hoc intervention required by sensor networks
a, d	AC's quality-KPIs and internal process norms do not require minute-to-minute temperature logs nor to expose individual temperature deviations as something to eradicate. This helps prevent wireless sensors to be perceived as a necessity
a, d	Pharmaceutical shipments yield a high margin. This increases management attention in AC and FR to consider technologies that help increase turnover
e, h+	The number of carriers allowing sensors aboard flights is rising. This slowly increases pressure on AC to also approve and adopt sensors
e, c, d, h+	AC is participating in the IATA Cargo2000 quality improvement project. This makes it more aware of transport quality and open to communication with other actors
e, c, d, h+	AC is participating in the European e-Freight project and is implementing an enterprise bus to its legacy IT systems. This makes AC more open and able to adopt IT-related technologies
e, c, h+	IATA issues an update of the Persishable Cargo Regulations chapter 17 defining the responsibilities and liabilities of carriers in temperature-sensitive transport. Carriers need to be able to prove that their conduct was within agreements. Sensors may help in meeting these regulations
e, b, h-	Sensor approval is fragmented over many stakeholders. Research and testing takes time in the approval processes

4.3 Direct and Reverse Links Related to Supply Chain and Industry Structures

Using the K&J model to analyze the case study also clearly reveals that the actions of an organization (FR) can have a transformative effect on the supply chain and eventually may affect the industry structure:

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Table 4: Evidence for links related to supply chain and industry structures in figure 4

Link(s)	*Supporting evidence*
f	FR offers training in GDP requirements and practices to employees of other logistical service providers, for instance road-carriers. This communicates the commitment of Panalpina to GDP, the effort that is required to adhere to it, and illustrates the need of wireless sensoring as an instrument for efficient monitoring
f	FR requires SLA's that promise GDP conformant operation by logistical partners. This makes them more aware of GDP requirements, and more likely to use wireless sensors
f	FR started to use on board wireless sensors successfully with one air carrier. This put pressure on other air-carriers to also adopt sensors to keep the high-yielding pharma flights/customers.
f	FR receives GDP certification from a European member state government for one of its warehouses. Since it's the first in this country to do so, this puts pressure on other handlers to also provide GDP-level quality
e, f	FR collects measurement at an Air Carrier, but does not share these measurements with this Carrier. This affects the Carrier's perceived benefits
f, e, a	FR lobbies with IATA for regulation of procedures on safely placing sensors. This precludes a common technology rejection by carriers, that (any particular) wireless sensor technology may not be safe for use aboard aircraft. IATA regulation may state what types of sensors are safe, what testing is required before placing them aboard aircraft, and prescribe where and how to place them
e, f, h+	Positive customer feedback increases top management support within FR. FR expands the project from two networked locations to nine locations
e, f, e, h-	Other forwarders approach FR to request sharing of their reader network in a warehouse in a major European hub. FR denies this, guarding their technological advantage. Forwarders choose to install their own network, fragmenting technology adoption.
e, h-	Customers of AC can detect problems with shipment earlier than AC. This makes AC hesitant to adopt wireless sensors at a large scale
e, h-	AC has no control in what forwarders do with collected data (e.g. unwanted benchmarks)
c, f	AC starts a pilot with another company. This builds experience, trust with that company, and may serve as a basis for further adoption (or rejection) of the technology.
a, e, f	Forwarders differ in their experience with the technology. Some have extensive experience with passive RFID sensors for pharmaceutical transport quality monitoring. Other forwarders without this experience, have a much steeper learning curve to the technology
b, a, f	TP has developed the software development to be independent from the hardware sensor manufacturer. In this way TP is better able to support other hardware sensors too, reducing hardware lock-in for LSPs
a, e, f, h-	In the view of TP, the lack of standardization and lack of LSP cooperation, leads to numerous and redundant installations of reader infrastructure at warehouses – one for each LSP – making warehouse owners hesitant to accept installations from any LSP
e, b, h-	In the view of TP, a barrier to adoption expressed by non-adopting forwarders, is that they do not own or control the warehouses that require infrastructure deployment, making them hesitant to adoption. This causes company AC to consider developing a public infrastructure at major stations
f, e, b, h+	TP liaisons with sensor manufacturers to convey LSP technical needs. This, in time, improves technology perception by LSPs

5 Conclusion

The Internet of Things promises great improvements for supply chain management. The Internet of Things paradigm's feasibility stems from the maturity level reached by several key technologies. Among the key components are the effective implementation and integration of WSN and RFID systems. This study focused on the implementation of WSN in supply chains. Analyzing the wide range of adoption factors, their interplay, and the various actors involved is helpful to explain the slow adoption of WSN in supply chains. WSN requires fulfillment of various tasks and responsibilities by supply chain participants. For instance, for WSN to be possible in a single trade lane, sensors need to be acquired and calibrated, a reader network infrastructure needs to be installed and maintained on multiple locations, and the complete operational process needs to be certified by the shippers. Then for each individual shipment, the sensors need to be transported and applied to the shipment, associated digitally with the shipment, removed from shipment, and returned to its owner; The collected sensor measurement data needs to be transported and translated between systems, rendered, and stored, all in an auditable and secure way. Apart from this active support, licenses need to be given too: the owners and exploiters of transport vehicles, storage rooms and warehouses need to grant permission for the use or installation of WSN and reader infrastructure.

