Use of sensor networks at logistics and supply chains market sector

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Abstract

In this paper Wireless Sensor Networks (WSNS) are presented thoroughly on an extensive level summarization. I focus at important factors need to be taken into consideration so that adoption can become easier. Every field of the supply chain and logistics market sector is presented using real type scenarios. The importance of differentiation and improvement is mentioned as also the choice of WSNS over RFID(Radio Frequency Identification) in supply chains. Still WSNS have not been massively adopted. I have prepared a qualitative case study of the ongoing adoption of WSN in a Pharmaceutical Cold Chain to prevent loss of high value shipments. A high importance note is given on overview of a WSN device its working ecosystem and the recent developments and outlooks. The study demonstrates that adoption process cannot be supported without understanding the process view contribution. Introduction of WSN'S is easier adopted after an inter-organizational view approach. Afterwards first findings are presented over the considered efficient application of wireless sensor networks in logistics. Accounting efficiency and metrics are being brought and deeply analyzed as described. Production costs are being mentioned helping the adoption of the WSNS as they get lower, introducing automated monitoring processes and considering investments as supported technology. Moreover a recommendation is being given on how companies can increase value capture through their supply chains relying on IOT platforms and accelerated advancement performances.

Keywords : Wireless Sensor Networks, WSN , RFID, Supply Chain, Pharmaceutical Cold Chain, Logistics, Ecosystem, Inter-organizational systems adoption.

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1 Introduction

Wireless Sensor Networks (WSNS) offer a variety of capabilities, which make their deployment very promising for several application areas with logistics and supply chains being two of them. Supply Chains need to be increasingly responsive to meet the needs of changing markets and customer demands. A sensor is a device that provides feedback on a physical process or substance in a predictable, consistent and measurable way. Smart sensors are different than typical general sensors as they use advanced platforms with onboard technologies such as microprocessors, storage, diagnostics and connectivity tools. All of those connect to each other and transform traditional feedback signals into true digital insights. All WSN consist of the same three basic components: i) sensor-tags ii) readers iii) 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 received by tags. Middleware is software that collects various measurements from readers and processes them in a usable form by existing organizational information systems. One very defining characteristic of sensor networks is their transmission range. A range longer transmission increases probability of a tag being in range of a reader network and show it send information regarding possible deviations as soon as they occur. A longer range than 3 meters requires presence of a battery in the tag to power transmission.

On the other flip of the coin logistics is a multi-player business which has changed significantly in the last decade. Some driving factors are smaller batch sizes (because of customization and individual orders) or by technological changes (RFID). RFID described as Radio Frequency Identification is a wireless communication between objects or tags and readers to automatically track and identify such objects. WSNS offer additional advantages over the use of RFID for supply chain management as tag transmission range is limited to several meters from the reader.

Very few studies have addressed adoption of WSNS. As technological barriers are being addressed the focus seems to shift to the organizational and inter-organizational factors. The costs of a lack at insight and limited ability to respond are high. A research question is being given thoroughly in my paper: How can the adoption of WSN in supply chains be explained? This question is answered using a process view adoption model and a case study of WSN adoption in a global pharmaceutical cold chain. Within this project my researches have gathered on studying the applications of WSNS in logistics i.e. transport of food where e.g. WSN nodes are attached to goods (mostly food because of the perishable content nature). Good are loaded from a warehouse to a freight vehicle in which their nodes need to be self-organizes to form a network of nodes. My research also is referred to new opportunities being created due to rapid developments of Cloud Computing and Internet of Things (IOT) which better integrate the real-time conditions of physical resources. The Cot has emerged as a promising framework and technology solution to integrate the distributed physical resources and manage the things in terms of cloud services in a scalable and flexible manner which can be seen as interfaces independent from location and accessed with simple and pervasive methods. As a conclusion we are going to talk about recent developments and outlook of smart sensors. As the global market of smart sensors is growing at a 19% annual rate it is expected to reach 60B$ by 2022. Technological advances have miniaturized the devices, improved performance and energy efficiency and reduced production costs. Smart sensor computing capabilities have strengthened substantially, thereby enabling data processing and analysis at or near the source ("edge computing") and reducing the amount of data that moves between the device and platform. Ending up with logistics it is crucial to mention that improvements by a better food transport logistic are among others the reduction of food scrap, improved food quality and better visibility of risks along the food transport chain. Logistics benefit clearly from Wireless Sensor Networks. However the requirements of logistics for applicable WSNS are challenging. Several research references will be given upon system architecture and deployments.

