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RADIO FREQUENCY IDENTIFICATION (RFID) TECHNOLOGY IN OCEAN CONTAINER TRANSPORT

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The central contribution of this paper is to present the status and the perspectives of RFID in ocean container transport. To accomplish this, we report the following: (a) the problem area and expected changes; (b) RFID and container ID fundamentals; (c) the RFID status quo in container transportation; (d) RFID perspectives in the ocean container industry; and (e) concluding observations and suggestions for consideration. We, preliminarily, note that the aforesaid tasks will be examined factoring the trend that ocean container carriers transform themselves from sea transport providers to total door-to-door logistics providers.

Keywords: RFID, container terminals, container security, intermodalism

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RADIO FREQUENCY IDENTIFICATION (RFID) TECHNOLOGY IN OCEAN CONTAINER TRANSPORT

1. INTRODUCTION

The Ocean Container Industry (OCI) –containership carriers and container terminals- is certainly the maritime sector with the foremost growth in the last decades. Apart from its inherent beneficial economic results, this catapulting in container volumes makes natural the question of whether today's container terminals are sufficient to handle it. This skepticism is amplified by the increased concern for maritime safety, security, and environmental protection, whose antidotes may have side-effects on various executional aspects in the OCI. Investments in container terminals, containerships as well as in the information and telecommunications technologies employed are rendered indispensable.

In tandem, Automatic IDentification (Auto ID) technologies, which could be used for the tracking, identification, etc. of containers, have been significantly augmented. Specifically, there is much controversy regarding Radio Frequency IDentification (RFID) technology. Although RFID's traces can be tracked back in the 1960s or even before, RFID had not gained enough publicity until the 2000s. Retail giants, like Wal-Mart or METRO, drive this non-small-scale utilization of RFID tags in terms of practitioners. Moreover, RFID currently attracts the increasing interest of academics, statesmen and other stakeholders. In the microcosm of shipping, RFID was at its infancy until five years ago; yet, many applications have emerged the last couple of years and the future is promising.

The central contribution of this paper is to present the status and the perspectives of RFID in OCI. To accomplish this, we report the following: (§2) the problem area and expected changes; (§3) RFID and container ID fundamentals; (§4) the RFID status quo in maritime transportation; (§5) RFID perspectives in the OCI; and (§6) concluding observations and suggestions for consideration. We, preliminarily, note that the aforesaid tasks will be examined factoring the trend that ocean container carriers transform themselves from sea transport providers to total door-to-door logistics providers.

2. THE PROBLEM AREA AND ITS TRENDS

In this section, we depict the scene of the problem to facilitate the better understanding of RFID in subsequent sections. Specifically, in §2.1 we report the liner intermodal operations and diagnose the symptoms of executional OCI problems. In §2.2 we discuss the increased need for maritime safety, security and environmental protection along with its implications on operations. Since RFID utilization is heading at the future, we report the anticipated changes in the OCI in §2.3.

2.1. The OCI industry, container handling operations, and executional problems

Both ocean container carriers and water container terminals, the two chief stakeholders of the OCI, exhibit a remarkable growth in the last decades. The growth of the former is

easily discerned in the following statistic: the world fleet capacity reached 857 million tons at the end of 2003, an increase of 25% over 1980, while the containership fleet capacity increased 727% during the same period. The development of the latter is exemplified by the statistic that the world TEU port throughput for 2002 reached 266.3 million TEUs, an increase of 22.5 million TEUs, or 9.2%, over 2001 (UNCTAD, 2004).
The ocean container carriers sector shares the characteristics of its "mother" liner market. Liner companies operate in a conference (cartelized) system dispatching unitized, *viz.*, containerized, cargo of relatively high value. Containerships are comparatively expensive high-speed ships with rapidly growing capacities (measured in terms of Twenty-foot Equivalent Units, TEUs). Liner fleets sail partly full throughout fixed schedules. Seaborne container carriers exhibit a remarkable concentration: in 2004, top 10 industry players held 53% market share (BRS-Alphaliner, 2005). Containers' gates to the hinterland are the water container terminals; so, it has evolved interdependence –with its inherent tensions and partnerships- between ocean container carriers and water container terminals. Actually, certain ocean carriers' subsidiaries have entered the terminals' business through acquisitions. Whereas carriers' core business is the dispatching of containers, the terminals are involved in a plethora of container handling operations such as loading/unloading, storage, and link with other modalities, among others.
Apart from the maritime transport and handling, the door-to-door delivery of containers involves also rail and truck transportation/handling. Ocean carriers monopolize the transport of containers between different continents, trucks always deal with "the last kilometers to the final destination" (e.g., warehouse), while rail gains share in large volume inland O/D pairs especially between water ports and inland cargo centers. Since a container may cross multiple countries before reaching its final destination, it is subject to different legislations, customs requirements, stakeholders, etc. The various factors/players that affect the transport containers can be seen in figure 1.

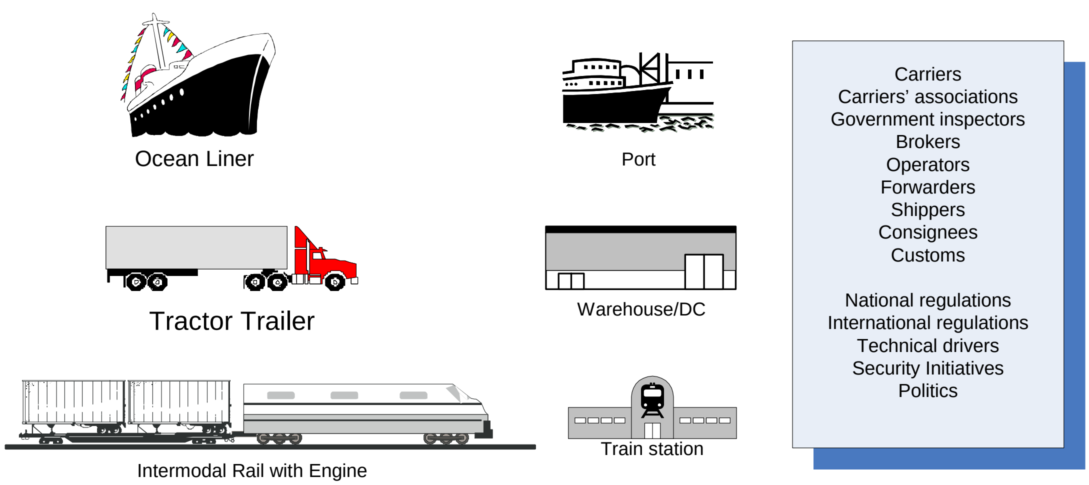

Figure 1. Various factors/players that affect container transport.

We present an overview of handling operations so as to thoroughly comprehend in succeeding sections the concepts of container tracking, security, etc.
For an international shipment, the flow of a container usually has as follows (figure 2): At the shippers' warehouse the container is becoming loaded (e.g., palletized); it is then dispatched to a consolidated warehouse (if any) via truck and afterwards to the harbor of departure by rail or truck. Ships usually call at multiple ports before approaching the destination port of container. The transshipment practice is often. At this practice, the

container is unloaded at an intermediate harbor (transshipment hub) and then loaded to another ship. Once the ship calls at the port where the container is supposed to be unloaded, it is then usually dispatched to a cargo center warehouse by rail or truck. In the end, almost always, containers are transported to their consignees via truck.

