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RFID in Maritime Container Logistics

A Delphi Study on Participant Specific Benefits

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About the autor

Thomas Will holds a diploma (with honors) in business informatics from the University of Trier. He is research associate at the Institute of Business Logistics and General Management at the Hamburg University of Technology (TUHH). In his PhD project he develops and implements a software prototype to accelerate container logistics, using the technologies RFID, SOA and software agents. He has been involved in many industrial projects dealing with IT systems and logistics.

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ISO – Organization for Standardization
RFID – Radio Frequency Identification
OBU – on-board units
WSC – World Shipping Council

1. Introduction

Asking experts for the relevance of RFID in a specific application area such as container logistics, some will call it a key technology, some will name it “gadget”. This study will contribute valuable data for this discussion, by identifying and clarifying the benefit of RFID in container logistics. Compared to other studies this work does not only focus on different benefit areas such as Tower et al. (2005, p.9), but also takes into account that the transport chain participants have varying degrees of benefit in different areas.

This work starts with an introduction into the RFID technology and a description of relevant RFID transponders (license plate, shipment tag and eSeal), followed by a brief comparison these transponders. Chapter 3 discusses the different benefits of RFID in container logistics and distinguishes between RFID benefits that embrace technology-based benefits and RFID-based information benefits that comprise benefits based on information generated through RFID. The latter group is very difficult to grasp, wherefore we designed and accomplished a Delphi study to estimate the participant specific degree of benefit. Chapter 4 starts with a brief explanation of the chosen methodology and its application, followed by a discussion of the aggregated and detailed results. Finally, chapter 5 concludes the study’s results and gives an outlook on the perspectives of RFID in container logistics.

2. RFID Technology

Thursday, 11th November 1886 can be seen as the birth of *radio frequency identification (short: RFID)*. On that day, the German physicist Heinrich Herz was able to transmit electromagnetic waves from a sender to a receiver (Fölsing 1997, pp.275-276), wherefore he is often seen as the father of this technology. Several other physicists developed on wireless telecommunication and Robert Watson-Watt investigated in the 1930s, more precisely in until 1935, the first usable radar system in the USA. During the Second World War, the military heavily used this application for their purposes. They take the advantage of the echo principle, where a radar system sent out radio waves, which were reflected by objects (e.g. airplanes) and received back by the system. This allowed the radar system to precisely locate the object as well as its speed. The convergence between radar and radio technology was the basis for developing RFID. Driven by several military developments, RFID entered civilian applications in the 1960s in the shape of electronic anti-theft device (Kummer et al. 2005, pp.12-13; Tellkamp 2006, p.44; Rieback et al. 2006, p.62).

RFID names a technology based on wireless data transmission between a data storage unit (*tag* or *transponder*) and a read/write instance (*reading device* or *reader*). The transponder is affixed to the object that should be identified and the reader can, via an antenna, read data from the transponder and sometimes even write on it (cp. Figure 1). As generally accepted, "reader" names devices that may also be able to write data (Finkenzeller 2003, pp.6-7; Franke & Dangelmaier 2006, pp.8-9; Kern 2006, p.13; Kummer et al. 2005, pp.12-15).

A passive transponder consists of a microchip that stores data and is activated if it is located in the electromagnetic field of a reader and an inductor, which is used as an antenna, sends data to the reader. From this sending and receiving results the madeup word "transponder", which is composed of "TRANSmitter" and "resPONDER" (Franke & Dangelmaier 2006, pp.8-9; Kummer et al. 2005, p.15).

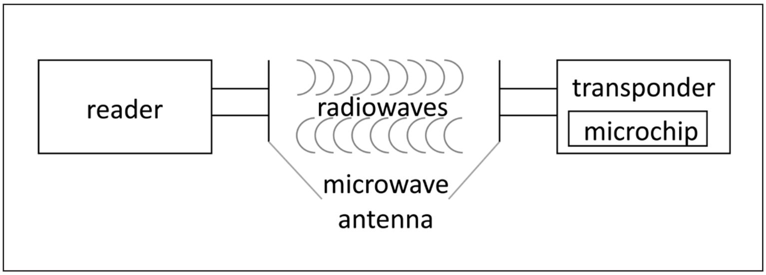

Figure 1: RFID system functionality

In general, RFID transponders are categorized according to the following differentiators: storage structure, energy supply, frequencies and reading distances. The RFID tags can have one of the following possible storage structures (Gillert & Hansen 2007, pp.147-148):

- Read-only transponders store specific data. In general, a serial number is stored during the manufacturing process, which can extrinsically be read but not changed. Nevertheless, internal data change, such as changing an eSeal status (cp. section 2.1), are possible.