Figure 1: The smart sensor ecosystem

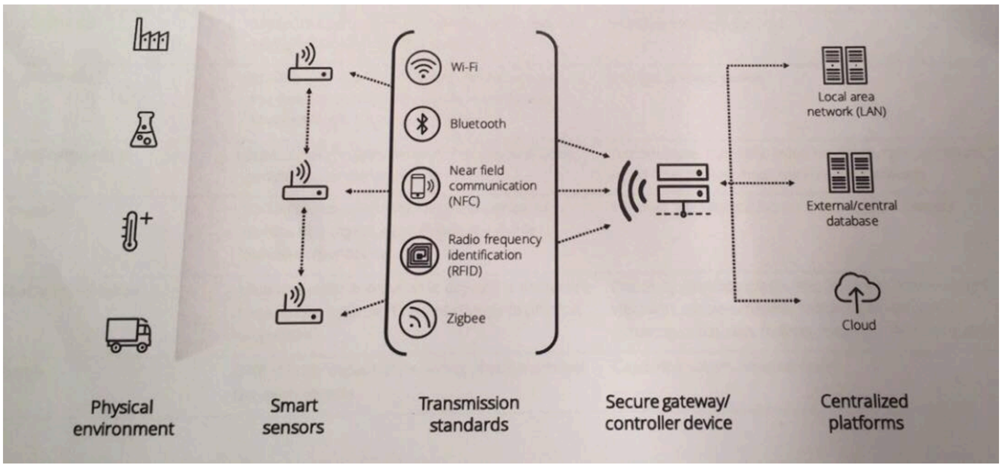


Figure 2: Types of smart sensors

Type	Definition	Example
Acoustic	Recognize audio vibration or frequency to determine activity, location, intensity	Piezo microphones, electret microphones, condenser microphones
Chemical	Measure fluid composition and concentration of biological/chemical compounds	MEMS technology, fuel cell
Electrical	Identify and examine changes or disruptions in electrical or magnetic signals based upon environmental inputs or conditions	Voltage, current, power
Environmental	Monitor and assess deviations in physical state, conditions, or surroundings	Temperature, humidity, color, moisture, light, pressure, liquid flow, air flow, heat, surface temperature
Image	Convert light waves into electrical signals to constitute a digital, optical form for visible condition monitoring	Infrared, ultraviolet (UV), visible spectrum camera
Motion and force	Measure static and dynamic objects to determine the amount, type, and rate of change to physical properties	Proximity (ultrasonic/acoustic, infrared), strain/weight, vibration, accelerometers, shock accelerometers, gyroscopic, position, motion, magnetic field, rotational
Touch	Detect body capacitance during physical contact between objects	Capacitive touch, resistive touch

2 Research Method

I will talk about how I did my research and how it was conducted.