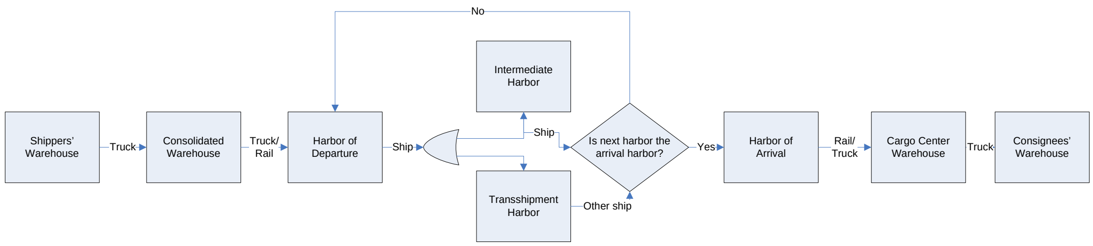

Figure 2. Suggestive non-detailed door-to-door transportation flow of seaborne containers.

Since we focus on the maritime leg in this paper, we describe in more detail the port operations. For the case of a container that enters the port from the sea, the operations have as follows. Ships wait in the harbor till they berth at a berthing point along the quay. Once the ship berthing process has been accomplished, the standard container handling procedures begin (like lashing/unlashing). Then, the gantry cranes unload/load containers off/on the deck/hold to the berth. Each time a container is unloaded, personnel visually checks the container ID, the seal intactness and if there is any damage. Once the unloaded container is checked, the internal port vehicles (like straddle carriers or other cranes) dispatch it from the yard to the berth and vice versa. Containers are stored at the yard stack till they are transshipped to another ship or till they are dispatched to another inland destination. Regarding the latter, a truck driver comes at the truck gate from an inland origin (e.g., depot). At the port truck gate three principal procedures take place: documentation, inspection, and assignment to a "parking" location. At the same time, the same assignment is given to the first available straddle carrier, which is going to load the container off the stack and load it on the truck. Again, the state of the container and its identity are checked. Once the loading is completed, the truck drives towards the port gate exit where a final documentation and check takes place. Synoptically, we have:

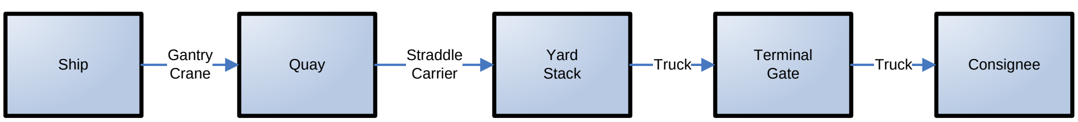

Figure 3. Flow of ocean containers at a port.

Inevitably, the above plethora of container handling operations is not devoid of executional problems. The slow upgrade in container handling infrastructure, the involvement of multiple players, and the imposition of many regulations result in significant delays, something that also has monetary implications. These problems are epitomized by the following statement of the International Chamber of Commerce in 2005: "Freight transport infrastructure is incapable of adequately handling current container volumes."

The chief symptoms of executional problems we diagnosed are the following:

- Excessive time waiting before mooring;
- Unsatisfactory terminal productivity;
- Congestion at truck gates;
- Exceedingly time-consuming inspection procedures;

- Information sharing among stakeholders below expectations;
- Coordination problems.

The *raison d'être* of these symptoms is that container traffic increases rapidly and the container handling infrastructure (equipment, procedures, etc.) is not modernized in a similar pace. In other words, the improvement in container handling infrastructure lags this tremendous increase in container volumes. Later in this paper, we investigate if RFID can help alleviate these symptoms.

2.2. Maritime safety, security and environmental protection in the OCI

Initiatives for increased safety, security and environmental protection would, indeed, aggravate the above symptoms. The side-effects of these initiatives, superimpose onto the actual efficiency of operations because the lawmakers do not factor implications on operational aspects when resolving safety. For example, US port operators currently inspect 2% of the more than 6 million containers that enter the US per annum. However, since US fears that containers will be a modus for terrorist attacks, they want to double the number of inspected containers. This could create chaotic delays as the infrastructure is certainly not ready to handle this.

Inspection is a significant, yet bureaucratic and time-consuming procedure. For the example of a certain EU port, ca. 2% of all the ocean incoming containers are checked for security purposes. Truck incoming containers are usually not checked. This check is not homogeneous in the sense that the majority of certain sets of “suspected” containers may be inspected while other non-suspected sets may not be opened at all. This is performed via a decision-support inspection system, which produces a probability inspection function. Variables of the function are cargo data like origin, destination, etc. In essence, this program resolves the containers that will be checked. The inspection takes place only after the container has been stacked, the operator has adduced declarative documents to the customs, and the container has been stored in the port information system as a stored container. If the decision support system suggests the inspection of the container, the customs broker/clearer communicates with the customs the inspection command. Promptly, the container is “blocked” and the container operator is informed via an XML message. Then, the container is moved to the area where the inspection takes place. When the inspection finishes, a new seal is put to the cleared container, the customs “unblock” the container, and the container is again stacked. Thus, the unblocked container can be retrieved by a trucker.

Whether increased safety, security and environmental protection may be contradictory with operational excellence or not, it is certain that these initiatives will be the drivers for change in container transport. Thus, the ocean container carriers and the port terminals that will deliver enhanced safety and security will attain a competitive advantage. Although RFID utilization is not mandatory, RFID and other innovative IT technologies can assist in regulatory compliance as regards safety, security and environmental protection. A non-exhaustive list of these initiatives has as follows:

- International Ship and Port Facility Security Code (ISPS Code)
- International Convention for Safe Containers (CSC)
- International Container Security Organisation (ICSO)
- Customs-Trade Partnership against Terrorism (C-TPAT)
- Container Security Initiative (CSI)
- 24-Hour Advanced Manifest Rule (AMS)
- Bioterrorism Act (BTA)
- Cargo Handling Cooperative Program (CHCP)

- Operation Safe Commerce (OSC)
- Smart and Secure Tradelanes (SST)
- Seal Verification Programme
- Supply Chain Security Regulation
- Port security act of 2006

2.3. Anticipated changes in the OCI

We think it is indispensable to discuss the anticipated changes that affect container handling as the use of RFID is heading at the future.
To start with, the industry itself changes. As regards ocean container carriers, the concentration of industry is increasing. IBM business consulting services (2005) predicts that in some years from now, the top 10 players will control about 80% of the market, with the next 20 players controlling about 15%, and all the remaining players sharing the last 5%. Moreover, ocean container carriers transform themselves from maritime carriers to intermodal door-to-door providers. A holistic, supply chain based, end-to-end perspective is certainly the trend and the vision. Furthermore, ships are becoming bigger with future ships being able to carry more than 11,000 TEUs. The historical evolution of the size of containerships can be seen in table 1. In addition, we observe a new generation of planners in the maritime industry that is more open (and familiarized) to high-tech and optimization solutions. The last holds true also for container terminals.