- Write-Once-Read-Many (WORM) transponders store specific data as well (a serial number in most cases). In contrast to read-only transponders, data can be stored while putting it into operation. After this first write operation, data changes are no longer possible.
- Read/Write transponders are many times readable and (re)writable.

The energy supply divides RFID transponders into three groups (Lampe et al. 2005, p.73; Finkenzeller 2003, p.13; Kummer et al. 2005, pp.15-18):

- Passive RFID transponders do not own a power supply and use the magnetic field energy generated by the reading device for running the microchip as well as for sending the data.
- Semi-active or semi-passive RFID transponders feature an internal battery for running the microchip, but use the field energy of the reader for sending the data.
- Active RFID transponders use their internal battery for both, running the microchip and sending the data.

Brown (2007, pp.69-70) states also a fourth transponder type, the so called „chipless tag“. They do not have an internal circuit chip to encode the data. Instead they store data permanently on the surface of various materials. Thus, these transponders are read-only.
The frequencies, commonly used by RFID systems, are located within four frequency ranges (Finkenzeller 2003, pp.161-181; Kern 2006, pp.44-46):

- Low frequency, LF: 100 KHz – 135 KHz
- High frequency, HF: 13.56 MHz– 40.68 MHz
- Ultra high frequency, UHF: 433 MHz, 868 MHz (Europe & a few far Eastern countries), 915 MHz (USA & Australia), 950-956 (Japan)
- Microwave frequency, MW: 2.45 – 5.8 GHz

It should be noted, that different countries allow certain frequency ranges and prohibit others. The maximum transmitting power is regulated by country-specific laws and can differ from country to country (e.g. four watt in the USA and half a watt in Europe).
Reading distances for RFID transponder are usually divided in three range categories (Kummer et al. 2005, p.17; Franke & Dangelmaier 2006, pp.18-24):

- Less than 1 cm (close-coupling)
- Less than 1 m (remote-coupling)
- More than 1 m (long-range-systems)

The RFID systems, presented in the standards described later on, consist of two components: transponder and reader. Two transponders of each type are affixed to a container. Furthermore, the standards discussed in this section apply to freight containers as standardized in ISO 668 (ISO 668 1995) and other containers that are not part of this ISO norm as well as container subsidiary equipment, such as trailer, trucks or chassis.

2.1. ISO standards for RFID transponder in freight container transportation

Until 1904, more than 600 different sizes and variations of fire hose couplings were throughout the USA in use. In this year, during the great Baltimore fire, summoned fire fighters from neighboring cities were unable to fight the flames, because their hoses did not fit with Baltimore hydrants. The fire destroyed an area of over 56 hectare, more than 1,500 structures, 4 large lumberyards and 2,500 businesses in Baltimore's downtown business district. Thanks to the fact that it broke out on Sunday, just four persons died. Nevertheless, 35,000 citizens were temporarily unemployed. In the following year, national standards for fire hoses were established in the USA (Nesmith 1985, p.185).
As this introductory example illustrates, the importance of uniform standards in partnerships is enormous. When two or more participants are cooperating with each other, all partners have to agree on the same principles (e.g. ways of proceeding, language or data formats) to ensure a smooth interaction. The need for standards increases, the closer the partnerships and the higher the number of participants are. The absence of consistent standards can be an obstacle for partnerships when a "translation" between different standards is impossible.
Getting a step closer to logistics or more specific to freight container transportation an adequate example is obviously the standardization of freight containers in the 1960s. By then, freight loading was a manual matter and therefore time-consuming and costly (Baluch 2005, pp.131-132). After freight containers had been introduced special container terminals, gantry cranes and containerships were developed and established to increase the efficiency in the transportation sector (Levinson 2006, pp.212-230).
Today, the proceeding globalization, which is closely connected with international trade growth, requires higher efficiency. Existing processes,

working forces and infrastructures are laid out for a specific amount of containers, which is threatened to be exceeded. New technologies have the potential to improve efficiency and consequently to delay or even avoid the overstraining of existing structures. Radio Frequency Identification is broadly discussed as the most feasible solution in this area, but along the lines of the container standardization in the 1960s, the technology required standardization to enable its benefits. Kern (2006, p.169) summarizes the following positive effects for RFID standards:

- Users will get the opportunity to choose between several equal, compatible RFID products and thus protect their investments in the long term.
- Better comparability between products will encourage market competition and consequently reduce the price.
- Emerging competition, as a result of existing standards, will push technological development, due to better comparability of RFID system's advantages and disadvantages.
- Cross-company use of RFID systems will be facilitated, the development of uniform infrastructures benefited and in conclusion, the establishment of networks enabled.
- Defined frequency ranges, transmitting power and communication protocols will avoid interferences with other radio applications such as mobile phones.