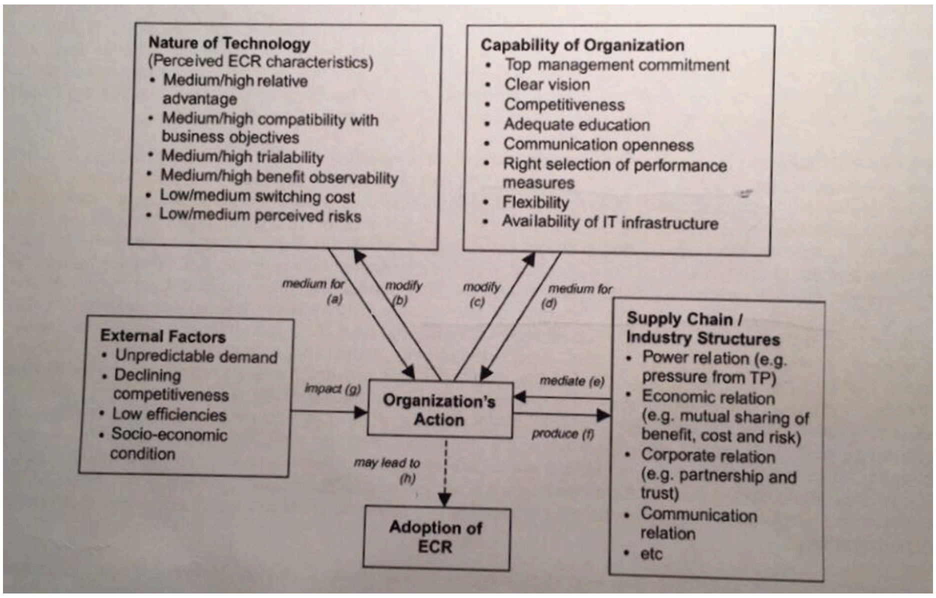
2.1 Multi-Actor Qualitative Case Study

Adoption method cannot be applied without underlying factor of various actors in a cold chain: i) The Air Carrier (AC) ii) The Forwarder (FR) iii) The Software and Sensor Technology Provider (TP). A qualitative case study allows the description and detailed understanding of a single occurrence of the phenomenon, at cost of the generalizability of the findings that can be achieved using a larger sample size. A more comprehensive understanding relative to the use of a single instrument, or multiple instruments on disparate variables.

2.2 A Process View On Wireless Sensor Network Adoption

The K&J model, is an inter organizational process-view adoption model used to introduce a sensor network adoption system. It is selected to analyze the case study findings. External adoption factors are subject to organizations outcome but can be indirectly influenced within a network of organizations. K&J model splits up into 4 big factors that influence organization's actions which leads to ECR Adoption. Those are i) Nature Of Technology 2) Capability Of Organization 3) External Factors (External Environment) 4) Supply Chain / Industry Structures. I therefore put the equivalent figure right below:

Figure 3

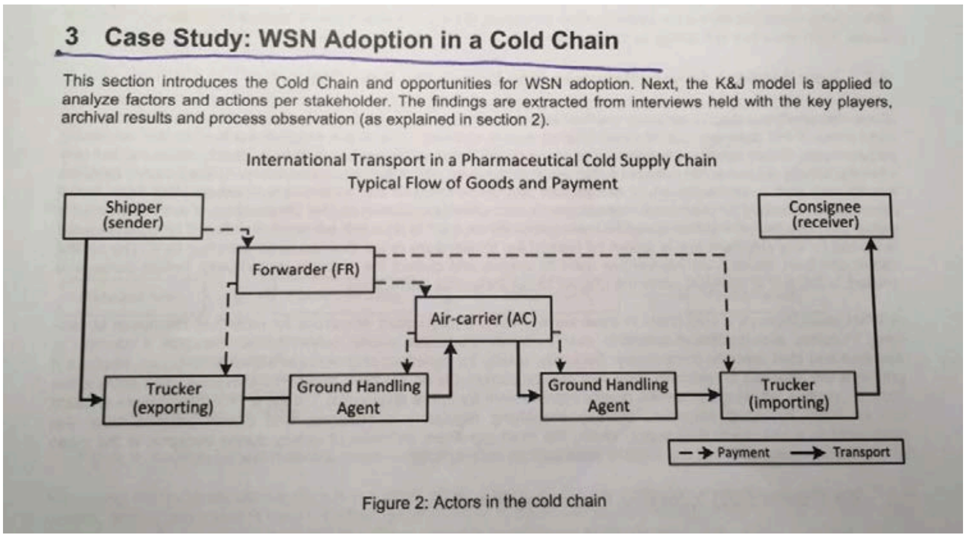


2.3 Archival Observation

In addition to observations I pay attention at temperature deviations and at which specific moments these problems are most likely to occur. Log files of errors and claims investigations were used and various process descriptions, International Air

Transport Association (IATA) Cargo 2000 process manual, World Health Organization’s (WHO), Good Distributions Practices (GDP) and variable requirements documents.