Table 1. Historical evolution of containerships size.

Generation	**Period**	**Capacity (TEUs)**
1st	pre-1970	1,700
2nd	1970-1980	2,305
3rd	1981-1986	3,220
4th	1986-2000	4,848
5th	2000-2006	7,598
6th	2006-?	11,000

Secondly, there are anticipated changes in technology standards. Standardization will regard many aspects that affect RFID in the OCI. Regarding the container seal, we note that the result of the Customs Convention on Containers (Geneva 1972) is hundreds of different seal designs to have been created. To tackle this, technical ISO committee 104 (“Freight containers”/Sub-committee 4 “Identification and Communication”) made a lot of progress during the years 2005-2006 and international specifications both on mechanical and electronic seals are expected soon. Regarding RFID standardization, evolution is under its way including signal strength, container tag specifications, etc. The advances in Ultra High Frequency RFID systems, which have increased significantly readability, is an area that we should expect more to evolve in the next years.
Finally, and more relevant to our paper, big ocean liners are expected to be the forerunners of large-scale RFID usage in container operations while feeder providers, terminals and inland transport operators the followers. This is the observation stemming from our status and perspectives research that follows in §§ 4 and 5, respectively.

3. RFID AND CONTAINER ID FUNDAMENTALS.

In this section, we present some prerequisite knowledge on RFID fundamentals and container ID practices, so that the reader will better comprehend the status and perspectives research that follows. Specifically, §3.1 presents RFID fundamentals and §3.2 container identification basics.

3.1 RFID fundamentals

Since a significant body of the maritime community is not familiarized with RFID, we describe its key elements in this section to better understand its status and perspectives in next sections. RFID description is compiled from various sources and especially based on certain articles from “the RFID Journal”.

RFID belongs to Automatic IDentification (Auto ID) technologies. This family of technologies includes the famous bar code system, optical character readers and some biometric technologies (like retinal scans). Auto-ID technologies have proved to reduce time and working resources needed and to increase data accuracy. Despite their practical value, the fact that a person is needed to manually scan items is itself a constraint. It is exactly this last part that RFID revolutionizes Auto-ID technologies.

RFID regards a system that transmits wirelessly the identity of an object using radio waves. This identity is usually a unique alphanumeric string or, simply, a unique serial number. RFID readers capture data on tags and transmit it to a computer system with no human intervention. Tags come in many kinds and can be active, passive or semi-passive. A typical RFID tag has a microchip attached to a radio antenna mounted on a substrate. Typical memory capacity of the chip is about 2 kilobytes. The tag antenna enables the tag to send and receive information. Passive, low- (135 kHz) and high-frequency (13.56 MHz) tags usually comprise of a coiled antenna that couples with the coiled reader antenna to create a magnetic field. Ultra High Frequency (UHF) tag antennas can have many shapes. Data retrieval is performed with an RFID reader. A typical reader has one or more antennas that emit radio waves and receive signals back from the tag. Then the reader, often called an interrogator as it “interrogates” that tag, transmits the information to a computer system in digital form. Readers also have antennas which are used to emit radio waves. The reader antenna energy is read by the tag antenna and is utilized to power up the microchip, which changes the electrical load on the antenna and transmits back its own signal.

RFID has been used by thousands of companies (only a very few of those belong to the OCI) in the last fifteen years. Yet, RFID gained enough publicity only recently. High cost and executional malfunctions of RFID have limited its mass employment. Regarding cost, there are many uses where the cost of tags is surely counterbalanced by the benefits it provides. However, in the case of open supply chains goods, where RFID tags are palletized by one company and read by another, cost has been a major obstacle to adoption.

A milestone in the life of RFID has been the inauguration of the Auto-ID Center in 1999. The Uniform Code Council and European Article Number International partnered with Gillette and Procter & Gamble to found the Auto-ID Center at the Massachusetts Institute of Technology. Principal objective of the center was to develop an RFID tag that would be very low cost for high-volume production. To do this, MIT partnered with private companies and ultimate goal was the 5-cent tag. Once such a cheap tag was attained, companies could tag items they own and then connect them to the Internet through a secure network. After some time, the center was under the aegis of the U.S. Department of Defense and about a hundred of international organizations. RFID was promising to these companies supply chain visibility: knowing where each supply chain item is at any time. The Electronic Product Code (EPC) was developed, a numbering scheme that makes it possible to put a unique serial number on every item manufactured. Moreover, the air interface protocol, a way for tags and readers to communicate, and a network infrastructure that stores information in a secure Internet database were created. In this way, a virtually unlimited amount of data associated with a tag's serial number can be stored online, and anyone with access privileges can retrieve it. The Auto-ID Center gave its way to a non-profit organization called EPCglobal. Before the Auto-ID Center proposed the EPCglobal Network, there was no way (other than manually phoning, faxing or e-mailing) for Company A to let Company B know that it has shipped something, and there was no way for Company B to let Company A know that the product has arrived.

The potential impact from mass RFID usage in commerce is enormous. Supply chain visibility could transform nowadays *push* system to a *pull* one. Today, companies plan and execute based on forecasts. The produced goods are pushed into the supply chain. When demand is greater than the forecast, sales (and customers) are lost. Otherwise, there are excess goods that reflect a loss. The vision is that goods are pulled through the supply chain based on real-time demand. RFID readers on shelves would monitor how many products are being sold. They would signal the backroom when the shelves get low and request more inventories be brought out. When inventory in the backroom gets low, readers there would signal the warehouse to send more products. When inventory in the warehouse gets low, readers would signal the manufacturer to send more products. If we continue this retroactivity, we finally have the manufacturer's suppliers. Wal-Mart in 2003 was the first mega retailer to require suppliers to put tags on cases and pallets of goods. Retailer giant METRO also employed RFID solutions and today many real RFID applications exist. Apart from the biggest retailers, supply chain solution providers (SAP, Oracle, and Microsoft) regard RFID as a powerful tool to optimize SC practices. Internet is expected to further catalyze the mass employment of RFID.

Research of the Auto-ID center unveiled that the price of tags could fall to 5 cents when 30 billion tags are consumed per annum. However, 30 billion tags will not be consumed with current costs of 20-40 cents. The business encounters a chicken-and-egg problem: tags will not become inexpensive until they are used massively, but a lot of companies will not exploit them until the tags get really economical. The five-cent tag appears still unrealistic to be created. In table 2, one can see the major RFID costs.

Table 2. RFID chief components and costs.

Component	**Actual cost**	**Cost depends on**
Passive tags[1]	20-40 cents (up to several USD for more sophisticated solutions).	• Frequency (e.g., HF is more expensive than UHF) • Memory size • Antenna design • Packaging around the transponder
Active tags	10-50 USD	• Battery size • Chip memory • Packaging
UHF readers	500-3,000 USD	• Dumb vs. intelligent readers Single-frequency vs. multi-frequency readers
Middleware	Depends on application	Depends on application

[1] Companies should bear in mind the cost of testing passive tags. Failure rates among tags ranged from zero to 20 percent in 2004 for UHF EPC tags.