In the following, we describe the three standardized RFID tags for maritime container: The license plate, which identifies the container, the shipment tag, which identifies the container's cargo, and the electronic seal, which has to seal the container door. Finally, we illustrate the scenarios and environmental characteristics that are valid for all standards.

2.2. License plate

The license plate, known as container tag, is planned to be standardized in ISO 10374.2 "Freight Container – Automatic Identification" (ISO 10374.2 2009). Due to the enormous changes and improvements, ISO (Organization for Standardization) and WSC (World Shipping Council) are currently discussing the creation of a subsequent norm, the ISO 10891.

The license plate is a passive WORM tag, which identifies the container it is physically and permanently affixed to, except for situations in which the container ownership or container equipment ID changes. Container tags should at least operate for 20 years at normal conditions of use and should not require any periodic maintenance. In the minimum capacity of 256 bytes– as shown in Figure 2 - the following mandatory and non-reprogrammable data about the container is stored; It starts with two characters tag manufacturer ID and two characters tag type, followed by one character tag location code, two characters conveyance, and ancillary equipment type. For the latter, ten different types are established; they range from intermodal maritime container – which is the most important type – over chassis to truck and trailer. The next eleven characters of mandatory container tag information are reserved for the equipment identification number. This is defined in ISO 6346 (ISO 6346 1995) and composed of container owner code (four characters), equipment category identifier (one character: “U” for all container, “J” for equipment that might be affixed to the container and “Z” for trailer and chassis), serial number (six characters) and check digit (one character) for intermodal maritime container. The last two character groups are size and type code (four characters) as well as maximum gross and tare masses with a length of 20 characters. In addition

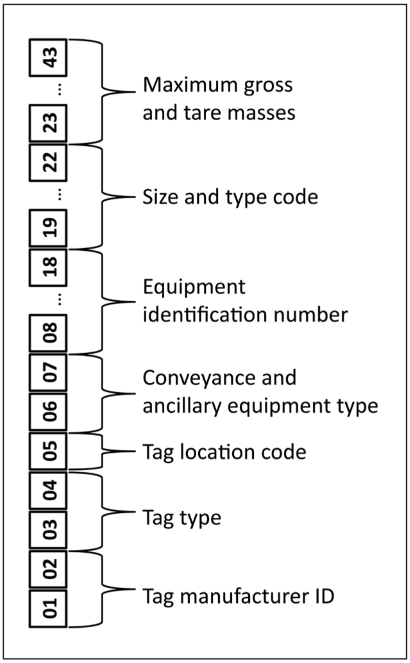

Figure 2: Mandatory information stored on container tag (license plate)

to mandatory data, the license plate can store optional information which is not specified in the standard.
The license plate is working with 860 to 960 MHz and must have a minimum reliability of 99.99%. This means no more than one “no read” in 10,000 readings, and an accuracy of 99.998 %, which means no more than one undetected, incorrect reading in 50,000 readings. The license plate itself should be affixed twice to the container (on the top and at the right side). Both should be placed 0.3m away from the front end, seen from the container door (ISO 10374.2 2009).

2.3. Shipment tag

The shipment tag, also known as cargo shipment-specific tag, is defined in ISO 17363 “Supply Chain application of RFID – Freight Containers” (ISO 17363 2007). This tag is an active read-write tag, which stores information about the cargo of the container where it is physically affixed. The shipper attaches the shipment tag to the container and the consignee removes it after delivery. Similar to the license plate, the shipment tag stores, in minimum capacity of 256 bytes, two different types of information: mandatory and optional data. The ISO norm only defines the manufacturer-assigned transponder ID as mandatory and non-reprogrammable data. The standard does not describe the optional data, but suggests semantics and syntax. The content of this data is left to the shipper’s responsibility. Therefore, it should be possible to store the container’s destination, route, cargo or storage and transport information. Stored data has to be protected against unplanned and unauthorized reads and changes. Because the shipment tag is active, the battery must be recharged from time to time. An indicator that shows if enough power for a 60 day trip with at least 20 readings is available, and a battery life countdown timer, that on request indicates remaining battery life, shall be part of the tag.
The shipment tag should be writable as well as readable within a distance of 35m, if it is separated more than 3m from other shipment tags. The maximum speed for moving the shipment tag, while reading, is 50km/h. The shipment tag system is operating with 433.92 MHz, must have a minimum reliability of 99.99% and an accuracy of 99.998%. The shipment tag itself should be affixed twice to the container (on the top and at the right side). Both should be placed close to the license plate positions (ISO 17363 2007).