Supply chains can adopt various scenarios to configure the allocation of tasks and responsibilities among their actors. Certain configurations do imply certain privileges, for instance whoever owns both sensor and reader infrastructure, will always be able to have access to operational performance data (unless specific mechanisms govern the access to data). The control over operational performance data yields power, by being able to point out quality errors in other's processes (liability allocation), reporting it to customers (shippers) and being able to benchmark among providers. Then, for detection of temperature deviations to be possible in real-time – the main benefit over passive sensor logging – the sensor data needs to be monitored in real-time. For every part of a transport, at least one actor should be responsible for monitoring for temperature deviations and triggering a mitigating action, and one actor should be responsible for performing that mitigating action, i.e. intervention. Adopting WSN requires resources to fulfill both; while detection may be centralized at one actor per shipment, preventive intervention is required to be *at* the shipment's location, and may require significant investment by the carrier and handlers to make it possible. There are however different notions of intervention. The first and most available method of intervention is to notify the shipper of a temperature deviation and allow him to inspect and/or cancel the transport. This may save the costs of further transport, shipment handling, and possibly claims processing to LSPs, and shows a pro-active quality approach to shippers. The second intervention method is to allow the local carrier or handler, who is in possession of the actual parcel, access to the information, and with it, direct control to intervene when the temperature threatens to deviate from the allowed parameters.

The case study demonstrated that organizational culture has an important impact on how WSN are perceived. Forwarder FR required two years to train its primary site to perform at a quality level required by GDP and to develop an *every-packet-counts*-mindset among its employees. Although the same technology and the same processes are implemented at other sites, their quality performance differs. At carrier AC, a diligent crew monitors shipments, intervenes on deviations, and reports these deviations to other functions; However, these reports are not always actable or acted upon. Although a monitoring technology, processes and KPI are in place, not all deviations are handled. Without continuous and consistent monitoring and action upon the sensor data, which is provided in real-time, quality of processes cannot improve using WSN.

Trust between supply chain actors is important for the adoption of WSN. At FR, it took over a year of lobbying with a long standing partner air-carrier before the carrier accepted WSN within their processes. Apart from safety concerns, the carrier perceived WSN as a means for the forwarder to ease allocation of liability in case of temperature deviations. Although WSN technologically facilitate monitoring and intervention at every (mis)step of subcontractors, FR regards this highly undesired and practically impossible. Still, in its currently proposed form, forwarders are the only party that have complete overview of the collected temperature data, making carriers dependent on forwarders for insight into their performance and proper (non-)disclosure of measurements to third parties.

At carrier AC, the strategic implications of this are also considered in adoption deliberations: WSN allow forwarders to increase the value that they provide to shippers relative to carriers, while simultaneously increasing the control over carriers. WSN is a technology that requires cooperation by forwarder and carrier to successfully improve a pharmaceutical trade lane (an outcome that benefits both forwarder and carrier). However, its overall benefits are skewed towards the forwarder and may allow room for misuse as a policing tool. To allow adoption throughout the value chain, the belief that the technology will be utilized for shared benefit instead of individual gain, a part of trust, must be developed sufficiently between forwarder and carrier to support the focus of improving the value to the common customer, instead of improving value over each other. A method of safely developing this trust, as displayed by carrier AC, is to run a fixed-time pilot project for WSN.

The processes of collecting sensors after transport to return them to their origin for reuse, collectively known as return logistics, require significant amount of operation, as observed at FR , and perceived at AC from experience with Envirotainers, large refrigeration containers that require return logistics too, yet are less numerous and more valuable. The operational cost of return logistics may be *solved* by lowering sensor unit prices to make it economically viable for sensors to be disposable after use, however this is not to be expected in the short term.

The adoption of WSN is fragmented over many technologies and many actors. There has not (yet) emerged a single dominant standard or technology. This makes the number of technology options large and their continued support by the industry uncertain. At forwarder FR's main site, another forwarder has installed a competing, incompatible infrastructure network. At carrier AC, it was indicated that the speed of development of the technology and the large number of technologies pushed the choice of a technology further into the future. Further, the decision to adopt a technology is dispersed over many actors, that due to the diverse technology offer have, invested in different technologies that they now have an interest in succeeding.

Our case study confirms that although many technological challenges remain, the use of sensor technologies to detect deviations and prevent damage to sensitive goods at any point in the supply chain, requires that LSP's share data in real-time that have been collected from their business processes, and may hold information that is considered sensitive. To share information in real time is a technological achievement, yet the technological challenge is found to be less complex than the organizational and political challenges [41]. The use of a multi actor view and a process adoption model can aid in understanding the impact and interplay of various factors (theoretical contribution of this study) but at the same time these insights can support practitioners in successfully managing introduction of WSN in supply chains (practical contribution of this study).

In future research we plan to explore various routes. Firstly, similar studies can be conducted in comparable case settings to replicate the findings and explore the generalizability of the findings to comparable high value supply chains. Secondly, over time we plan to follow this case study to collect more longitudinal data as the WSN technology progresses, the organizational capabilities develop, and factors such as standardization and regulation mature. Thirdly, we plan to explicitly address the inter-organizational business case for WSN. While frameworks and methods are available in the literature to assess cost and benefits of WSN across a supply chain [3], [7]-[8], [35] in our case study the business case was only implicitly addressed and only by supply chain actors individually. Finally, we aim to study the inter-organizational governance mechanisms at play. What governance of the WSN is needed to optimally serve the cold chain? Is there a role for third parties or alliances to achieve a sustainable and high quality real-time monitoring solutions? What technologies can aid in establishing trust and willingness to share information? In [19] and [40] protocols are discussed to transfer ownership of tags between supply chain participants. If after ownership transfer, prior organizations should not be able to access the tag's data, a trusted third party (TTP) is always required to prevent current owners from accessing the data. Both studies propose a transfer protocol, designed for security, but neither addresses organizational and political issues to the sharing of tags and the resulting data. The benefits and impacts on adoption of such technologies should be explored. We hope such studies will contribute to a higher level understanding, an increased awareness, maturity and knowledge on how to manage WSN adoption in multi-actor supply chains.

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