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Adoption of wireless sensoring for pharmaceutical logistics

A case study on the adoption of an inter-organizational system by competing, mutually dependent actors within a logistical value chain.

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Management summary

Pharmaceutical goods are of high value and highly sensitive to temperature. This is why they are transported in a cold chain: a logistical value chain where every logistical service provider (forwarder, carrier, handling agent) takes precautions to keep the temperature of the goods within a specified range. However, this cold chain often fails: research by the World Health Organization and others show that due to temperature control issues, up to a third of vaccines do not survive the transport from origin to destination, while this transport may form up to 80% of the vaccine costs.

Wireless sensoring is a technology that allows real-time and continuous monitoring of the temperature of pharmaceutical shipments. By automatically notifying supervisors of dangerous changes in temperature before the goods are damaged, individual shipments can be saved, and flaws in transport processes improved. This does require cooperation and information sharing between logistical service providers.

By adopting wireless sensoring, logistical service providers increase their value proposition to clients, as is agreed to by forwarders and carriers alike. Yet, the adoption of this technology develops slowly, and meets resistance from those same stakeholders. This forms a paradox that is researched by means of case study at one adopting forwarder, one (for now) non-adopting carrier, and a sensoring technology provider.

Results show that the adoption of wireless sensoring requires development of a strong organizational culture aimed at removing all temperature deviations from the transport process; and, a sufficiently developed level of trust between forwarder and carrier to use wireless sensoring for mutual quality improvement instead of liability allocation and individual gain; further, the significant organization that is required for the coordination of reuse of sensors is a deterrent; also the adoption decision for a single trade lane is fragmented over many stakeholders while these stakeholders may have invested in different incompatible sensoring technologies, as there is yet to emerge a dominant technology or standard. Finally, the analysis shows that wireless sensoring allows multiple business models, the currently proposed one of which is more advantageous to forwarders than it is to carriers.

Recommendations to the participating air-carrier are firstly to start testing with wireless sensoring as it will take time to develop the experience required for managing continuous public scrutiny of process quality; secondly, to cultivate trust in relationships with partner forwarders of equal ambition levels to allow focus on mutual improvement instead of liability allocation; and thirdly to delay adoption of wireless sensoring with non-partner forwarders until a more equally advantageous business model of wireless sensoring is available. Recommendations to the participating wireless sensoring technology provider are firstly to continue research into founding a trusted service provider, as it may mitigate the adoption delaying factors regarding stakeholder trust, the fragmented technology landscape, and the organization of sensor reuse, and allow a business model equally advantageous for forwarder and carrier; secondly to provide guidance to clients in developing their organizational culture and skills required to perceive wireless sensoring as a necessity.

1. Introduction

Summary: Wireless sensoring is a new technology that may improve the quality of transport for temperature-sensitive pharmaceuticals. However, the technology requires cooperation and information exchange by competing parties in the logistical value chain. This research aims to describe the adoption process of wireless sensoring technology by a logistical value chain through use of a case study at two logistical service providers. In this case, a paradox is apparent: technology that would save valuable of euros meets resistance from stakeholders. The factors driving this paradox are analyzed and explained, to facilitate the future design of an approach to stimulate adoption.

In this research, a logistical value chain for temperature controlled transports, or cold chain, is studied in its natural context, in which different stakeholders – shippers, carriers, forwarders – make up a complex whole through which pharmaceuticals are airlifted and shipped over the entire world. In this case, a paradox exists: like in all 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. Technology to help prevent this is available, yet remains in little use thus far, as there seems to be resistance against the technology from different stakeholders. This paradox is object of study for this research.

1.1 Wireless sensoring in pharmaceutical logistics

Wireless sensoring is a technology that may improve the quality of transport for temperature-sensitive products, in particular pharmaceutical goods. 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 these logistical service providers (LSPs), pharmaceutical goods are incidentally exposed to temperatures that are either too high or too low, resulting in costly losses. For instance, Matthias & Robertson (2007) show 14% to 35% of international vaccine transports to irreparably damage the vaccine, and Blake (2008) shows 32% of major deficiencies in pharmaceutical transport recorded by UK government inspectors is related to temperature monitoring and control. Wireless sensoring 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, for wireless sensoring technology to be successful, it requires cooperation among the logistical service providers. The collected temperature data must be shared outside the organization that it was collected from. This data may be considered sensitive, since it discloses the organizations' performance.

In this perspective, wireless sensoring is an inter-organizational information system (IOS). A description of the adoption of this technology as seen from within the potentially adopting organizations in a logistical value chain, may prove valuable to future implementations of IOS technologies; more on this issue will be discussed in chapter 3. A practical result of better understanding the adoption is to facilitate further use of wireless sensoring, a technology that holds the potential to increase value for *all* its participants.

Existing scientific theory may assist in identifying the individual factors that are of influence in this case. Prior research on IOS adoption identifies antecedents and factors that influence organizations and individuals in their decision to adopt or reject a technology, e.g. Rogers (2003); Tornatzky & Fleischer (1990); Iacovou, Benbasat, & Dexter (1995). This research approach of identifying the independent factors to inter-organizational technology adoption has recently been applied to adoption of ERP2 (another form of IOS) in e.g. Koh, Gunasekaran, & Goodman (2011), and adoption of RFID (a predecessor of wireless sensoring) in e.g. (Tsai & Tang, 2012). 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 an ongoing process in which actions of individual organizations may influence the decisions of others. The process-based technology adoption model that Kurnia & Johnston (2000) designed (hereafter: K&J model) supports this notion. In this model, Kurnia and Johnston build upon the earlier work of e.g. Tornatzky & Fleischer (1990) in that factors from technology, organization, and the environment influence organizational actions, but also acknowledge that organizational actions may modify these factors in return and affect adoption by the chain as a whole. The presence of a paradox indeed suggest the influence of multiple opposing factors, and multiple actors are required to adopt for the technology to be successful, therefore the K&J model allows a more comprehensive analysis of this adoption compared to single factor models.

1.2 Problem statement

The objective of this research is primarily to explain the reasons behind the delay in adoption of the technology and propose which factors require action in order to overcome the stakeholders' difficulties in the most apt manner possible. The second objective is theoretical in nature: to show which factors from the existing scientific models are active in this real technology adoption situation. The problem statement for this research is defined as:

Explain the adoption of wireless sensoring in a pharmaceutical logistics value chain in order to understand how to progress it.

The remainder of this chapter describes research questions and section overviews.

The problem statement is analyzed by use of the case study research method. The subject of research, 'technology adoption by value chains', is a complex phenomenon with unknown dynamics. For instance, the information exchange between competing parties is a sensitive subject. This prefers a case study over surveys and formal interviews, sacrificing scale (generalizability) for better understanding of a smaller setting. Further, a case study allows exploratory research, whereas testing an adoption model only by use of surveys or formal structured interviews, would have limited the results to the vocabulary predefined by the tested models and their questionnaires. A case study, aiming to understand each potential adopter in-depth, may have had uncovered details that expand these models.

To answer the question posed in the problem statement, the case study should gather evidence of influential factors and organizational actions regarding wireless sensoring, to compare with known adoption factors. This is reflected in RQ4 and RQ5.

RQ1. Who are potential adopters and stakeholders of wireless sensoring in a pharmaceutical supply chain?

RQ2. What flows of goods and information exist between actors in a pharmaceutical supply chain?

RQ3. How may wireless sensoring improve or otherwise affect pharmaceutical supply chain logistics?

RQ4. What considerations and organizational actions regarding wireless sensoring can be observed from potential adopters and stakeholders?

RQ5. How do the observed considerations and actions match to known adoption factors?

The primary instruments in answering RQ1 – RQ5 are interviews with experts, process observations and archive research. The design of the case study research is further explained further in chapter 4.

1.3 Overview of the thesis

Chapters 2 and 3 provide a background into pharmaceutical logistics, and technology adoption theory respectively. Chapter 4 explains details of the case study participants and case study research. Chapters 5 and 6 list the results from the case study and its analysis. Chapter 7 states the conclusion and recommendations to involved parties.

2. Background to pharmaceutical logistics

This chapter aims to provide readers with a general understanding of logistics, specifically the logistics of pharmaceutical goods. It should answer RQ1 (i.e. who are the stakeholders) and RQ2 (i.e. how do they currently interact). Primary sources for this chapter are supply chain textbook (Simchi-Levi, Kaminsky, & Simchi-Levi, 1999) and IATA documents (International Air Transport Association).

2.1 Cold chain, Pharmaceutical Logistics

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.

Regular air cargo is subject to handling in ambient temperatures. These may shift between sub zero and over 30 degrees Celsius. For most shipments these conditions have little or no consequences: Most commodities are less sensitive to volatility of temperature. Pharmaceuticals are sensitive to temperatures: most drugs and other vaccines lose their effectiveness when exposed to ambient temperatures for too long. Further, 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. Cold storage is that 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.