2.4. Electronic seal

The freight container electronic seal (short: eSeal) is standardized in ISO 18185-1 to ISO 18185-5 (ISO 18185-1 2007; ISO 18185-2 2007; ISO 18185-3 2007; ISO 18185-4 2007; ISO 18185-5 2007). It is an active read-only tag, which has to seal the container door, and follows the same specifications as the mechanical seal described in ISO 17712 “Freight Containers – Mechanical Seals” (ISO 17712 2006). Beside the mechanical feature of sealing the container, the eSeal is able to submit data via radio frequencies. The first mandatory data stored on eSeals is the seal tag ID (32 bits), which consists of four parts: (1) the identification number, (2) the container model ID (16 bits) that the manufacturer assigns to the seal, (3) the tag manufacturer ID (16 bits), (4) the seal version (16 bits). In addition to this information, three types of operational information are mandatory: First, the battery status (1 bit: low / good) that indicates if the battery lasts for another 60-day-trip with at least 20 readings. Second, the seal status (2 bits: open and unsealed / closed and sealed / opened). Third, sealing and opening time (each 32 bits), which have to be stored by internal mechanisms with a tolerance of 5 seconds per day in use.
The electronic seal is operating with 433 MHz/ 2.4 GHz, must have a minimum reliability of 99.99% and an accuracy of 99.998%. The eSeal itself should be affixed to the container door, such as common mechanical seals. Regardless of the scenario, a seal check has to proceed with following steps; Identify container, container’s eSeal, type and status. Finally, assure that the eSeal is the correct seal (ISO 18185-1 2007; ISO 18185-2 2007).

2.5. Comparison, scenarios and environmental characteristics

As described above, ISO standards for RFID transponder embrace diverse information. Table 1 summarizes and compares the most important facts for the three different standardized RFID transponders.
The ISO standards specify that the above-described tags have to be able to use the same infrastructure, regardless if it is active or passive. ISO 18185-2 (ISO 18185-2 2007) distinguishes between four different scenario sets: (1) container handling and moving equipment, (2) restricted lane, (3) short-range hand-held and (4) long-range hand-held scenarios.

name	license plate	eSeal	shipment tag
norm	ISO 10374.2	ISO 18185	ISO 17363
frequency	860 MHz - 960 MHz	433 MHz, 2,4 GHz	433.92 MHz
power supply	passive	active	active
storage structure	WORM	read-only	read-only & read-write
most important storage content	container ID maximum gross tare weight	seal ID seal status	shipment Tag ID cargo specific information such as route, destination, storage conditions
place of installation	seen from container door: back right side In front, top left side	container door	near license plate
reliability	99,99%	99,99%	99,99%
accuracy	99,998%	99,998%	99,998%

Table 1: Comparison of ISO-RFID transponder for maritime containers

The first scenario set is the most difficult, but most important one. Concerning the standard, automatic identification devices can be mounted on components of the container handling or moving equipment, which are directly connected to the container (ideally on the spreader). In these cases, they must be water-resistant, ongoing shock and vibration. If mounting is impossible, an installation within 35m for cranes (e.g. a crane leg) and 10m for mobile equipment away from the tag (that has to be read) is required. Container handling and moving equipment, that is able to move more than one container at once, has to be capable of managing any combination of container orientation (all doors left aligned, right, mixed etc.).

The restricted lane scenario set describes how containers have to pass a reading device on trucks or rail cars, within a predefined space, in only one direction. The set is distinguished in portals, single- and multiple-lane gates. The scenario has a speed restriction of 50km/h and the lanes must be between 3 and 6m wide.

Short-range hand-held scenarios extend the previously described scenario. In addition to affixing reading devices on gates or portals, a hand-held reader

can be used. The devices must operate in a range of 3m and the allowed speed of the person using the hand-held is 5km/h.
For long-range hand-held scenarios, the standard specifies that the maximum distance between reader and container is limited to 50m, and the container speed is equivalent to or less than 12m/s.
The ISO standards require that license plate, shipment tag and the electronic seal operates under various circumstances, which are defined in ISO 18185-3 (ISO 18185-3 2007). Concerning this norm, those tags should operate accurately within a temperature range of -40°C to +70°C and assure data integrity of stored information in a range of -51°C to +85°C. A mechanical shock of 30g for 11 milliseconds, a random vibration of 2g for duration of 2 hours, a drop shock from a height of 3,3m shall not interfere with the tag. An electromagnetic field strength of 50V/m for 60 seconds, rain, snow, salt fog, a submersion under 1 m of salt water or 95% humidity must not affect the tag as well (ISO 18185-3 2007).