It would be one-sided not to present the common problems of RFID. Common problems with RFID are reader collision and tag collision. Reader collision happens when the

signals from two or more readers overlap. As a result, the tag does not respond to simultaneous queries. However, we can overcome this problem by careful design. Tag collision happens when many tags exist in a relatively small area; but since the read time is very fast, it is easier for vendors to develop systems that ensure that tags respond one at a time. As containers are not so small objects, we conjecture that tag collision will not be a problem in container RFID applications. Other technical challenges include ultimate accuracy (99.5% accuracy can still be a problem) and occasional electromagnetic interference. Moreover, there are also organizational challenges related with the fact that the importance of information sharing has not been acknowledged by the industry.
For comparative purposes, the following table is the résumé of the differences between bar coding and RFID.

Table 2. RFID vs. barcode systems capabilities.

System specifications	**Barcode**	**RFID system**
Data quantity	1-100b	2-64kb
Machine readability	Good	Good
People readability	Limited	Impossible
Influence of dirty/damp	Can lead to failure	None
Influence of covering	Can lead to failure	Moderate
Data carrier cost	Very low	Medium
Reading electronic cost	Low	Medium
Unauthorized copying/modification	Slight	Slight
Multiple reading	No	Yes
Reading speed	Relatively Low	Fast
Simultaneous scanning	No	Yes
Reusable	No	Yes

3.2 Container ID fundamentals

The major objectives of container ID tracking are to perform quickly and with accuracy: (a) container identification; (b) seal check; (c) damage inspection. With current practices, these tasks are done by multiple players (shippers, forwarders, consignees, etc). Indeed, one stakeholder may do each task many times (e.g., as we know at a container terminal all (a), (b), and (c) are done at the gate, at the quay, etc.). To make matters worse, the different players do not share the information of the checks and these are inevitably repeated.
Container identification regards the correct reading (and correct storage of this information) of the markings that associate with the container ID. The principal ID marking of the container and its explanation are depicted in figure 4. The container identification system specified in DIN EN ISO 6346 consists solely of the elements shown, which can only be used together: owner code, consisting of three capital letters; product group code, consisting of one of capital letters U, J or Z; six-digit registration number; and a check digit. Typically, container ID check is done visually by employees

and, rarely, via video check done again by an employee. In any case, human intervention takes place.

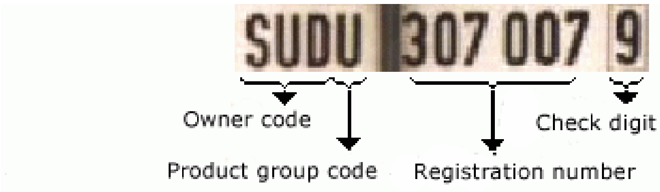

Figure 4. Explanation of container ID markings. (Source: www.containerhandbuch.de)

Container identification check should not be confused with seal check. The use of container seals aims to “stamp” the correct loading of container and ensure its non-malicious contents. Thus, if someone tampers illegitimately the container, the seal will unveil this. After applying the seal so that the internal locking mechanism comes into play, the operator must ensure that pulling hard on the head locks the seal. This will confirm that the seal is locked and secure at the time of closure. Tampering is not only suggested by a completely broken seal but also by other events. At destination, before breaking the seal, the operator must check if the seal itself has indentations or scratches, which would suggest tampering with the integrity of the seal. The head of the seal should be checked - if it opens easily, this again would suggest tampering. Naturally, the identity (usually with numbers) of the seal should also be checked. It is implied that the check of a mechanical is necessarily done by a human. Mechanical seals of containers can be seen in figure 5.

Figure 5. Container seals (Source: www.oneseal.com)

However, it is possible that a seal is broken and replaced in such a way that tampering is not identified in the next check. To solve this, a specific workforce in ISO TC 104 discussed various approaches to an electronic seal. Some basic principles have been agreed on meanwhile: The standard electronic seal will be an attachment device fixed to (or integrated into) the mechanical seal that secures the door of the container. A photograph of an electronic seal is depicted in figure 6.

Figure 6. Container e-seals. (Source:www.ejbrooks.com)

Finally, the third part regards damage inspection. It is observed that most of the damages occur on the top of the containers because the spreaders of the straddle carriers exert forces on the containers. Thus, the damage check must regard all six sides (top, bottom and four sidelong sides) of the container. This is usually done visually by employees and rarely via video check from an employee. For example, when a container is unloaded from the sea it is checked from the bottom and sidelong. Moreover, when a straddle carrier comes to move it to the stack, its driver checks for damage on container top.

4. RFID USAGE STATUS IN OCEAN CONTAINER TRANSPORT

In this section, we review projects regarding RFID utilization in the OCI. We note that the review scope is “RFID in seaborne containers” and not generally in transportation and logistics. Hundreds of broader projects exist in the literature, yet not reviewed herein. Actually, even regarding RFID projects within the OCI, we found dozens of related references and here we resort to describe selected ones due to space considerations. Prior to reporting these selected summaries of articles, projects or scientific publications (§4.2), we present some generic findings of the literature review in §4.1.

4.1 Generic findings of the literature review

The chief generic findings of the literature review have as follows.

a) Commercial projects predominate over academic ones.
The literature review unveiled a plethora of pragmatic applications where RFID adoption was completely successful. Although universities participate in some of the projects, the vast body of literature regards commercial applications of private companies. As regards academic publications on RFID applications within the OCI, only a few germane papers were reviewed. After a second look on the references reviewed, we observed that the sub-industry “RFID in maritime transport” exhibits a remarkable concentration with Savi Networks being one of its leaders.
b) The EU lags far behind the USA as regards RFID utilization to promote maritime security.

Another generic finding is that RFID adoption in the EU significantly lags than in the US. RFID projects in the US abound (some of them are described in subsequent pages), something that contrasts with the fact that there seems to be no finished European Commission project on seaborne RFID. Probably, this phenomenon is due to the increased sensitivity on transportation security that the US Government shows following the 9/11 terrorist attacks. Moreover, the catalyst of RFID applications at Asian ports seems again to be the US. The US exerts pressure on Asian ports to adopt RFID insofar as it is impossible for all the checking to take place solely in US ports.

As regards EU projects, research via Cordis and Extr@web showed that there is only one European Union project regarding RFID in the OCI, *viz.*, CHINOS: Container Handling in Intermodal Nodes – Optimal and Secure! CHINOS, whose anticipated duration is 3 years and kick-off date October 2006, aspires to employ RFID technology to enhance container handling practices both from a commercial and a legal/security aspect. CHINOS is coordinated by the Institute of Shipping Economics and Logistics (ISL) of Bremen. All three authors of the present paper participate in the CHINOS project.