Because of the sensitivity of pharmaceuticals combined with the severe potential consequences of having ineffective or even harmful pharmaceuticals on the market, pharmaceutical producers audit the cold chain before trusting service providers with their goods. This process may take years and includes various trial runs. For logistical service providers (LSPs), this process forms a significant barrier to entry to pharmaceutical logistics; consequently, for producers, this process is part of the switching costs between LSP's.

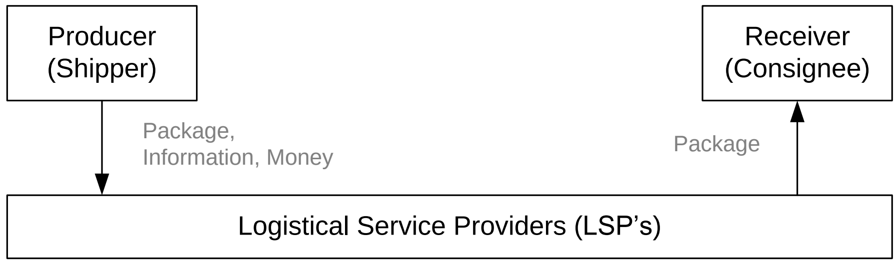

Figure 1. Pharmaceutical transport from producer's perspective

Several governmental and other regulatory institutions (FDA, IGZ, WHO, IATA) require systematic temperature monitoring. This requirement entails installing sensoring of cold storage rooms and periodical auditing; real-time sensor control is not specifically required, but it must be proven upon request that shipments were in certified cold storage for their particular journey.

Pharmaceutical producers add a passive sensor 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. More on the benefits of sensoring will be exposed in the last paragraph of this chapter.

2.2 Overview of stakeholders

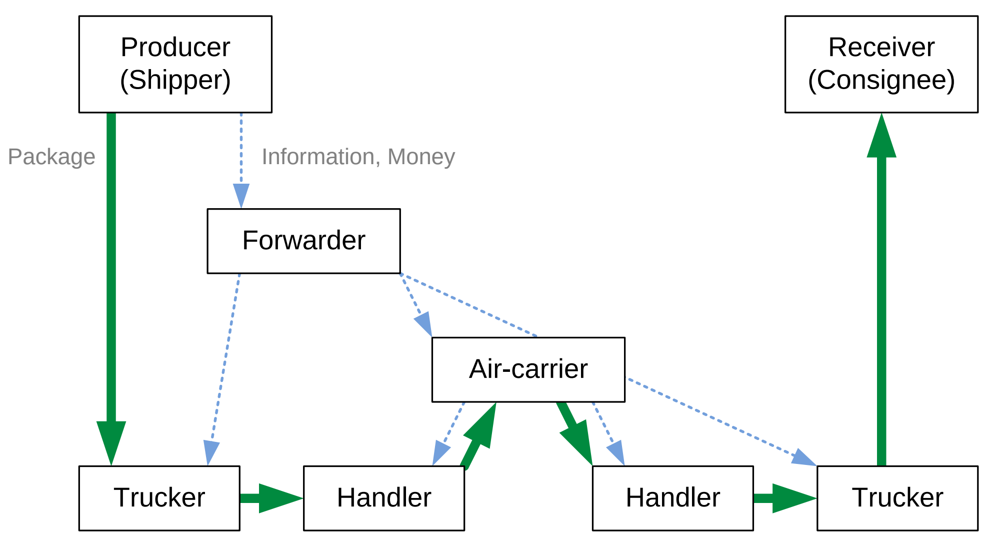

Figure 2. Flow of goods and information between primary stakeholders.

Typically, six organizational roles are involved in the primary process of transporting a parcel through a pharmaceutical supply chain. Parcels are either transported between a pharmaceutical producer and local distributer, in case of approved drugs, or, in case of drugs pending approval, between laboratories of a pharmaceutical producers. In both cases, the sending actor is called the *shipper* and the receiving party the *consignee*. In case of airlifted transport, a *local trucking provider* receives the parcels from the shipper's factory and transports it to an airport warehouse, where a *ground handling agent* (GHA) accepts the parcels. The GHA prepares it for flight, and loads it into a *carriers* airplane. The carrier airlifts the parcel to the destination country, where another GHA unloads the parcels and processes it for pickup by again, local trucking providers who will deliver it to the consignee warehouse. Immediately before and after flight, local *customs* may require inspection of the goods. Since the orchestration of truckers, carriers, and expertise local customs may lie outside of a typical producer's core business, a *freight forwarder* may offer coordination services, along with consolidation of parcels for the same destination, and preparation of paperwork required for international transport. Upon acceptance by the consignee the transport is complete.

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 a carrier too. Typically, forwarders hire local truckers and a carrier. 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 to adoption.

Wireless sensoring however, does require cooperation from hired parties. For instance, wireless sensors and transmissions are not legally allowed on aircraft unless tested and approved by carriers, and sensor technology may require vehicles and warehouses to be equipped with hardware receivers. Further, the amount of hirable parties may be limited, e.g. for the airport of Schiphol, the Dutch government licensed only eight different GHA. Finally, any corrective action during transport requires activity from the party in possession of the parcel, i.e. truckers, carriers and GHA.

Since forwarders and carriers may offer similar services, they may compete for the door-to-door transport of a shipment. However, each have clearly defined core businesses. Forwarders may integrate to some degree with shippers 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 are not likely to integrate with customer processes.

Forwarders benefit from carriers in that they specialize in exploitation of a fleet of transport craft. The procurement, operation and maintenance thereof in particular regions requires significant investment, and since forwarders may use multiple modalities (road, rail, ocean, air), owning fleets and/or real estate at ports of all of them, everywhere, is a vast undertaking. Carriers benefit from forwarders in that they book larger volumes -, and may consolidate the handling of multiple smaller clients into one, cater to specific client wishes, simplify use of the carrier's service for infrequent reducing booking errors since they are aware of all rules & regulations regarding transport.

The pharmaceutical industry itself is driven by producers, the shippers. This is because it is very resource-intensive to enter this market: researching a product that is successful is a process with low yield. Several phases exist in this process, each with unique characteristics to its supply chain: Before a drug is commercializable, it undergoes various development processes and clinical trials. Shipments then are smaller unique batches and have a high replacement effort. If a drug reaches commercialization stage, shipments are more voluminous, and value loss in product damage consists primarily of lost revenue, replanning and reshipping (Pedroso & Nakano, 2009; Singh, 2005).

Other stakeholders include insurance companies, who in case of damaged goods, provide compensation to shippers, forwarders or carriers depending on who was at fault, the World Health Organization, for maintaining the pharmaceutical industry standard Good Distribution Practices, the international air traffic association (IATA) for maintaining the air-freight industry standard Perishable Cargo Regulations , and government bodies for development and enforcing of (safety) regulations and standards on pharmaceutical transport.

Considering wireless sensoring, stakeholders also include hardware and software technology providers, standardization bodies such as ISO for sensor protocol standards, and air traffic regulators such as the US Federal Aviation Administration and the European Aviation Safety Agency.

2.3 Process description

A consortium of IATA and forwarders, carriers en ground handling agents, have developed an industry standard process model that describes in detail each step in the transport of goods via air-freight, and the information notifications that logistical chain actors share with each other. This model is published and publically available in the Cargo2000 quality improvement initiative (IATA, 2011). Both Forwarder B and Carrier C have adjusted its processes onto it.

The Cargo2000 Master Operating Plan describes ten major milestones that each successful shipment goes through:

- Booked (BKD): a forwarder receives a shipment request from a shipper, and accepts this
- `Pickup (PUP): the forwarder physically retrieves the shipment from the shipper. The shipment is identified by the forwarder using a shipment number and house-air way bill number.
- Forwarder Booking (FWB): the forwarder relays the booking to the carrier, who confirms this. The shipment is identified by the carrier using a master-air way bill number.
- Received from Shipper (RCS): the carrier receives the shipment and has successfully validated shipment information
- Departed on Flight (DEP): the shipment is aboard an aircraft, and the aircraft departs
- Arrived on Flight (ARR): that aircraft lands
- Received from Flight (RCF): the shipment is successfully unloaded from the aircraft

- Notified Forwarder (NFD): the shipment is ready for further transport by the forwarder, and he is notified of this.
- Delivered to forwarder (DLV): the shipment is handed over to the forwarder.
- Proof of Delivery (POD): the shipment is delivered at the consignee.

Currently, pharmaceutical producers add passive temperature loggers to pharmaceutical shipments to prove to consignees the goods are unaffected by temperatures during transport. Verifying the temperature requires physically connecting the temperature logger to a computer, downloading temperature data, and manually checking it for temperature excursions. Logistical service providers keep track of shipment temperature manually by use of measurements of transport times between known cold rooms, outside temperature, and math (observed at a forwarder, November 2011).

In case of pharmaceuticals damaged by transport, shippers may claim for compensation at their logistical service providers. Currently, the claims process starts when a consignee receives the pharmaceutical goods, checks the included passive temperature logger and finds the product exposed to damaging temperatures. The consignee contacts the shipper with the temperature log. The shipper may start an investigation, and claim the cost of shipping at its forwarder or carrier. The forwarder will also start an investigation, and if blame is appointable to a subcontractor, it may claim the damages there. Similarly, carriers may claim at handling agents. All approved claim compensations are in part covered by insurance.