Case Study Number : WSN Adoption in a Cold Chain
This section introduces the Cold Chain and opportunities for WSN adoption. Next, the K&J model is applied to analyze factors and actions per stakeholder.


3 Case Study: WSN Adoption in a Cold Chain

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

Figure 2: Actors in the cold chain

2.4 How Wireless Sensor Networks May Benefit The Cold Chain

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

A WSN could improve a cold chain in 3 significant ways:

- Deviation detection for individual shipments in real time allowing the recipient to alter any business processes and/or damage is detected and start resending immediately.
- Quality for censored shipment is expected to go up because if problems are detected in real time they may also be correctable on the spot or otherwise expose weak spots in the transfer process allowing systematic quality improvement for future shipments.
- Thirdly a WSN may create an audit trail for each individual shipment, thereby simplifying regulatory compliance, and claims process alike.

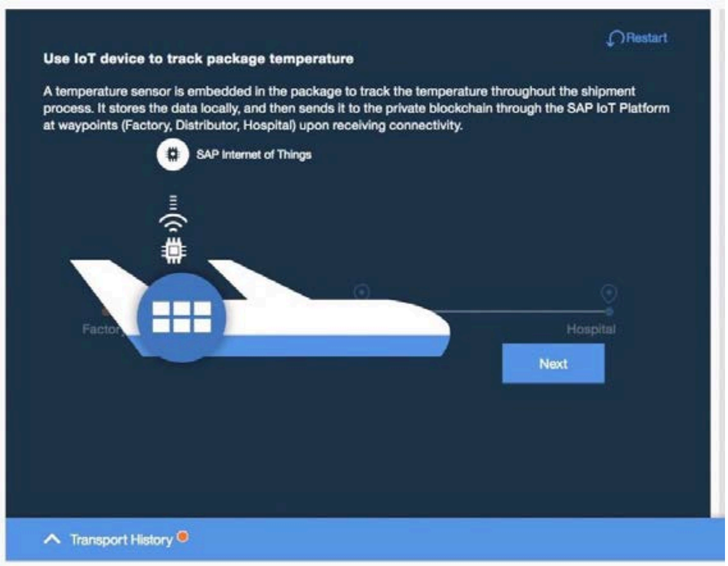
2.5 Real-time Information Supply

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

2.5.6 Sensor Radio Interference with Aircraft Electronics

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

for usage of these kinds of sensors. However, this barrier may slowly disappear as several other air carriers are already flying with such sensors. Also within AC, small scale tests were conducted in the sensor pilot project with the forwarder.



2.5.7 Cost of Sensors

Shippers themselves currently have budgets for passive data loggers of up to $60 per single-use logger. Technology providers aim to redirect this spending towards wireless sensor networks and services (wireless sensors are $20 a piece and prices are dropping). Shippers are hesitant to adopt new technology since they are subject to regulation. Their aim for Sensor networks is to prove the quality of the product to the consignee. Eventually, technology providers hope that pharmaceutical companies will demand the monitoring service that early adopting forwarders offer. This will convince non-adopting forwarders to adopt sensor networks as well.

Below I am going to mention some general value drivers for smart sensors that improve the supply as a market sector generally.
Smart sensors increase the level of automated collection and processing of data and broaden management visibility across the supply chain to help companies reduce operating costs, improve asset efficiency and generate incremental efficiency.