Moreover, there only a few of other EU projects with which synergies can be developed. One of these projects is ConTraffic, a system developed by the European Commission's Joint Research Centre in collaboration with the anti-fraud office of the EC, which automatically collects container transport information. The purpose of this information gathering is to facilitate a more accurate input to customs risk analysis. Current risk analysis does not factor container route details at a global level, like the loading/unloading ports and transshipment hubs. Data mining techniques are used to spot suspicious movements. Thus, atypical container itineraries or uncharacteristic collective behavior of groups of containers, which could not be targeted before, are likely to be timely noticed.

<u>c) The central motivation for RFID use in OCI has been security and not operational excellence.</u>

It is our understanding from reviewing dozens of articles, projects and publications that the motivation for RFID adoption in the OCI has been to increase security standards rather than to promote operational excellence. This contradicts the chief motivation for RFID adoption in open supply chains, which is operational excellence. This difference can be explained by the fact that RFID in the OCI is initiated by the State, namely, the US following the 9/11 attacks, while in the open supply chains by private organizations. Finally, it reflects the fact that the maritime industry is more traditional and risk-averse than other supply chain industries.

<u>d) RFID does not only revolutionize technology employed, but also serves for business processes re-engineering.</u>

RFID in the OCI is either at the test or at the "substitution" phase. The former means that RFID trials have successfully taken place at certain terminals, containers, etc., but not yet being widely adopted. The latter means that real-world RFID-enabled solutions begin to substitute certain current transportation practices. For example, RFID-enabled e-seals replace mechanical seals and automatic messaging triggered by RFID replaces communication via e-mails and the telephone.

However, it is our understanding that the adoption of RFID has not been accompanied by real business processes re-engineering. In this sense, organizations cannot leverage RFID advantages to full extend. Process modeling should be utilized to identify the bottlenecks of operations and re-design processes accordingly. RFID should integrate into the stakeholders' processes. This means that business processes should be modified to match the particularities of RFID.

e) Intermodal port-rail RFID-enabled applications are scarce.
We were surprised to discover that only a few applications regard RFID-enabled rail operations at ports. We opine that rail applications offer to an extend economies of scale and, thus, should be exploited. Apart from the economies of scale, RFID benefits in port-rail operations could also be significant. For example, identifying and tracking 40 TEUs that have just arrived with a block train is a challenging task to be done by port staff. Moreover, rail is more dependent on schedule reliability than trucks and, so, RFID can assist in rail's alignment with projected time windows.

4.2 Summaries of selected articles, projects, and publications

In the following paragraphs, we will try to present short summaries of the most important and relevant commercial projects.

Mullen, D. "The application of RFID technology in a port"
This article's contribution can be summarized as follows: (a) Presents ports' direct benefits of RFID: accurate and complete data collection; and better utilization of employees' time. (b) Identifies the five major areas of potential RFID applications in a water ports mindset, viz., access control; container security; container identification and location; activity tracking; and regulatory compliance. (c) Concludes that RFID should be utilized within maritime container terminals.

The RFID Journal "RFID container seals deliver security, value"[1]
The article mainly explains the motivation for the creation of Savi Networks, a joint venture between Hutchison Port Holdings, a global terminal operator, and Savi Technology, an RFID technology provider.
Hutchison appears to have invested in Savi Networks, because it wants to secure its container terminals as well as other terminals. Initially, the idea is to load the containers and then x-ray them. Afterwards, an electronic seal that detects tampering will be placed. The e-seal has sensors to detect changes in light and temperature. Light and temperature conditions change if someone cuts a hole in the container or if the container is damaged. If a container is tampered or if any changes in light and temperature exist, the e-seal records that information and sends it to the system at the next tag read. The system used is the ISO 18000-7 standard for active RFID tags. The article notes that Savi Networks watches closely the evolutions on electronic seals and intends to adopt the new standards.

The RFID Journal "Port turns to RFID for security"[2]
This article describes Port of Houston's use of RFID as part of the Smart and Secure Tradelanes initiative (SST). The Smart and Secure Tradelanes initiative was established by the container shipping industry to ensure the security of cargo containers. The purpose is to identify the tampering of containers while in transit using automated tracking, detection, and security technologies. Port of Houston aims to thwart terrorists from using its facilities to get terrorist material into the United States of America.
To do this, readers are placed at strategic port points so that they receive signals from active (battery-powered) electronic seals. E-seals are capable of recording security information. For example, when a container has been opened without authorization or when any other indication of tampering occurs, signals alert shippers and the port

[1] Robert, M. (2005): "RFID container seals deliver security, value," *The RFID Journal*, http://www.rfidjournal.com/article/articleview/1965/ (accessed 21-7-2007).
[2] http://www.rfidjournal.com/article/view/367/1/1/ (accessed 21-7-2007).

authority. The port can leverage this system to conduct inspections. Moreover, port authority and other stakeholders can track and authenticate containers in a real-time fashion. The Port of Houston will use the system to track shipments originating from manufacturing, distribution, and port facilities in Europe and Latin America. At the point of writing the article, 13 ports allegedly have installed or are about to install the various SST technology components, including Seattle/Tacoma, Los Angeles/Long Beach, New York/New Jersey, Antwerp, Rotterdam, Felixstowe, and now Houston. In the summer of 2002, the world's three largest seaport operators, Hutchinson, Whampoa, PSA Corp, and P&O Ports, agreed to deploy the network.

The RFID Journal "RFID adds to security at Virginia Port Authority"[3]

As of July 2006, the Virginia Port Authority (VPA) utilizes RFID to improve the security and efficiency of the processes surrounding its cargo container shipments. The VPA system provides cargo owners and carriers with data regarding the location and, at certain cases, the condition of containers passing through the port.

To do this, VPA is deploying RFID systems from Savi Networks and GE Security. GE Security is employing CommerceGuard Container Security Device (CSD), which regards an RFID system that transmits data to CommerceGuard readers operating at 2.4 GHz and stationed within a 100-foot range. Savi Technology is employing Savi ST-676 ISO Container Security Tag, an active 433 MHz RFID tag that clamps onto the cargo container's door. This tag transmits data at the above frequency to readers located within a 100-foot range.

The installations of readers at the exit and entrance gates provide shipment details as containers arrive and depart from the port. Optionally, the use of sensors can detect: whether cargo-container doors have been opened; whether the container had a shock; and changes in temperature and humidity. This information is stored onto the RFID tags. The capabilities of RFID tags are reflected in their cost that is in the range of $10-$100. Apart from the gates, the port may install RFID readers on cranes, which will collect information regarding loading/unloading.

The CSD provides tracking information to its customers. In the event of a tampered container entering the port area, the CSD sends an alert message to the RFID reader exactly when the tampered container comes within reading range. Then, this data is communicated to the container shipper. In turn, the shipper can stop and inspect the container. Shipping customers and port or government agents can access this information with a password over a secure Internet database; thus, information sharing is straightforward and user-friendly.

According to the same article, RFID use can by catalyzed by the Port Security Act of 2006, signed into law on Oct. 13, 2006. This act, whose objective is the security of containers that enter the USA, gives regulatory incentives and clarifies best practices and adherence to international standards.

The RFID Journal "Colombian shipper to use RFID"[4]

As of June 2006, Colombian shipper Emprevi, which mainly dispatches pharmaceuticals, utilizes RFID to track containers shipment within Colombia. Savi Technology's SmartChain Transportation Security Solution (TSS) supports Emprevi to track the container's location and, optionally, its temperature, humidity and shock history.