2.4 How wireless sensoring may benefit the cold chain

With wireless sensoring, small sensors are attached to pharmaceutical shipments and 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.

In interviews performed as part of this research, logistical service providers expressed wireless sensoring to help in three ways. Sensoring may detect deviations for individual shipments in real-time, therefore allowing, after notification, the sender or recipient to take mitigating action. For instance, they can cancel further transport if damage is detected, or start a resend process immediately if required. Secondly, quality for sensored shipments is expected to go up: if problems are detected in real-time, they may also be correctable on the spot, or otherwise expose weak spots in the transport process, allowing systematic quality improvement for future shipments; Thirdly, depending on future certification, wireless sensoring may create an audit trail for each individual shipment, thereby simplifying regulatory compliance.

2.5 Causes of damage during transport and damage types

From an analysis of logistical service provider incident logs, it is clear that there can be multiple causes of damage to pharmaceutical transport, and different types of damage. The analysis shows damage types to include:

- Temperatures too high or too low, however also
- Shipments wet, for instance from rain
- Missing boxes, or entire missing shipments
- Boxes subjected to unauthorized opening

Wireless sensoring is only likely to detect temperature deviations. Damage type frequencies were not available.

Causes of the damage include:

- Storage at incorrect temperatures, for instance using a cooling truck when regular transport was booked.
- Data and/or booking errors, for instance specifying pharmaceutical shipments as regular cargo during the booking process, or misrouting it to a different airport than required.
- Facilities or material being unavailable, for instance cold storage being full.
- Delays, for instance Envirotainers (temperature controlled air-freight containers) running out of battery power or dry ice.

This chapter shows how multiple logistical supply chain actors together provide the cold chain. Forwarder and carrier organizations can be simultaneously competitors and mutually dependent on each other. Wireless sensoring allows real-time detection of temperature deviations, enabling intervention before damage occurs. Apart from damage by incorrect temperature, there are also other damage types to pharmaceutical shipments; it is not researched how wireless sensoring affects these.

3. Literature review

3.1 Literature review process

To start the review process for literature that is relevant to the adoption of wireless sensoring in a logistical supply chain, the search query (RFID or "wireless sensor") and ("supply chain" or logistic*) was applied to the libraries of ScienceDirect and Web of Science. 'RFID' and 'wireless sensor networks' are the two major technologies that enable wireless sensoring. The search query yielded over 700 publications, after which the search results were limited to include only publications from 2010 through 2012, since wireless sensoring and RFID are fast-evolving technologies: 84 articles remained. These were manually filtered for relevance on basis of title and abstract, and together with frequently cited publications, reviewed below.

3.2 Wireless sensor technologies and their application in supply chains.

Wireless sensor technologies allow the 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. There exist multiple technologies to fit this description, along with different methods to apply them to pharmaceutical supply chains, and supporting standards for communication and processing.

All wireless sensor technologies 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.

The most defining characteristic of sensor technologies is its transmit *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 (Tajima, 2007). Finally, range has an influence on positioning accuracy: tags with a maximum range of 3 meters must be near the reader while being read, and are therefore associable with a specific task in a business process, e.g. loading a shipment onto a platform; a tag with a range of 100 meters is harder to link to an operational step.

Wireless sensor technologies are generally referred to by the technology family that is used to perform the wireless data transmission. Technologies that perform this function are RFID (radio frequency identification), WSN (wireless sensor networks) and GPRS (general packet radio service).

RFID technology is often described as the successor to barcode technology that does not require line-of-sight and can read multiple tags simultaneously. RFID technology however, can be subtyped according to their power source. *Passive* RFID tags are solely powered by the radio signal emitted from readers; this limits transmission range to 3 meters and their operational zone to the proximity of readers, but allows low tag cost (typically below € 0.10). However, the lack of a power source prevents use of sensors in passive RFID. Active RFID tags use a battery for transmission of data, allowing ranges up to 100 meters, but the operational life is limited to that of the battery, requiring battery recharge after a maximum of weeks, and requiring higher cost (typically ca. €50). Semi-passive RFID use a battery for powering internal circuits including sensors, but not for transmission. This allows them to economically use a battery for sensoring and processing, and a reader's signal to power communication yielding a battery life up to years, but reliable transmit range limited to 3 meters. Semi-passive tag cost is similar to that of active RFID (typically ca. € 50).

Wireless sensor networks (WSN) are similar to active RFID technologies, in terms of power source (battery), reliable transmission range (up to 100 meters), operational life (battery-limited) and tag cost (ca. € 50). 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, wireless sensor networks 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 (Decker et al., 2008; López, 2011).

GPRS-based sensors have a reliable transmit range of up to 25km. These sensors communicate using the GSM-network, therefore require no separate acquisition, installation and maintenance of readers at organizational sites, and allows sensors to have global network coverage similar to that of cell phones. GPRS sensors can therefore easily be deployed anywhere without cost of reader infrastructure. This is offset by subscription to a 3rd party GSM network and a higher tag cost: typically upwards of €350. Since they use a battery power source for both sensoring and communication, operational life is limited to that of the battery, a maximum of weeks.

In supply chains, RFID products have been primarily applied to reduce inventory inaccuracy, the bullwhip effect and their consequences, to limit shrinkage (theft and oth er 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 (Ngai, Moon, Riggins, & Yi, 2008; Sarac, Absi, & Dauzère-Pérès, 2010). Wireless sensors in supply chains are primarily aimed to monitor perishable and otherwise temperature sensitive cargo, e.g. (Hsueh & Chang, 2010; White & Cheong, 2012; Yan & Lee, 2009;Amador & Emond, 2010; Dada & Thiesse, 2008).

For application in a pharmaceutical supply chain, the most significant indicator of quality during transport is the mean kinetic temperature, or MKT, of the shipped pharmaceuticals (Elliott & Halbert, 2008). There are two distinct methods to estimate the MKT using wireless sensor technology. The first, labeled the *Eulerian* approach by (Montanari, 2008), is to carefully monitor the temperature of all locations that a shipment can be located in(e.g. warehouse, truck, etc.), together with outside temperature, and to carefully measure the durations of transit between locations. By averaging the temperature of each location according to the time spent within it, an estimation of the mean kinetic temperature can be derived. This technique is also used in sensorless or manual auditing environments. This method depends on continuous and reliable monitoring of storage and transit areas being available and functional at all locations. This is required by regulation on handling of pharmaceutical goods, e.g. (GDP, 2009), but has been known to fail (Blake, 2008).

The second technique, labeled the *Lagrangian* approach by (Montanari, 2008), is to affix one or more sensor-tags to each product, or other object of interest, to monitor the temperature near the object itself, wherever it is transported to. Note that depending on the cost of a sensor-tag, accuracy may vary, in that one sensor's data may be assigned to cover a single box of pharmaceuticals, or an entire pallet of boxes, where temperature may differ significantly between any two boxes (Amador & Emond, 2010; Jedermann, Ruiz-Garcia, & Lang, 2009).

Finally, it should be stated that there is no single standard yet that covers all functions that are required for sensoring. The RFID-based sensors adhere to the ISO 18000 family and, in scientific publications, frequently the EPC Global EPCIS network architecture. For instance, (Chang, Son, & Oh, 2011) developed a tracking system specifically for use in air-cargo, based on passive RFID and EPC Network. WSN sensors, if using open standards, are based more frequently on the IEEE 1451.x and OGC SWE architecture, due to their elaborate support for functionality for sensor functionality. Unified standards are being worked on, but are not currently available, nor accepted by vendors (López, 2011).

From the above it follows that multiple technologies and different approaches are suited to aid in wireless sensing in supply chain scenario's. The above technologies are each suited to provide wireless sensing and collection of measurements, although some are better suited to particular environments than others. 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.

3.3 Adoption of RFID and wireless sensor technologies in supply chains

Understanding the difference between adopting and non-adopting companies may be relevant for the successful introduction of a framework to exchange temperature information and for coordinating joint intervention.

Adoption of RFID technology is a frequently recurring theme in the literature on RFID. This may be due to a difference between the potential and actual benefits of RFID technology (Tajima, 2007). In their literature review of RFID research, Sarac et al.(2010) note that although '*Enterprises generally conduct pilot projects to validate [RFID] technology in a limited environment*', there are '*not many real supply chain applications yet*.' In the literature from 2010 to 2012, research is aimed to identify the factors that influence the decision to invest in RFID technologies, or the intention to do so. To understand the forces that affect adoption of the framework joint decision making with potentially conflicting interests, it is useful to summarize these factors here.

Seventeen distinct factors have been found to influence the adoption of RFID and sensor networks in supply chains. These factors stem from adaptations to two theories: the Diffusion of Innovations theory (Rogers, 1962, 2003), and the Technology Organization Environment framework (Tornatzky & Fleischer, 1990). The DOI and TOE theories explain the rate of adoption of a new technology within cultures and other social structures, including industries and within supply chains.