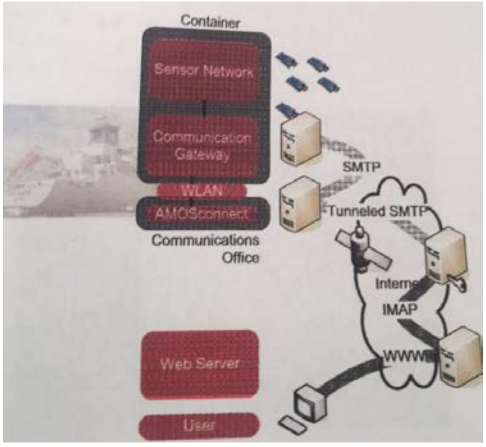
Logistic Applications with Wireless Sensor Networks

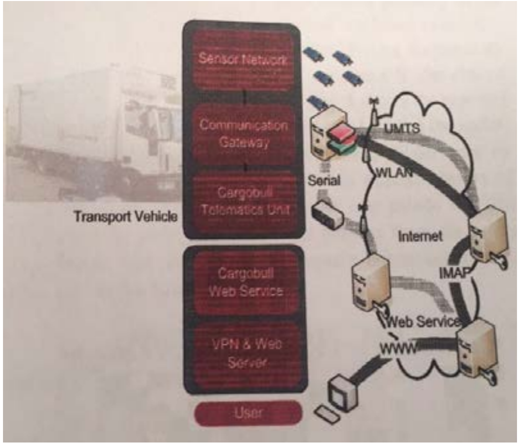
A small brief up:
Logistics benefits clearly from Wireless Sensor Networks. However, the requirements of logistics for applicable WSNS are challenging. I have deployed WSNS in several food transports and I am reporting on their experience and state research challenges with mobile WSNS.

I. System Architecture And Deployments

Mentioned deployments can be divided into land and sea deployments. One deployment was with a food distributor to hotels and restaurants in a delivery vehicle. Another deployment was in a storage facility for food ripening. Yet another deployment was in two cargo containers on a vessel from Central America to Europe.

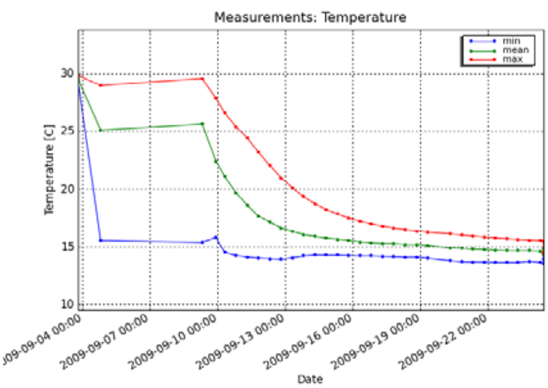
The food was monitored especially for temperature and humidity. Sensors for the monitoring of ripening gases, such as Ethylen are in development.





A. Gateway
The architecture differs mainly in the uplink of the Wireless Sensor Network gateway. For the sea transport the satellite system on the vessel was used by connecting the cargo containers' WSN gateways to the vessel's network via WLAN. The satellite system (Stratos/Xantic/AmosConnect) is providing a Simple Mail Transport Protocol (SMTP) server, which was used for delivering the messages to the satellite system. The messages are then sent over the satellite link to an Email Server.

For the land deployments the uplink was provided in a different way. The gateway (the same hardware as for the sea deployment) is equipped with WLAN and UMTS cards and is able to choose between them according to application profiles (based on security, cost, etc.). Additionally as future logistic WSNs would be tightly integrated with telematics units, a current telematic unit can be used for data transmission as well. The telematic unit is additionally providing further information such as location, ignition state, refrigeration unit state, etc. This data is provided by the telematic unit operator, it is accessible over Push Web Services and is integrated with the WSN data on the Django Web Server. The user can currently access the information using his web browser and an RSS feed reader.