[3] Swedberg, D. (2006) RFID adds to security at Virginia Port Authority," *The RFID Journal*, http://www.rfidjournal.com/article/articleview/2748/ (accessed 21-7-2007).

[4] Swedberg, D. (2006): "Colombian Shipper to use RFID," *The RFID Journal*, http://www.rfidjournal.com/article/articleview/2335/ (accessed 21-7-2007).

Previously, Emprevi tracked its shipment containers manually; now, human intervention exists too, but is less. Manual tracking entails sending a company's own employees with each shipment from the factory or distribution center to the port and onto the ship (for exports), or from the port to the distribution center (for imports). The employee tracks the containers' movements and is also present at a Colombian port in the event that a customs official wants to open it. Benefits for Emprevi have as follows: decrease in manual tracking; fewer customs inspections; less pilferage; and, possibly most importantly, real-time (including en route) tracking.

This is accomplished as follows: An ISO 18000-7-compliant, 433.92 MHz, created by Savi and EJ Brooks, RFID tag is affixed to the outside of a container. A bolt seal plugged into the tag secures the container. In case the bolt is removed from the container, a "tamper-event" warning is sent to the RFID tag. On the tag are stored the container ID number and the name of the person who sealed the container. During container's trucking to the port, it passes numerous RFID interrogators installed at various highway points, which capture its time and location. At the port entry, the truck passes another interrogator. As regards inspection procedures, before the container is opened, the RFID tag must be "deactivated" and the bolt must be cut to allow entrance. For certain shipments, Emprevi uses Savi's ST-676 tags, which measure temperature, humidity and shock. Again, these data are retrieved when the container passes an RFID reader.

According to the article, Emprevi plans to use RFID as part of a global tracking system enabling the visibility of a shipment from the container's origin to its destination.

The RFID Journal "Georgia Cargo Terminals becoming RFID-enabled"[5]

The Port of Savannah among other Georgia terminals is equipped with RFID readers and software to enable shipments' tracking. Terminal operators gather information of containers equipped with RFID. Many players along the supply chain can benefit from information sharing. Apart from the port authority carriers, also logistics companies, retailers and product suppliers profit from container visibility and condition statistics. These stakeholders will be able to log into the hosted system to track shipments and locate containers.

Program administrator is the Maritime Logistics Innovation Center (MLIC), a state plan that aims to bring close industry (like Savi Networks), academia (like Georgia Institute of Technology) and federal and state authorities (like the Georgia Ports Authority, GPA). Know-how is provided by Savi Networks, a joint venture of RFID systems provider Savi Technology and seaport operator Hutchison Port Holdings (HPH). The RFID implementation will leverage Savi Networks' SaviTrak, an RFID-enabled global container shipment-tracking service.

On the implementation side, RFID tags are affixed to containers to track them en route. Savi Technology's ST-676 ISO Container Security Tag is used (refer to previous reviewed application for its specifications). The unique serial identification number is associated with the shipping manifest and other documents. These are stored in a SaviTrak database. At its Savannah terminals, GPA has fastened readers to all their cranes. The readers operate at 433 MHz. The interrogators, which are placed at the cranes cabs, read tags on containers being lifted off and onto ships. Additionally, readers will be stationed at other port locations. Regarding software, the terminals utilize SaviTrak's network software, which synchronizes information collected from the RFID tags and guides it to the SaviTrak system.

[5] Bacheldor, B. (2006): "Georgia Cargo Terminals becoming RFID-enabled," *The RFID Journal*, http://www.rfidjournal.com/article/articleview/2493/ (accessed 21-7-2007).

The Maritime Logistics Innovation Center (MLIC) tests this project as part of a broader project for the R&D of RFID and other technologies pertinent to maritime supply chains.

The RFID Journal "Korean seaport tests RFID tracking"[6]

Port of Busan, South Korea's largest port, utilizes RFID to track containers, thus, securing and speeding its business processes. RFID tagging is complemented with automated advance notification of when containers are scheduled to arrive at the port. With this information, the Port of Busan can then provide the appropriate staffing needed to check containers. Real data are undisclosed; trial records have as follows. 1,605 containers were tracked from two mainland South Korean locations. At the inland locations the containers were loaded and secured with RFID seals. At the two terminals of Port of Busan the containers were loaded on ships for an overseas destination.

On the implementation side, two types of RFID tags were tested. Both kinds of tags operate at 433.92 MHz and are created by Savi Networks. The first is the Savi Tag ST-645, an electronic bolt seal, and the second is the Savi Sentinel, an RFID-enabled sensor seal. One of the two seals was affixed to each container tested. The tags record and communicate key data (e.g., container's location and security status, changes in light, temperature and humidity inside the container). Moreover, other equipment is used like: three Savi Mobile Reader SMR-650P handhelds for sealing the containers; Savi SP-600-211 Signposts at the port entry gates; and Savi SR-650 fixed readers attached on cranes. The Signposts are short-range transmitters that send a 123 kHz signal that triggers Savi's active tags to broadcast their data and the ID of the Signpost that activated them. In this way, we have an RFID-enabled location system. The accuracy of the location system depends on the number of Signposts. The whole system manages to track containers at gates and the cranes. Data monitoring is enabled by Savi's Transportation Security System.

Optionally, the Port of Busan may connect to other ports via Smart and Secure Tradelanes: the global industry-driven initiative aimed at improving both the security and the efficiency of containerized cargo shipments.

The RFID Journal "APL Reaps Double Benefits From Real-Time Visibility"[7]

The article regards the use of RFID by APL Ltd., a subsidiary of Neptune Orient Lines (NOL). APL offers intermodal services, moving containers through ships, trains and trucks and deploys thousands of containers and trailer chassis. APL aspires to track and locate its chassis and the chassis status, e.g., when the chassis is disengaged from a tractor. This is the reason the company resorted to RFID.

To manage its terminal at the Port of Los Angeles, the company employs WhereNet's active RFID WhereNet Real-Time Locating System (RTLS) and marine terminal software. This sophisticated RTLS system includes WhereTag transmitters attached to more than 35,000 chassis of the facility as well as APL's entire fleet of terminal tractors. The WhereTag devices send an RF transmission at discrete pre-programmed intervals, ranging from 5 seconds to 1 hr. Moreover, the WherePort device, prompts the WhereTag to send RF transmissions. When a WhereTag is in field by a WherePort, it sends more frequently RF transmissions to enable the precise tracking of the tagged asset flow. The tag's signals information includes the identification number of the WherePort. APL

[6] Collins, J. (2005): "Korean seaport tests RFID tracking," *The RFID Journal*, http://www.rfidjournal.com/article/articleview/1438/1/12/ (accessed 21-7-2007).

[7] Violino, B. (2006): "APL Reaps Double Benefits From Real-Time Visibility," *The RFID Journal*, http://www.rfidjournal.com/article/articleview/2375/1/352/ (accessed 19-11-2006).

stationed WherePort devices at 12 entry and eight exit gates at the terminal of the Port of Los Angeles.