DOI and TOE attempt to explain organizational behavior as well as that of individuals, contrary to other technology adoption theories (i.e. TAM, TPB, and UTUAT).

DOI classifies adopters based on the earliness of adoption: innovators (first 2.5% to adopt), early adopters (next 13.5%), early majority (34%), late majority (34%) and laggards. The adoption by the early majority, is linked to the emergence of a dominant strategy for use of the technology (Rogers, 2003). That is, once it is known how to successfully apply a technology, the technology is more likely to be adopted by users. The existence of an accepted standard may facilitate in the emergence of a dominant design (Koh et al., 2011). Further, DOI formulates the existence of *opinion leaders*, whose approval of a technology is copied by potential adopters, provided the decision is not forced, e.g. a collective or authoritative decision. By influencing opinion leaders, adoption may be controlled. However, this is only effective in an environment that is generally supportive to different ideas and innovation, a *heterophilous environment*. Contrary, innovative ideas in *homophilous environments* are seen as controversial, and supporting these may cause an opinion leader to lose status.

Both DOI and TOE identify factors that influence adoption, that relate to characteristics of the *technology* and of the adopting *organization*. TOE also adds a third context, the organization's external *environment*, wherein it conducts its business, and finds its customers, competitors, partners, regulatory institutions and government. DOI identifies the organizational characteristics that stimulate adoption: organization leader's positive attitude towards change, decentralized power and control structures, informal procedures, large organizational size, slack in resources, presence of complex knowledge and skills, interconnectedness of internal groups, and openness to information from outside the organization. TOE agrees with this and identifies a lower level of formalization, existence of linking structures, communication processes, and larger size and slack. The technological characteristics that DOI (Rogers, 2003) identifies are

- *relative advantage* – "the degree to which an idea is better than the idea it supersedes".
- *compatibility* – "the degree to which an innovation is perceived to be consistent with the existing values, past experiences and needs of potential adopters".
- *complexity* – "the degree to which an innovation is perceived as difficult to use".
- *trialability* – "the opportunity to experiment with the innovation on a limited basis".
- *observability* – "the degree to which the results of an innovation are visible to others adopters".

The adoption factor of relative advantage states that adopters compare new ideas to the idea that they find to supersede it. That means that adopters compare monitoring and intervention based on wireless sensing to what they currently have in-house, which is the use of hindsight-temperature loggers, barcode technology, and possibly passive RFID. For the framework to be adopted, judging solely on relative advantage, the framework should either convince adopters that wireless sensing is a superior alternative to these other techniques, or support data gathering for these other techniques too.

TOE and DOI assume that a technology is adopted by a single individual or organization. However, in the case of wireless sensing in a supply chain, the maximum benefit is only possible when supply chain partners collaborate; hence, the unit of adoption can be considered not just a single individual or organization, but rather a full (logistical) supply chain.

Therefore, inter-organizational variables are relevant. In research of adoption of EDI systems, Iacovou, Benbasat, & Dexter (1995) find that the *perceived benefits* of the technology, and *organizational readiness* (having the required financial and IT resources) are relevant, and that *competitive pressure* and *trading partner power* are of influence too. More recently, Koh et al. (2011) have researched antecedents to adoption of ERPII systems, or systems that provide "full collaboration in the supply chain". Between adopting organizations, the *trust*, *power structure*, *existence of shared goals*, *priorities* and *culture*, and having *similar IT capability* have been found relevant. Also, the existence of accepted *standards* for *data exchange*, and information sharing initiatives, helps adoption. *Knowledge* of one's *business*, *enterprise*, *processes* and presence of *pre-existing*, already *efficient IS* also positively influence system adoption. Finally, similar to TOE and the model of Iacovou et al. (1995), factors from organization's external environment, such as *social pressure* from competitors and customers, and *regulation* and *sponsorship* from vendors and government, may also be of influence (Koh et al., 2011).

3.4 Information sharing in supply chains

Finally, 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 (Yang & Maxwell, 2011).

From the selected literature, it follows that an organization's *willingness* to share information with any other partner, and after that the *completeness*, *openness*, and *truthfulness* of their information sharing is dependent on several characteristics of the exchange. These characteristics can be linked to the relationship between sharing partners, and a specific information exchange between them.

For the relationship between partners in an information exchange, the trust between two partners is a strong determinant in successful information sharing. Kwon & Suh (2004) state that "in high-trust relationships, [parties] are not afraid to share all information and believe in the content of the information received". However, "trust decreases when there are concerns of *autonomy loss* and information misuse by other organizations that would *incur liabilities* for the sharing organization" (Yang & Maxwell, 2011).For interpersonal relationships, trust consist of benevolence (the belief the other party will act in best interest of the relationship) and competence (the belief that the other party can perform to promise); For trust between organizations, the competence factor is found more relevant than benevolence, since the emphasis in supply chains is on results(Fawcett, Jones, & Fawcett, 2012). The required level of trust for information exchange has been researched by Fawcett et al. (2012) and Du, Lai, Cheung, & Cui (2011). Both publications link the level of trust to types of information exchange: A low level of trust limits exchange to formally defined, only-what-is-agreed data exchange; Higher levels of trust facilitate voluntary, pro-active, share-anything-that-is-helpful information exchange. Both researchers find that the low trust exchanges are a required stepping stone to grow into higher, collaborative information exchanges. Other relational factors that influence information sharing are commitment (e.g. Kwon et al., 2004; Müller & Gaudig, 2011), connectivity (Fawcett, Osterhaus, Magnan, Brau, & McCarter 2007); power symmetry, interdependence, reputation of the sharing organization, organizational cultural similarity (Yang & Maxwell, 2011).

Concerning characteristics of the information exchange itself, the use of incentives/premiums, presence of specific investments/asset specificity, frequent meetings, explicit contracts, monitoring of information exchange, verifiability of the shared information, technological characteristics (similarity of data formats, existence of data standards), concerns about data security and unauthorized access, and compatibility of information sharing with existing processes affect information sharing (Kwon et al., 2004; Müller & Gaudig, 2011; Yang & Maxwell, 2011).

Information sharing, such as in the considered framework, is not only affected by the characteristics of the information exchange itself, but as much by the relation between the parties that share information. If this is possible, the framework should foster creation of trust between parties.

3.5 Supply chain visibility

Supply chain visibility refers to the degree of which information is available to supply chain participants. Zhang, Goh, & Meng (2010) refer that supply chain visibility can be decomposed into inventory-, demand-, and logistical visibility. Similar to Bardaki et al. (2011), they propose a mathematical model to measure supply chain visibility within a supply chain as a whole, and from the point of view of a single participant, based on the ratio of the information that is available to participants, versus the information that is available in total. Both models allow discussion about how a single unit of information is counted, and do not account for the time value of information, i.e. the delay before information is available. To help compare visibility levels achievable by different technologies, supply chain visibility modeling may help, but the listed models need to be adapted to measure the difference that real-time knowledge makes. Information only has value if it affects the course of action; the value of information is then is equal to the value of the different course of action, compared to the course of action without the information.

3.6 Ownership of tags

Yang (2011) and Kapoor et al.(2011) discuss protocols to transfer ownership of tags between organizations, c.q. supply chain participants. If after ownership transfer, prior organizations should not be able to access the tag's data, Kapoor et al. (2011) determine that a trusted third party (TTP) is always required to prevent current owners from accessing the data. Both publications propose a transfer protocol, designed for security, but neither publication addresses organizational and political issues to the sharing of tags and the resulting data.

3.7 Processual-based view of IOS adoption

Kurnia & Johnston (2000) note that organizations are not only subject to influence by the above factors, but may themselves also modify these factors, indirectly influencing the technology adoption outcome within a network of organizations. By acknowledging that organizations may influence the factors, it becomes necessary to split up the dimension of External environment into that of the Industry environment (that an organization can influence) and the true External factors (that an organization cannot influence, e.g. socio-economic conditions). The model is based upon earlier research in which the external factors are not only Acts of God but wherein the influence process is multilateral.

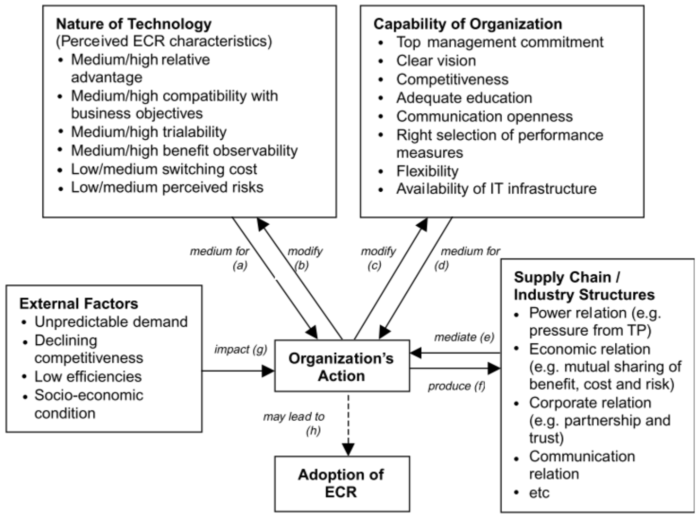

Figure 3. Kurnia & Johnston (2000) process model of technology adoption

An illustration of the model is given in figure 3.