B. Wireless Sensor Network
The WSN consists of 20 sensor nodes and was running a modifie networking protocol. The application was extended to store measurements and to flash memory as well. A watchdog component has also been integrated to make sure the nodes are awake and in a working state. The watchdog is resetted in the Medium Access Control sublayer send function. The nodes were enclosed in water resistant housings with pressure compensation units because of the expected pressure and relative air humidity changes.

EXPERIENCES

During logistical deployments several experiences are made. This section describes the experiences that are deemed as important for logistical applications.

A. Signal attenuation

The major challenge discovered, when WSN nodes are deployed in the cargo container densely packed with fruits, was the signal attenuation. The attenuation was even higher than with previous preparation tests, which were executed with fruits which are being transported every two weeks in average. During that time fruits lost water content and the surrounding air was of higher relative humidity compared to the conditions at the start of the transport due to the cooling unit.

The higher attenuation by the high relative humidity in the air and moisture on the housing results in a lower connectivity between nodes and leaves nodes without connectivity to any neighbor node, although the distance to the closest neighboring nodes is only 50 cm in average.

Future Directions In Truck

For a full support of the general application area Logistics, more challenges have to be solved.

Telematics Units

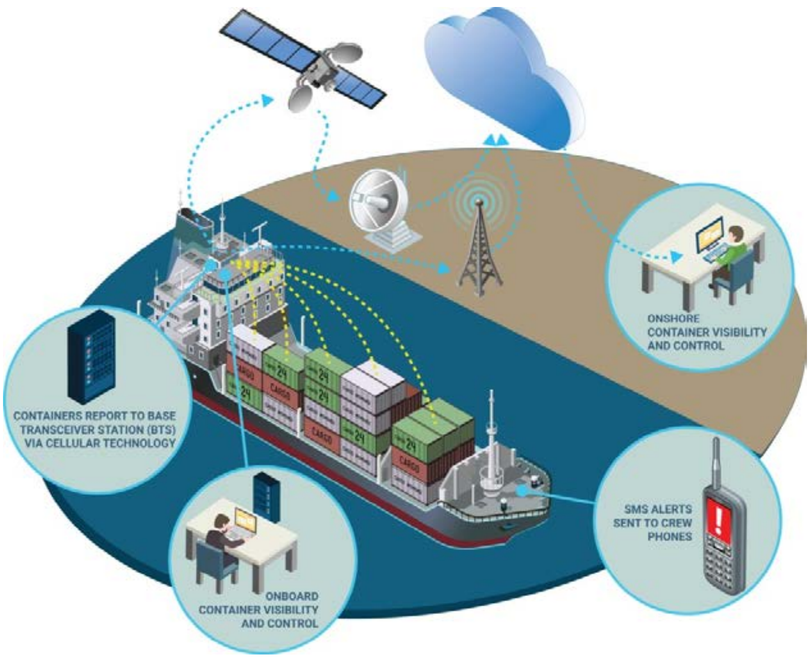
Telematics units are already present in many currently built freight vehicles. Those telematics units usually have hard-wired sensors attached. Those sensors could be replaced with WSN nodes, reducing the need for wiring the vehicle (which is one of the main cost factors of equipping a vehicle with a telematic unit). Additionally, WSN nodes that belong to freight owners could be integrated. Research should work on preprocessing the data on the telematics unit, taking into account the ownership of the goods and the nodes. The additional supervision service might get billed to the sender of the good. Methods to configure the supervision, for billing and notification of the owner should be researched.