3. RFID Benefits in container logistics

RFID technology in container transportation has often been criticized, because of the lack of suitable standards, wherefore a worldwide exploitation of RFID is impossible (ABI Research 2004, p.4). Transport chain participants are only willing to buy or develop an infrastructure for this technology, if the compatibility to other participant's RFID hardware is guaranteed and they do not run the risk of implementing the infrastructure twice or more. The availability of RFID-ISO norms makes it possible for all supply chain partners to implement their hardware based on these standards.
Nevertheless, another important problem remains. Companies will only invest in a new technology if they benefit there from, or are constrained by laws and regulations. Due to the absence of compulsory laws, an investment in RFID technology has to be beneficial. Ideally, the investment generates profit, but non-monetary aspects can also be taken into account. Therefore, this section deals with new features, functions and benefits provided by RFID technology. In the following, we point out the advantages (cp. Will & Blecker 2008). Subsequently, our Delphi study, dealing with the benefits of RFID in container logistics, is presented.

3.1. RFID benefits

First of all, RFID tags are data storage units. Compared to conventional technologies such as barcode, the volume of storable data can be bigger, the storage itself is saver, the data access is simplified through automating and some transponders are rewritable (Glover & Bhatt 2006, p.5). Therefore, the advantages of RFID are more data with an improved availability, i.e. reading more or less independent of tag orientation and intervisibility with a reader (Braun et al. 2008, p.1), simultaneous reading of multiple RFID tags (bulk reading) (Üstündag et al. 2007, p.1), increased data acquisition speed, higher resistance against environmental influences (Grote 2006, p.6) and higher reading range (Brown 2007, pp.128-130) (cp. Table 2).

data	availability
higher data volume	reading independent of tag orientation
saver data storage	reading without intervisibility with a reader
rewritable	simultaneous reading of multiple RFID tags
	increased data acquisition speed
	higher resistance against environmental influences
	higher reading range

Table 2: RFID benefits

3.2. RFID-based information benefits

Additional features and functions in the context of container logistics are not directly based on the technology, but on data generated through RFID and their better availability. In literature, several advantages of RFID-generated information such as process efficiency, higher transparency and security and less media breaks are discussed (Franke & Dangelmaier 2006, p.153; Maruschzik 2007, p.59). Furthermore, it increases available data quality, improves protection against counterfeiting, quality management, traceability and process knowledge as a result of higher visibility/transparency. Because of standards, the RFID technology based information, depending on the used tag (license plate, shipment tag or electronic seal), generates several advantages, which will be achieved in the future of container management. In transport logistics, most authors name the reduction of: misrouting, losses, thefts, stock outs, human errors, minimum inventory level, real-time inventory data, time of circulation or loading and unloading time as well as expenses for searching multi way containers, production stops due to missing containers, higher precision of loading/transport/reception, automated triggering of container maintenance, and automated receipt of goods (Fleisch et al. 2005, pp.3-4; Franke & Dangelmaier 2006, pp.72,73,79-139; Kortmann 2006, pp.91-92; Poirier & McCollum 2006, pp.377-395; Boslau & Lietke 2008, pp.35-37; Chow et al. 2005, p.785; Michael & McCathie 2005, p.623; Tellkamp 2006, pp.200-201). Further benefits mostly refer to tagging of smaller transport units or items, which cannot be realized in the context of maritime 20ft or 40ft containers.

As mentioned above, we distinguish between RFID benefits and RFID-based information benefits. In literature as well as in practice RFID benefits are widely considered as fact and RFID-based information benefits are mostly listed unevaluated. The authors also name these benefits on different abstraction

data quality	**process efficiency**
less media breaks	reduction of human errors
real-time inventory data	higher labor productivity and utilization
real-time tracking and tracing data	lower loading and unloading time
improved process knowledge	automatic receipt of goods and payment
better quality management	higher precision of loading/transport/reception
inventory management	reduction of misrouting
automated triggering of container maintenance	less expenses for searching a container
lower minimum inventory level	less production stops (due to missing containers)
less stock outs	less time of container circulation
reduction of (container) losses	**security**
more efficient usage of existing containers	protection against counterfeiting
	reduction of theft

Table 3: RFID-based information benefits