The model's dimensions are based on a synthesis of earlier research. The Nature of Technology is a derivative of Rogers (2003), whose contributions to this research field has been mentioned above. The capability of an organization borrows elements from Tornatzky & Fleischer (1990) and Iacovou et al. (1995). The dimension of Supply Chain and Industry Structures is a dimension that Kurnia and Johnston distinguish from the "true" external factors. They suggest several factors which combine into this dimension, such as power relations, economic relations, corporate relations, communication relations, etc. The mix of all these dimensional factors predicts the willingness to adopt a certain technology (in Kurnia and Johnston's example, ECR).

3.8 Conceptual model

To be able to bridge the results to the main adoption model, that of Kurnia & Johnston (2000), that model is abstracted to the conceptual model rendered in Figure 4.

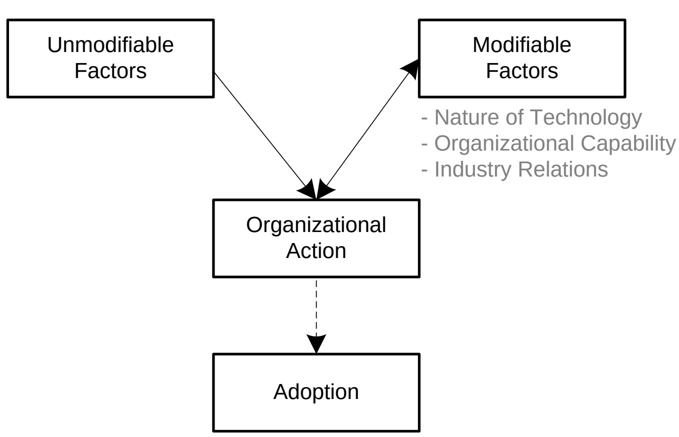

Figure 4. Conceptual model; Arrows indicate influence

Kurnia & Johnston (2000) derive the individual adoption factors from their model from earlier studies of technology adoption; this acknowledges that these factors are subject to development and their applicability may differ from case to case. After removing the explicit adoption factors from the model, what remains are three constructs: organizational *action*, which is influenced by *adoption factors;* most factors may be *modifiable* by organizational action, the remaining factors are *unmodifiable*. The compound of organizational action may eventually lead to the adoption of technology.

4. Case description & research design

4.1 Case study design

A case study is a qualitative research method in which a phenomenon is studied, while it is occurring, in its natural environment. It allows the description and deep understanding of a single occurrence of the phenomenon, at cost of the generalizability of the findings that is more likely using a larger sample size. For this case study, the phenomenon is that of adoption of wireless sensoring in a logistical value chain. This phenomenon is a specific instance of a more general phenomenon: adoption of inter-organizational information system (IOS) technology in a value chain of actors (actors that may have competing interests).

In this case study, three research instruments are used to collect measurements regarding the adoption: (semi-structured) interviews, (process) observation, and archive research. Where possible, the application from these instruments is chosen to have overlapping results, approaching the same aspect of the phenomenon from different angles, and triangulating the measurements. For instance, to understand the requirements for applying sensoring to an existing process, first the current standard operation procedure (SOP) 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. This increases validity and allows a more comprehensive understanding relative to the use of a single instrument, or multiple instruments on disparate variables.

The first objective of this research is to understand the factors in effect in the adoption of wireless sensoring technology for this specific cold chain, so it is important to find out the needs and desires of the main stakeholders in this process. Further, for the case study to contribute to the scientific body of knowledge, the research should aim for balance between connectedness to existing technology adoption theory, while not being restricted by it. Using the conceptual model introduced in §3.8, the aim in the case study is to find evidence of organizational actions, their motivation or trigger (to discern influencing factors), and effect (to discern affected factors). The collection of measurements ends when either the time allocated for measuring is depleted, or when saturation is achieved, meaning that continued use of the different instruments yields no measurements that complement or disprove the other measurements, i.e. measurement may stop when continued measurements yield the same results and form a congruent picture.

There are dozens of stakeholders involved in this entire cold chain, requiring a sample choice. This sample choice is based on the amount of influence in adopting new technology throughout the chain; the likelihood of rendering complementary information; the willingness to cooperate in this research process; and finally and foremostly, in having complementary or opposing interests in this specific cold chain. On this specification, the research focuses on one adopting *forwarder* and one (for now) non-adopting *carrier:* Carriers specialize in execution of inter-continental transport. Forwarders orchestrate transport from producer via carrier, to the final recipient. Together they cover the entire pharmaceutical transport chain, while the most relevant contrast is possible between adopters and non-adopters of the technology. To allow uncensored data collection, all case results have been anonymized. This is summarized in Table 1.

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

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

With the case study participation of company B (adopting forwarder) and company C (non-adopting air-carrier), the most theoretically covering set of two organizations is available, although it is noted that the participation of an adopting air-carrier (mentioned by company B) or non-adopting forwarder would have further enriched the result data. Importantly, a principal provider of wireless sensoring technology participates in the case study, company A. Their participation allows for a broader account of the evolution of the technology and the (influential factors in) adoption thereof.

This particular case study allowed for a single researcher to be embedded for four months at air-carrier C, and for two-and-one-half days of interviews and observation at forwarder B, in three visits. The visits to company B were distributed as one day before the embedding at company C, a half day during, and one day after. The embedding at the non-adopting company C allowed for nearly unrestricted access to the employees and internal processes, while the visits at company B were higher in intensity and more focused on acquiring specific information. The unequal distribution of research time allowed more time to understand the factors involved before adopting (company C), and inclined the time at company B to be aimed at cross-actor comparison of specific issues highlighted from measurements at C.

4.2 Interviews

For the interviews within company B (forwarder) and company C (carrier), the participants were chosen to include everyone with knowledge or influence relevant to the adoption of wireless sensoring.

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 exception to this was forwarder B, for which a journey abroad was necessary, and therefore the interviews had to be planned within a limited time frame.

4.3 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 carrier C, the criterion was to look for processes that would be affected by the implementation of wireless sensoring. 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. The researcher aimed to observe cold chain stakeholders in their natural context, in order to independently conclude what the main motivations would be to choose (or not choose) to accept wireless sensoring throughout the organization. This prevented the organization to answer in a socially acceptable way (in this case, confirmation bias). Together, the observations touched a covering set of the processes involved in handling pharmaceutical transports in the hub.

4.4 Archive 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 incidents were consulted, and various process descriptions, i.e. IATA/Cargo2000 process manual, WHO GDP requirements documents, standard operating procedures manuals.

4.5 Validity

The factors that were identified in the theory of chapter 3, form the basis of technology implementation, and were used to form a systematic framework with which to identify all these factors. The researcher has therefore used a premeditated model for orientation, but did not confine observations to those mentioned in the model only. However, it is true that the researcher had a preconceived idea of the adoption process after studying literature on the topic. In case study research design, such information gathering is always a threat to validity.

Furthermore, two biases may hazard the validity of the results from interviews: the subject of the interviews – the motivation and actions regarding adoption of wireless sensoring, may at times be sensitive, preventing the interviewee from speaking openly. Also, individual interviewees may not be aware of all intricacies involved in the technology and integrating the technology into an organization. Lastly, informants did choose to keep information confidential, rendering some of the valuable information out of reach for the researcher. In order to counter this the researcher has, along with the interviews, also performed process observations and archive research.

Stakeholders were informed about the objectives of this research beforehand. It is well conceivable that stakeholders only rendered information beneficial to their own goals in order to influence other stakeholders in this process. However, at neither of the participating organizations this was detected by the researcher; for instance, organization B genuinely improved its own processes and those of partners using wireless sensoring technology, and has been very open about their own struggle to this achievement.

Next to this, the researcher aimed at non-participant, non-intervening observations. However, since there was a knowledge barrier for the researcher, operators and handlers at carrier C had to explain their actions to the researcher. This means that the observer has influenced the observed, not only by being present, but also by asking the observees to explicitly explain their actions.

The time spent in research at organizations B (days) and C (months), differed significantly; and has affected the researcher in being more perceptive to the issues observable at carrier C than to that of forwarder B.

4.6 Description of participants to case study.

Although Forwarder B and Carrier C perform pharmaceutical shipments together, both parties have a large number of other partners for this purpose too. The main locations of observations and interviews are a hub airport location of forwarder B and the main airport hub of carrier C. Both are airports in Europe, and both in the lower half of the top-30 of largest airport by cargo traffic according to the ACI (2011). Forwarder B hires a ground handling crew at this hub, while carrier C is performing the ground handling function themselves at their main hub airport. Organization C therefore fulfills both role of carrier and that of ground handler. Both organizations B and C are actively committing to Cargo2000, the air-freight industry quality improvement initiative that prescribes basic process templates, key performance indicators and information collection and dissemination among logistical partners. Also, both organization B and C are involved in implementing e-Freight, the air-freight document and process digitalization initiative. Both the committal to Cargo2000 and e-Freight may influence the capability to adopt a digital quality monitoring technology.