B. Service Discovery for WSNs

One of the challenges of general-purpose WSNs in logistics includes self-configuration of sensor nodes especially in the case of mobility (typically present in logistics). When a node enters a new WSN, e.g. as in fig. 1, it needs to configure the channel, acquire connectivity within the network and to the gateway. Additionally the node has to figure out, where to send its data to (a database at the gateway, in the

network behind the gateway, in the Internet). WSN for logistics are very likely not tailor-made WSNs, but general-purpose WSNs with tailor-made services. Logistics involves many parties (senders, shippers, receivers). The WSN nodes are thus of different ownerships (e.g. the gateway node belongs to the container owner, the freight supervision node is owned by the sender or the receiver), are possibly of different hardware platforms, have different supervision algorithms (depending on the good to supervise). A WSN in logistics would therefore be made up out of nodes which are greatly varying. Tailor-made WSNs (e.g. based on query-based protocols) would therefore not be applicable, but standardized protocols which allow for dynamic reconfiguration are needed. In addition to globally standardised physical layer, medium access control, and networking protocols, a mechanism for solving the typical dynamic application layer problems in logistical applications is needed. One such mechanism are service discovery protocols. The protocols are distributing available services in the network. Nodes could then discover services at their current location and could reconfigure themselves to integrate in the prevalent network. Exemplary services of Wireless Sensor Networks are:
_ Measurement and supervision services (e.g. humidity, temperature, gases)
_ Identification services
_ Gatewaying services
_ Database services
_ Data processing services
_ Time service

The solution needs to enable service discovery between Wireless Sensor Networks and Internet Protocol Networks, so that nodes in a local-area IP network can discover services in the Wireless Sensor Network (shown in figure 8a) and vice versa (shown in figure 8b). In logistical applications special sensors are for example gas detection sensors and door opening sensors, which are required for food environment monitoring and container or warehouse security violation detection. Simple WSN nodes with usual sensors have to deliver the data to an IP network, the location of the delivery is likely to change before, during and after transport, so that the need for discovery of the delivery location as shown in figure 8b is obvious. The shown use cases are just two examples of many use cases in logistics and even more in other application domains (e.g. smart grids). A generic solution for across-network service discovery thus has high applicability for the shown and mentioned uses cases. The common service discovery solutions for Internet Protocol (IP) based networks are extremely resource demanding, so that they are not feasible in this form for the resource constrained devices in Wireless Sensor Networks. The devices are particularly constrained in terms of memory, computational power, communication bandwidth and energy. Thus new and adapted methods (e.g. by employing the Trickle algorithm).

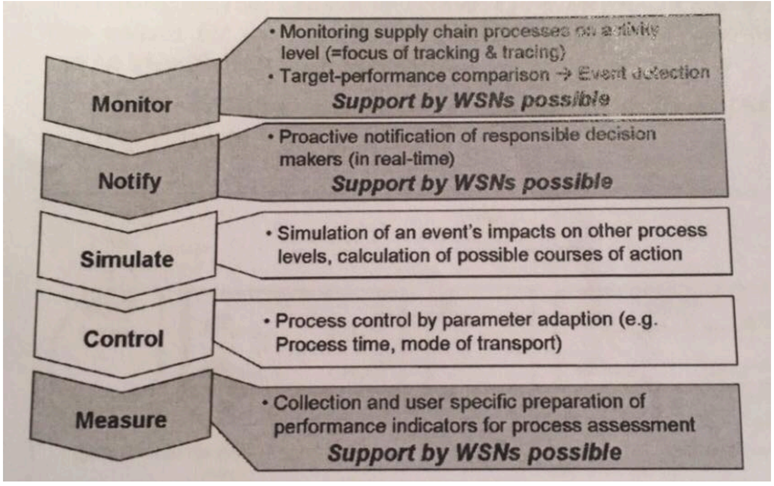


REQUIREMENTS FOR THE USE OF WSNS IN LOGISTICS

In Section II, we have presented possibilities for the use of WSNs in the domain of logistics. To realize the described potential inherent by this technology, several requirements have to be considered. As these requirements have quite different origins, we distinguish four different categories of requirements:

• Technological Requirements: Comprises properties and constraints of the applied technology, e.g. energy constraints of WSNs.
• Economical and organizational requirements: Comprises economic constraints and potential needs for the integration in an existing infrastructure, e.g. cost-benefit ratio for deployment of WSNs.
• Regulatory requirements: Comprises constraints by law and standardization bodies, e.g. usable frequency bands for transmission.
• Logistics market specific requirements: Comprises properties and constraints of the application domain, e.g. massive cost pressure.