There is a special WhereNet RTLS infrastructure receiving the tag signals and information. It is comprised of WhereLAN Location Sensors (LOS) and Locating Access Points (LAP) that “forward” the messages to a server. The server is operating the WhereNet Visibility Server Software, which determines the location of the tags using sophisticated "time differential of arrival" algorithms. The software, which is compatible with Windows Operating System, manages all tag-blink data and ensures that APL gets accurate information about chassis location. Software engineers took into account the specificities of the facility.

The whole system is rather complicated and the reader is referred to the original article for additional information. APL soon benefited from its new RTLS system. Thanks to the system, the California Trucking Association in 2006 named the terminal where the system was developed the "fastest and best overall marine terminal" at the ports of Los Angeles and Long Beach.

The RFID Journal “APM terminals readies its RFID system”[8]

APM Terminals in Long Beach, CA, has successfully tested an RFID system at its port terminal. According to the article, as of July 2006, the company will begin using the RFID and GPS system.

On the implementation side, the piloted system is a hybrid of RFID and GPS. It comprises of: WhereNet's RFID real-time locating system (RTLS); Navis' SPARCS terminal operating system; APS Technology Group's optical character recognition (OCR) system; and a Sattel GPS system for locating containers. WhereNet active RFID tags attached to container handling equipment, such as cranes, track the flow of containers. In addition, the system records the time the container was moved and the equipment that performed the operation. Location sensors installed in the lot triangulate the tags and send data to the server over an Ethernet connection. Moreover, GPS receivers, also attached to the terminal's container-handling equipment, allow APM to know the exact location of each container. A tamper-proof WhereNet tag affixed to each truck's windshields contains information about the vehicle, its driver and the trucking company. WhereNet interrogators stationed at the terminal gates will identify arriving trucks. The optical recognition system mentioned above is used for reading the identification information of containers while they are loaded/unloaded. In the future, APM aspires to use e-seals.

The RFID Journal “Bremen researchers developing intelligent containers”[9]

The LogDynamics research cluster, a University of Bremen’s interdisciplinary center, has created a working model of an intelligent container handling system. The system regards a truck logistics system designed to alert users about potentially harmful changes in the temperature and humidity of loads throughout the entire delivery process. Eventually, the system aspires to minimize human intervention at the various processes. Currently, autonomous control is not realistic. Human intervention is indispensable in containers identification processes. In order to be pragmatic, the group has purchased its own equipment and the project is in its testing phase. The intelligent container system will be tested as follows. An RFID reader will gather data from passive tags affixed on bins holding goods inside a container. Thus, the system will identify which bins are in the

[8] Swedberg, C. (2006): “APM terminals readies its RFID system,” *The RFID Journal*, http://www.rfidjournal.com/article/articleview/2323/ (accessed 21-1-2007).

[9] Wessel, R. (2006): “Bremen researchers developing intelligent containers,” *The RFID Journal*, http://www.rfidjournal.com/article/articleview/2774/1/1/ (accessed 21-1-2007).

container. The intelligent system will exchange data from RFID tags and temperature and humidity sensors to the processor module. The processor module will then send information over wireless telecommunications networks to system operators. Data can be sent via WLAN or by a GPRS or UMTS mobile-phone network.
This project is a multi-year project and there are 10 years remaining for the completion of the project.

Information Week "RFID helps to track cargo containers"[10]
Marine terminal operator SSA Marine has tested an RFID-enabled cargo-container tracking system to more competently track shipping containers. Special emphasis has been put on the accurate container identification. This is because as Ed DeNike, the Chief Operations Officer of SSA terminals at SSA Marine, asserts "10% to 20% of the container IDs aren't copied correctly, which causes the company to lose track of containers". Traditionally, when cargo containers are unloaded from ships, workers must go to each container to log the container's identification number. The cargo containers are often stacked five high and six lanes wide throughout hundreds of acres of land; thus, wrong container identification may result in many container moves in excess.
The company began testing a system from WhereNet Corp. at the end of 2004 that uses active RFID tags on container-handling equipment such as cranes to track their location. An optical character-recognition system installed on the cranes captures an identification number from the side of a cargo container. That ID number and the location of the cargo-handling equipment are wirelessly transmitted to business-intelligence applications, which pinpoint the location and status of each container.
According to SSA officials, the benefits are: track containers; reduce the costly errors that result from lost containers; reduce the human resources costs assigned to identifying containers and locating wrongly identified containers. One of the trickiest parts of the test was setting up the cameras on each of the cranes so that the ID numbers are discerned.

Industryweek "Savi Networks Extends RFID to Largest Container Port in UK"[11]
This article regards the application of SaviTrak software and RFID readers to the container terminal of the Port of Felixstowe (PFL). We note the PFL is the largest port in the United Kingdom in terms of container traffic. The chief operating officer of Savi Networks thinks that this application is a landmark for Savi as it links a European hub with US and Asian ports that already utilize SaviTrack services.
On the implementation side, SaviTrak RFID readers track the location and security status of containers and monitor their contents condition as they are transported throughout the global supply chain. The readers are stationed at PFL's Trinity Terminal and are placed on dockside cranes and at entry and egress gates. The SaviTrak information service is offered via an open technology platform, which accommodates many different Automatic Identification and Data Collection technologies, such as barcodes, EPC-compliant passive and active RFID technologies, and Global Positioning Systems (GPS) used to track ships and trucks that transport ocean containers. Emphasis has been placed on interoperability and standardization issues. The interoperability levels of these technologies are considered successful. As regards standardization, active RFID technologies used are compatible with the ISO 18000-7 standard and the sensor seals are compatible with the ISO 18185 draft standard.

[10] Hulme, G. V. (2005): "RFID helps to track cargo containers," *Information Week*, http://informationweek.com/story/showArticle.jhtml?articleID=160501261 (accessed 21-1-2007).
[11] http://www.industryweek.com/ReadArticle.aspx?ArticleID=12746 (accessed 28-2-2007)

Bizjournal.com "Mitsui subsidiary to offer RFID services at port"[12]

Trans Pacific Container Service Corp. (TraPac), the wholly owned, terminal-operating subsidiary of Mitsui O.S.K. Lines Ltd., signed a long-term (30-year) deal in August 2005 with the Jacksonville Port Authority. TraPac reached an agreement with Savi Networks, a leader of RFID-enabled container solutions. Services are offered to the ports of Jacksonville, Los Angeles and Oakland, California. Shippers and carriers calling on TraPac port facilities are connected to a growing worldwide network that provides real-time information services on the location, status and security of containers. Additional implementation details are undisclosed.

The RFID Journal "GE Uses RFID to Secure Cargo"[13]

The security division of General Electric is conducting research on creating RFID-enabled containers. A partnership between GE and China International Marine Containers (CIMC) aims to integrate GE's solution, the so-called Security Tamper Evident Secure Container (TESC) system, into CIMC's next-generation containers. While TESC use of wireless technology cannot ensure that no post-seal tampering has taken place, the recording of potential tampering seems achievable. Benefits regard increased security and customs processes acceleration.