Technology provider A develops the software used by forwarder B to translate measurements from various sensor technologies into user-oriented shipment status information.

Forwarder B is asset-light, meaning that it does not aim to own a large fleet of vehicles. Forwarder B does own several warehouses at international airports.

Carrier C operates with a single hub model. This means that all cargo shipments pass through this hub during transport from origin to destination. Carrier C also orchestrates trucking to some extent, a function usually performed by forwarders.

5. Results

The adoption model by Kurni and Johnston (2000) prescribes that the adoption of wireless sensor technology by logistic service providers is not solely dependent on organizational, technological, industry, and environmental factors, but that organizations may in turn influence these factors by their own actions over time.

This section applies the K&J model to describe relevant factors and actions per stakeholder, extracted from interviews and observations during the case studies.

5.1 Company C (Air carrier)

5.1.1 Observable organizational actions

Company C is piloting inter-organizational sensoring technology. The pilot project is executed together with a partner, but Company C is not currently deploying the technology actively. The partner supplies the reading equipment for installation in the Company C warehouses. The pilot has a fixed duration. Company C did not disclose the evaluation criteria for this pilot.

5.1.2 Adoption factors

As an air carrier, company C has expressed multiple factors of wireless sensoring to be relevant to its adoption decision.

5.1.2.1 Potential decrease of value offering towards shippers

Pharmaceutical air freight yields a high profit: the additional services required for cold storage quality preservation are compensated by a high margin. In its current business model, wireless sensoring offers 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 by the forwarder: Carriers then become subservient to instructions from this center. This may lower the profit margin from pharmaceutical services for carriers.

By accepting sensors into business processes, without any control over what is being collected, processed, and stored, and by whom, forwarders gain in control over carriers. The value that is added by individual air carriers to pharmaceutical transport shifts to forwarders, and with interchangeable sensor networks implemented at competing air carriers, the services that carriers offer may become more interchangeable too, similar to how trucking has evolved. Sensoring may therefore lead to higher influence from forwarders on carriers processes, which may affect margins.

5.1.2.2 Real-time information supply

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

5.1.2.3 Sensor radio interference with aircraft electronics

Radio signals from sensor transmissions may interfere 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 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 locality-independent solution to this. However, this requires that a sensor is able to accurately detect when flights are about to start, and 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. Company C's engineering department is yet to give their permission for any kind of wireless sensor. However, several other air carriers are already flying with sensors, and at Company C, a sensoring pilot project, although small in scale, is taking place.

5.1.2.4 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.

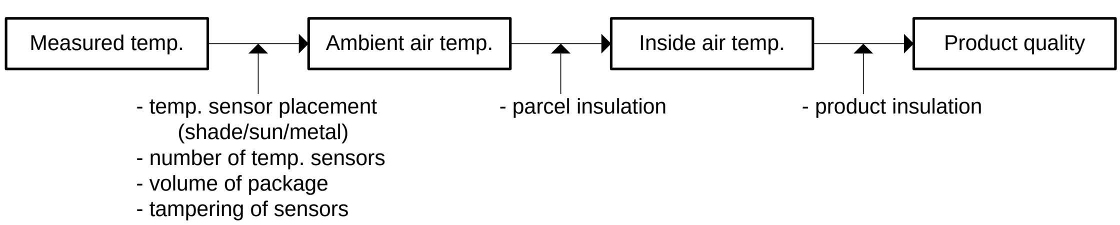

Figure 1. Relation between sensor measurements and product quality: observable phenomena and modifiers.

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 (Jedermann, 2009). Both these extremes may not provide a valid measure for the ambient temperature, to be useful for in quality calculations such as the mean kinetic temperature (MKT).

Measuring the in-parcel temperature is not trivial either: 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 of 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 sensoring 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.

5.1.2.5 Data ownership

Company C expresses concern for who will own the data that is collected by the sensor: 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 sensor, 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 of the parties that pay for any of these contributions to sensoring. The data owner may apply or require constraints on the use of data. For instance, for any party it shares the 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, or choose to delay data sharing by 30 minutes instead of sharing in real-time, or release data only on the premise that it is not suitable for legal purposes. Company C has indicated that it prefers if it would (also) be possible to share data directly with the shipper, to report independently from forwarders, to shippers. Data ownership helps control risks of liability, validity issues, and the load on customer service.

5.1.2.6 Technology stability

Sensoring technology is evolving. Sensors are progressing to lower cost, lower power-consumption, and standardization of interfaces. Common problems in application for aircraft are being researched and developed upon. However, no covering set of standards has emerged for use in sensoring, and sensors are still too expensive not to require organization to re-use them. It is arguable that it is better to defer investment until the next generation of sensors, to prevent buy-in in a soon outdated technology.

5.1.2.7 Increased load on customer service

Company C expects that the 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 is possibly not compensated, as these inquiries are currently not billed.

5.1.2.8 Return logistics

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

5.1.2.9 Insurance against claims

Any compensation that may be awarded by air carriers, as result of a claim of damage to parcels, is covered by insurance for above a set monetary value per kilogram. The insured value of pharmaceuticals is higher than this, yet carrier liability is capped at this monetary value and does not have to pay the rest. This insurance coverage is a small contributor to the total insurance fee that carriers require to operate their fleet of aircraft. Any significant change herein is likely to be insignificant (<1%) to the total fee. However, the damage to the relationship with the customer is considered much more significant in case of damage.

5.1.2.10 Organization of detection and intervention

To maintain current customer satisfaction levels using sensor-based quality monitoring, Company C's capability to intervene on detected temperature deviations is likely to require change.

Company C currently cannot detect every temperature-deviation on pharmaceutical shipments. It does not currently monitor all shipments, its monitoring requires some manual action and may therefore be intermittent, monitoring is based on parcel location instead of parcel temperature while that location is sometimes misreported, and this monitoring only occurs in the hub location. Sensoring allows automatic continuous monitoring of any shipment, based on temperature, in real-time if within range, and during its entire transport. Therefore, it is likely that sensoring will cause an increase of detected (temperature) deviations.

The quality norms that company C uses within its hub are set to place pharmaceutical cargo in the correct temperature-controlled storage area within a set time of flight arrival, and to keep it there until a set time before flight departure. 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 2% to 5% of cold chain shipments. The actual number of claims filed for pharmaceutical shipments is much lower. The ratio of claims to incidents suggests that the current monitoring by shipment location, although intermittent, is sufficient for guaranteeing its quality, assuming that all shippers have filed claims if errors were detected.

However, if company C commits to sensoring and shares measurements in real-time, it is obligated to address any detected temperature deviation equally in real-time. From this perspective, with above incident rates, the company would appear to fail to correct deviations in at least 2% to 5% of relevant shipments in the hub location alone. Assuming the intervention capability remains unchanged but the detection volume increases under sensoring, this is likely to negatively affect customer's quality perception.

The capability to control departments have indicated that this incident list is currently not always used to improve processes. Regarding the main hub, commonly reported causes are parcel congestions, cold room storage scarcity, lack of room for Envirotainers, and it also occurs that it is unclear if a temperature deviation actually took place, due to 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 may not be possible (e.g. understaffing is caused by forecasting inaccuracy and economic climate) or require change of 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 for use of sensoring.

5.1.2.11 System integration

The IT architecture of company C is not trivially extended to handle the processing, storage, and real-time dissemination of sensor data. Company C 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 sensoring and intervention requires data to be exchanged to and from both legacy systems. However, between these two systems data is currently known to show conflicts. Both these systems are based on (IBM) 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, it was faster and more cost-efficient to develop in-house a separate application that uses screen-scraping of the legacy systems, instead of opting for outsourcing the development. A bus-architecture is however in development; this will allow the different systems to exchange data with any compliant system, but this is not expected to be production ready in time to affect adoption of sensoring. Apart from integration with the legacy systems, the in-house development of support for processing streams of large sensor data is also not trivial. The investments required to update the IT-architecture to support sensoring and intervention requires financial resources and non-trivial time to be production ready.

5.2 Company B (Forwarder)

5.3 Company A (Technology provider)

5.3.1 Adoption factors

Company A focuses their efforts primarily on forwarders and shippers, less on carriers.

Forwarders can improve their added value to shippers. Forwarders also see other forwarders using sensoring, increasing the pressure. Forwarders are considering, if not adopting wireless sensoring to better provide in the needs of pharmaceutical producers; to increase the added value of their service to shippers. Real-time monitoring of valuable shipments ofcourse increases this value and creates a unique seller proposition. Ofcourse, if all forwarders do this, the uniqueness diminishes, but the technology will still improve operational processes for adopters. Company B used the technology to improve their own internal processes first. A practical barrier to adoption for currently non-adopting forwarders, is that they do not own most of the warehouses that require installation of readers. Company B and another experimenting forwarder, Forwarder D, do own the warehouses for their tradelanes. For Company B, it was easy to install 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.