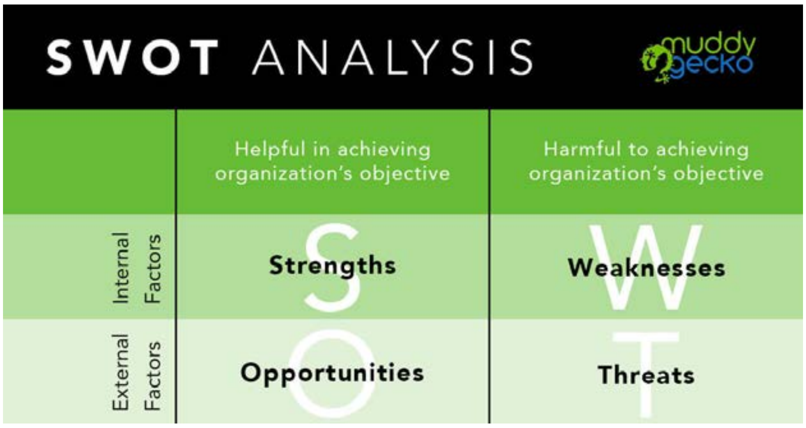
Additionally, interdependencies and conflicting goals between these requirement categories exist. For example, a redundant deployment of motes is preferable as a consequence of technological requirements to ensure functionality despite individual mote failures. But, this implies higher costs, conflicting with logistics market specific requirements. As we have seen in Section II, enhanced information availability can be exploited in several ways and can lead to significant benefits. But this enhanced information availability realized by WSNs does not come for free. Therefore, and especially against the background of the massive cost pressure in the logistics market, a sufficient cost-benefit ratio must be ensured as part of the logistics market specific requirements. Consequently, a thorough and detailed investigation of the economic value of a specific WSN deployment in a logistics context should be mandatory. Unfortunately, most often a technological view focusing on technological requirements only is chosen.



UPCOMING

SWOT ANALYSIS :

In my SWOT analysis all the forces are being analysed and explained in questions style.



- **Strengths**

Company profile
Several companies attributes—strategy, business model, finances—play a critical role in the choices a company must make about smart sensor deployment. Key Considerations include:

1. How can smart sensor integration support your supply chain strategy?
2. What challenges in data collection and aggregation do you currently face?
3. How can automated data generation and edge computing support improvements?
4. Are the financial and operational goals for the supply chain clearly defined?

- **Weaknesses**

Operating environments and locations

Identifying how and where the sensors will operate can provide valuable understanding of the type of sensors required, the infrastructure needed to support smart sensors, and the variety of supply chain insights to be gained. Key considerations include:

1. How do current environmental conditions impact your supply chain?
2. What type of capital assets do you own and how can they be smart sensor Enabled?
3. Are your supply chain resources concentrated in one area or are they distributed nationally or globally?

- **Opportunities**

Investment

Though technology advances are driving down the cost of smart sensors, building the Technology stack to enable a smart sensor ecosystem requires significant investment in product software and hardware, security tools, networking, storage, and systems Integration . Key considerations include:

1. What additions to your current IT infrastructure will be required to support a smart sensor ecosystem?
2. Should you build these additions internally or outsource?
3. How should you be structured to support longer-term growth and agility in the face of continuous technology advances?
4. Are there sensors or connected devices already being used today?
5. If so, how are they being integrated ?

- **Threats**

Security and risk

Adding sensors to the supply chain could potentially create hundreds, if not thousands, of new surfaces for cyber-attacks. Deployment of sensors across the supply chain requires heightened awareness of vulnerability and an intense focus on protecting systems. Key considerations include:

1. Are you capable of defending against the types of cyber attack vulnerabilities introduced by smart sensors?
2. How well do you know and understand your current data?
3. How will your data governance need to be amended to include smart sensor information?

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