Shippers themselves currently have budgets for passive data loggers, up to $60 per single-use logger that Company A aims to redirect towards wireless sensoring (wireless sensors are $20 and dropping). Shippers are hestitant to adopt new technology since they are subject to regulation. Their aim for sensoring is to prove the quality of the product to the consignee; the loggers that 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' pharamaceutical shipper explained that its yearly volume is around 200.000 data loggers. In time, Company A hopes, pharmaceutical companies will demand the monitoring service that early adopting forwarders offer, from currently non-adopting forwarders.

Carriers show a much more wait-and-see attitude towards the technology. One of their concerns is safety; In an meeting, with IATA, Company A, and Company B, another air-carrier announced that they had to reinvent the wheel concerning what to evaluate sensors on. IATA regulation may help with this. Company A considers it beneficial if independent bodies operating on behalf of IATA, the flight authorities EASA or FAA, were to be able to certify sensors such that any air-carrier would be able to accept them without further checks, removing that decision authority from air-carriers. This however takes years, and air-carriers are seen as not supportive to this. Carriers are in a different position than forwarders, in the logistical value chain. They provide airport-to-airport transport, not door-to-door. Forwarders have better access to shippers, to apply sensors, and are each implementing their individual choice from unstandardized incompatible technologies. This makes it hard for carriers to choose which one to support.

Other forwarders are also advancing wireless sensoring. Forwarder E also installed a reader network at the same Luxemburg warehouse that Company B installed its network. It is from a competing hardware technology, CartaSense. Forwarder D is also considering the Ambient technology, and deliberating the installation of a third reader network, next to the Ambient network of Company B and the CartaSense network deployed by forwarder E. 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 Company A, is the understanding and acceptance by LSPs 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 e.g. the wireless sensoring technology correctly. Also at Company B, a decentralized organization, this is apparent: not all sites have equally progressed. Company A perceives that the number of actors in a logistical supply chain complicates the adoption.

Company B deployment started out in Luxemburg, where it is its own GHA, allowing it complete control over operational processes. And it grew from there. Hopefully, this is also the case for Forwarder D. The sensors are already approved by the involved air-carrier, making the adoption for D on a Luxemburg trade lane easier.

Forwarder D already applies RFID sensors for quality monitoring to one of their tradelanes that include Luxemburg airport. Their sensors are passive, with a low read range, and D may be looking for an upgrade that does not involve added steps to place shipments in proximity of a reader. Forwarder D also uses passive RFID, only on an existing trade lane, and has the operational experience to monitor their shipments, although not in real-time. For different forwarders, the adoption is a much larger effort, to change to operational processes. Also, for forwarder D at a different trade lane, this may take more effort.

Forwarder D exclusively owns a monitoring solution/network for Ocean Freight, that Company B is possibly interested in. Company A tries to facilitate an exchange between both Company D and Company B, where D may use B's infrastructure of Ambient readers, and Company B may use D's ocean freight monitoring solution.

The actual roll-out of a reader network is quite easy and cost-efficient, for both Ambient and CartaSense hardware. 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.

Ambient's hardware and software were mostly used for cold room monitoring. Company B chose Ambient hardware because it had characteristics that allowed it to perform both wireless sensoring on shipments, and on cold rooms.

Software development is fully driven by requests from customers. Since the software was sensor oriented at first, Company A developed the concepts of shipments and locations, including alerts for deviations on shipment and location level, instead of alerts on basis of sensors.

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, readers infrastructure would be deployed at key locations in transport, and the USB could be used at the outset stations. Company A relay these requests to Ambient, but such innovation may initiated by both wireless sensor hardware manufacturers (Ambient, CartaSense) but also by current manufacturers of data loggers (Elpro) should they license a wireless technology and add a radio to their existing product.

6. Analysis

6.1 Case results analysis

The paradox that emerged in the introduction, that of a beneficial IOS technology finding only slow adoption, can be explained better after the case study.

Wireless sensoring requires fulfillment of certain responsibilities by supply chain participants. For instance, for sensoring to be possible on 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 sensoring and reader infrastructure.

Although all these responsibilities need to be fulfilled, supply chains are free to configure the allocation of responsibilities among its actors. Certain configurations do imply certain privileges, for instance whoever owns both sensors and reader infrastructure, will always be able to have access to operational performance 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 sensoring requires resources to fulfill both; while detection may be centralized at one actor per shipment, preventive intervention is required to be *at* the shipment, and may require significant investment by the carrier and handlers for it to be 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 organizational culture is important to perceive wireless sensoring as a useful instrument. Forwarder B required two years to train its primary site to perform at a quality level required by GDP, to develop a 'every-packet-counts'-mindset in its crew. Although the same technology and the same processes are implemented at other sites, their quality performance differs. Forwarder B suggest this to be due to differences in organizational culture. At carrier C, 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, the quality of processes cannot improve using wireless sensoring.

Trust between supply chain actors is important for the adoption of wireless sensoring. At forwarder B, it took over a year of lobbying with a long standing partner air-carrier before the carrier accepted sensoring within their processes. Apart from safety concerns, the carrier perceived sensoring as a means for the forwarder to ease allocation of liability in case of temperature deviations. Although wireless sensoring technologically facilitates monitoring and intervention at every (mis)step of subcontractors, forwarder B 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 C, the strategic implications of this are also considered in adoption deliberation: sensoring allows forwarders to increase the value that they provide to shippers relative to carriers, while simultaneously increasing the control over carriers. Wireless sensoring 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 C, is to run a fixed-time pilot project for wireless sensoring.

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 forwarder B, and perceived at carrier C 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 discardable after use, however this is not to be expected in short term.

Finally, the adoption of wireless sensoring is fragmented over many technologies and many actors. There is not (yet) emerged a single dominant standard or technology. This makes the amount of technology options large and the its continued support by the industry uncertain. At forwarder B’s main site, another forwarder has installed a competing, incompatible infrastructure network. At carrier C, 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.

6.2 Theoretical analysis

In the description of results from the previous chapter and the above analysis, the dynamics that underlie the adoption of wireless sensoring by actors in a pharmaceutical logistical chain have been described. This section explains how these dynamics may be attributed to various adoption factors using the Kurnia & Johnston model.

To refresh, the K&J process model of adoption identifies eight causal links between adoption factors and organizational action, rendered in Figure 5:

- 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).
- 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 not a 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)

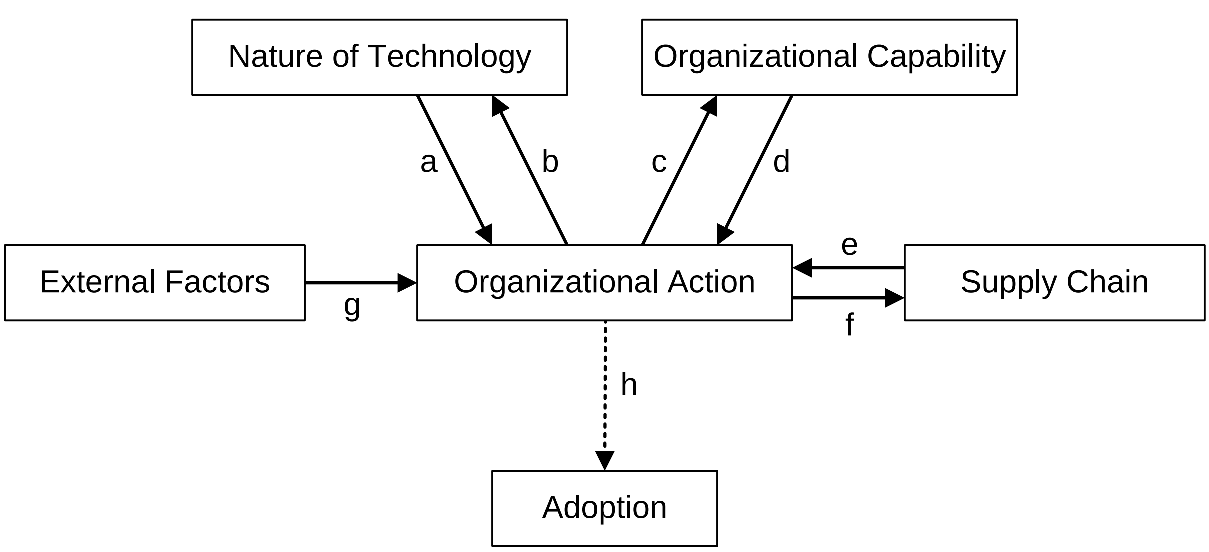

Figure 5. Causal links *a* - *h* in the Kurnia and Johnston (2000) process model

Kurnia and Johnston organize the supporting evidence from their analysis of case studies, into the categories listed above. In addition, they identified the evidence that uses more than one causal relation: For instance a supply chain event that changes the perceived benefits of the technology, is listed as *E, B.* This research follows that organization. K&J develop one single, integrated model for each of their multi-actor case studies. In the analysis in appendix C, this research shows one single evaluation per actor of this multi-actor case study. This allows a separate understanding of the perceptions, actions and influence per actor.

6.2.1 Low level test

To test how the Kurnia and Johnston process model explains adoption using the factor-based models, the results from chapter 5 are matched with the eight causal links. The understanding apparent from factor-based models alone will be available by observing links A, D, G and H. The increased understanding by the use of process model, is available by reading links B, C and E. To test this, every statement in from the results chapter –sentence, or part thereof– has been assigned one or more of the causal links of the K&J model. Every statement that could not initially be placed, was marked, but later found to be placeable with some effort. In a subsequent phase, the individual factors that are mentioned in the K&J model, have been checked with the raw results log.

From this test it follows that the reciprocal influence between organizational action and adoption factors allows the K&J model to identify interactions that traditional factor models that K&J base upon, do not. For instance, it shows the interaction of how a Forwarder actively lobbies at the industry standardization body IATA for regulation on sensor safety procedures, in order to reduce influence from carriers on delaying technology adoption. Also, it shows the process that was required to gain support internally within the Forwarder, by cycling through positive customer feedback, increasing senior management support, and development of requested features.

Being based on time-tested traditional factor models that prescribe adoption factors to be in technology, organizational and environmental groups, the K&J model inherits their qualities. K&J however supplement the factor list with the term ‘etcetera’, delegating the responsibility of comprehensively stating all relevant adoption factors, to the user of their model. This makes it hard to find a phenomenon that cannot somehow be made to fit in the K&J model.

However, when strictly applying the causal links that are modeled, some issues may be identified. K&J for instance state that the adoption factors that affect organization X can only be modified by actions from that same organization X. However, if for instance a technology provider Y were to modify a technology’s sale price, this would affect the perceived trialability of the technology by organization X: Provider Y would through its action, directly modify the perception of the technology by X. This should not be possible according to a strict interpretation of the K&J process model, but arguably occurs frequently in practice. An objection to this may be that organization X does perform an action to modify their perception, for instance in that it needs to inform itself of the price change before its perception of the technology changes. This would require recognition of relatively trivial organizational action, e.g. the reading of whitepapers, to be of similar significance to root triggers, e.g. development of price-reducing technology break-throughs.

Further, the process model, being based on traditional adoption-factor models, is focused on organizations that are considering to adopt technology. However, not all actors that have a strong or active influence in the adoption of the technology are potential adopters: Technology provider A plays a critical role in the adoption of wireless sensoring by other organizations; yet for this actor the technological and organizational factors to adoption are irrelevant, since it does not adopt the technology but provide it.

K&J classify the relations between adoption factors, organizational action, and industry into four groups, being 1) factors influencing actions, 2) industry influencing actions, 3) actions modifying factors, and 4) any compound relationships, for instance factors influencing actions and industry simultaneously. In K&J and for organization B in this research, the latter compound group is significantly larger than the other groups, suggesting that it can be further refined. Further, it may be arbitrary which observations belong to which group: compound groups may be split to form observations in the other groups, and single observations may be composed to form compound relations of arbitrary length.

7. Conclusion

7.1 Case conclusion

This research shows the dynamics that affect the adoption of wireless sensoring technology for the quality monitoring of pharmaceutical transports, in a logistical value chain where most actors are simultaneously mutually dependent on each other, yet also in competition. In order to structure this research, the Kurnia & Johnston (2000) process model was applied to a logistical cold chain case, containing several stakeholders. These stakeholders and their interorganizational relations were studied over a six month period via several instruments including, but not limited to, observation, interviews and archive research. These yielded measurements from which consistent and congruent information were apparent, and therefore adhered to case study research validity standards. The measurements collected at these stakeholders, more specifically a forwarder, an air-carrier, and a technology provider, prove that several similarities in adoption concerns exist at these stakeholders. The weight of these concerns is in the application of wireless sensoring to the organizations, and not as much in concerns with the capability or maturity of the technology.

The culture of an adopting organization must support the continuous improvement of process quality, for the technology of wireless sensoring to be perceived as a useful instrument. A logistical service provider that is to adopt wireless sensoring, requires a culture that is aimed at removing all unplanned temperature deviations, and requires these cultural traits at all actors in its logistical chain, for sensoring to have an effect on the quality of transport. Wireless sensoring provides quality measurements per shipment and in real-time, implying the use of this data to prevent individual temperature deviations from escalating to product damage. This is called pro-active intervention and requires the ability of service providers to intervene for any parcel anywhere in their processes. If the organization does not have this intervention capability, or the intention to develop it, wireless sensoring will not be used optimally.

Wireless sensors collect sensitive quality/performance data within all organizations that they traverse, usable for both mutual quality improvement, or liability allocation, for which the level of trust between measured and measuring organization may not be adequate as of yet. Currently, data is already collected via passive sensoring, controlled by a shipper, in order to find out in hindsight if a shipment has been subjected to critical temperature deviations. If this were to be replaced by any form of real-time logging shared by both stakeholders, mutual trust should be established. In order to make sure that stakeholders do not regard the collection of data as a way of potentially gaining control over the other party, nor as a means to use the data as a source for competitor information, and forwarders and carriers more specifically, will have to be able to rely on the other stakeholder with access to the information.

Both the participating forwarder and air-carrier have expressed concern over the investment required in organizing return logistics of wireless sensors. Since the physical sensors at the time of the interviews were not yet affordable enough to discard after single use in an economically feasible fashion, sensors need to be collected from destinations for reuse. Tracking and coordinating the sensors' return adds a significant workload to the logistical service provider.

The authority to adopt a technology within logistical value chains is fragmented over many actors, and none of the (incompatible) wireless sensoring technologies has emerged as dominant, further dispersing the attention of actors. For each vehicle or storage object that pharmaceuticals traverse during transport, there may be a customer, operator, object owner, ground owner, government authority and multiple industry bureaucracies whose approval or certification is required for the use of wireless sensors or the installation of reader infrastructure. This slows down any form of adoption.

Summarizing, it can be said that the main barriers to technology are not technological of nature, but rather a matter of priorities and stakeholder quality approach, trust between carrier and forwarder, return logistics of the individual physical sensors and the fragmentation of decision over many actors. In order to implement any kind of standard technology, these barriers must be considered and overcome first. This process will require time, as mutual trust is a factor that does not come in existence overnight.

7.2 Recommendations

With the preceding conclusions, it is possible to state recommendations to further the goals of participating organizations concerning wireless sensoring.

7.2.1 Recommendations to technology providers (Company A)

Provider A has deliberated the idea of founding a third party service provider, to offer a public hardware reader infrastructure, that LSPs and Shippers can make use of. This would free those clients from installing and maintaining a global reader infrastructure individually.

The idea of a third party infrastructure provider (TSP) may solve many of the issues found to delay adoption. By leasing the use of the infrastructure, clients are more free of their choice of sensoring technology: the risk of investing in a technology that evolves not to be dominant or standard compliant, is now at the TSP.

Should the TSP support multiple sensoring technologies, this would hedge against the risk of investment in an obsoleting technology, and further abstract the technology choice for the client, allowing clients to simply acquire 'certified sensoring' with the TSP, instead of dealing with complexities of technical ownership.

For this same purpose, the TSP may also consider leasing sensors to clients together with the infrastructure. Given the global network that is required for the infrastructure maintenance, the TSP may also provide a distributed network for supporting return logistics of sensors.

For any of the above, the TSP requires trust from potential clients to not be partial to a single LSP, to be competent in its service, to continue to exist, and to ensure security of collected data on shared infrastructure.

Finally, the use of a TSP is the only way in which a carrier may directly provide temperature data to a shipper, without a forwarder accessing that data first, using only one single sensor for the door-to-door process: sensor data management by a TSP is a solution to the benefit asymmetry favoring forwarders in the currently prevailing business model of wireless sensoring. Therefore, the initiative of a wireless sensoring TSP should be subject of further study.

However the acquisition of global reader networks and their maintenance may be an issue, it appears not to be the primary cause of adoption delay. This primary cause seems to be developing awareness, motivation and skill to fully conform to a zero tolerance of temperature deviations level of process quality, such as implied by (the complexly documented) GDP. Once given this mindset, the clear benefits of real-time wireless sensoring should appear naturally to potential adopters. Apart from providing the technology, a new service to clients may therefore be to guide them in how to optimally implement the technology within their company.

7.2.2 Recommendations to air-carriers (Company C)

In the case of wireless sensoring in its current business model being favorably considered, three recommendations to air-carriers appear from the case study.

Firstly, start private testing with sensors as soon as possible, for it will take effort and time to develop the current operational procedures to those that are ready for the continuous public scrutiny that wireless sensoring entails.

Secondly, develop trust in relations with partner forwarders to form a shared responsibility of the quality of transport of pharmaceuticals (opposite to mutual liability allocation). Choosing a forwarder with an similar quality of processes and quality aims may help in reducing friction while developing quality services together.

Finally, do not allow unrestricted use of wireless sensoring by non-partner forwarders until there is better control of the collected data, or until internal processes are prepared for continuous public scrutiny, or until sensors have developed to measure the actual product quality, or the internal temperature of parcels.

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