The great innovation of this method is that seals are affixed on the internal side of the containers and not on the outside. While mechanical seals have predominated, a new generation of electronic seals is progressively used more and more. These e-seals use battery power and transponder seals that are not electrified while monitoring, but are briefly powered up by the seal reader to check if tampering has occurred. The e-seals are a sensor bolt or smart seal with an embedded RFID tag that is used to lock the container doors, but also monitor any tampering with the container door lock. However, even these e-seals can be wrong. The reason is that the external locks and hinges can be removed without being detected by the e-seal. In that sense, making containers with no hinges and seals outside may be functional.

The new containers have internally both their hinges and a new GE TESC device affixed in the seal of the door's frame. Only the device antenna is visible from outside. The TESC device, which operates in 2.4 GHz, records activities like the opening of a door. Shippers secure the sealed containers with a handheld RFID reader that sets the device and records information from the TESC device, including the unique ID numbers of the device and of the container it is attached to. Moreover, the GE system comprises of fixed readers and software that pass data gathered by the readers. The data can be transmitted over GSM cellular networks to a GE-hosted shipping management application.

One of the few relevant academic papers reviewed is that of Muller (2007). Based on the review of its abstract, we present the following. Bremen, Federal State of Germany, is founding a centre for Global Monitoring of Environment and Security (GMES). The objective is to promote container security with an emphasis on maritime transport security. Suggestive problems that the project wants to tackle are the accurate and timely identification of tampered e-seals and of containers dispatched to wrong locations. These two events could imply acts of pilferage or terrorism, respectively. The Institute of Shipping Economics and Logistics (ISL) is developing a Security Event Management System to record all security related events in the intermodal flow of a container. The system registers the schedule and transport information of a container and assigns a

[12] http://www.bizjournals.com/jacksonville/stories/2006/01/09/daily28.html?from_rss=1

[13] Collins, J. (2005): "GE uses RFID to secure cargo," *The RFID Journal*, http://www.rfidjournal.com/article/articleview/1317/1/1/ (accessed 28-2-2007).

corridor for its transport. During the transport, the system receives the events which are generated by RFID, GPS or a combination of these and/or other systems. The generated events will be used for computing a security risk factor for each container, by considering restrictions like position with respect to the assigned corridor, duration of standstill and others. According to the value of the security risk factor the user will be informed using web services, EDI or email.

Another academic paper is that of Park et al (2006). The paper regards an RFID-enabled Real-Time Location System (RTLS) whose objective is to decrease ship turnaround time at ports among others. According to the authors, ship turnaround time is a critical factor when carriers design their network and their port of calls. However, having not access to the method employed, we are quite skeptical of the efficiency of their method.

Chen (2005) devised an original "RFID and sensor-based container content visibility and seaport security monitoring system". Its summary has as follows. In 2002, 56,596 ships called at US ports unloading ca. 8 million containers got into the U.S. No more than 2% of these containers were inspected through x-ray equipment. Indeed, it is planned that more sophisticated radiation-detection equipments will be stationed to chief US water ports of entry. The limitation of these techniques is that they cannot identify individual items inside, thus, they do not advance item traceability. At the same time, there is increased call for container inspection systems, which do not virtually open the containers. To tackle this, this paper proposes a RFID and sensor based Container Content Visibility and Seaport Security Monitoring System. The eclectic system combines the latest evolutions in RFID, sensor, door tamper-proof device, and Wi-Fi communications. According to the paper, it is able to inspect the contents of containers without opening the containers.

Chin and Wu (2004) confer on the potential use of RFID-enabled e-seals rather than describing an original application. Following the 9/11 attacks, the US is focusing on transportation security and, especially, on the security of containers inasmuch as more than 85% of cargo entering the United States is coming in seaborne containers. To advance security, the Container Security Initiative (CSI), the Electronic Container Seal (E-Seal) and Radio Frequency Identification (RFID) technology are introduced. Chin and Wu (2004), describe RFID fundamentals as well as potential applications. This paper observes how the technologies perform in the real-world operational environments and reports the trade-offs on functionality, reliability, utility, and cost that exist with e-seal design.

Murphy-Hoye et al (2005) report their real-world look on RFID. The paper reports its update on RFID adoption and perspectives. The authors suggest pragmatic applications that are promising and that belong to all industries. They specifically suggest an application that belongs to the OCI. They suggest using sensors on seaborne containers. The containers are connected via a GPS system to IT networks. Stakeholders -like shippers, carriers and customers- can access these networks. Murphy-Hoye et al (2005) propose the use of "decision-rule" algorithms to spot promptly deviations and respond to them. The authors state that RFID adoption in containerization can lead to higher performance levels.

5. RFID PERSPECTIVES IN OCEAN CONTAINER TRANSPORT

We state right at the beginning of this section that RFID perspectives in ocean container transport are rosy. In the next pages of this section, we will discuss what drives our optimism regarding RFID adoption (§5.1) and present certain future paths of RFID evolution in the OCI (§5.2). Finally, we will discuss the challenges that remain open in §5.3.

5.1. Drivers for RFID adoption

First, RFID perspectives in ocean container transport reflect both the perspectives of the ocean container industry as well as the perspectives of RFID. Regarding the former, the OCI is the maritime sector with the biggest growth in the last decades. Current massive investments in container fleets and container terminals modernization in parallel with the trade growth and the fact that an increasing number of items are produced overseas of the place they are consumed render the future of the industry promising. As regards the latter, RFID awareness is becoming rapidly increasing regardless of the type of industry and application. Figure 7 epitomizes the exponential growth of RFID applications. Figure 7 depicts the number of RFID-related articles based on Factiva, a database of 8,000 news and business publications, by Dow Jones & Reuters.

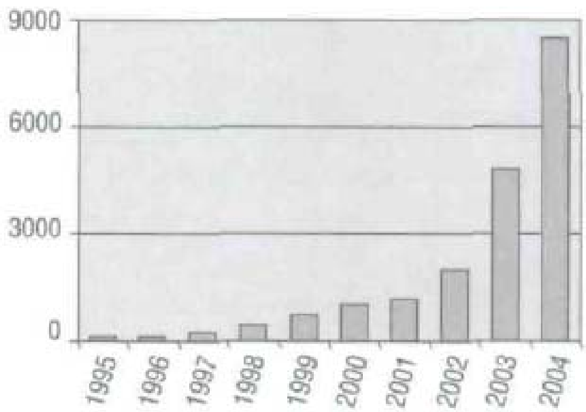

Figure 7. Number of RFID publications (Source: Sheffi, 2004)

Second, another positive indication is the fact that the as-yet trials and real-world seaborne applications of RFID are considered successful. Indeed, RFID results appear to alleviate the symptoms of the executional problems diagnosed in §2.1. Allow us re-visit these problems and see if and how can RFID assist us in confronting them.

<u>Congestion at truck gates</u>

RFID-enabled gate procedures can decrease truck-in and truck-out gate times significantly. Specifically, documentation of driver and truck can happen automatically by means of RFID identification tags. Moreover, time for check of container ID number and seal number can be reduced, if this is done automatically by RFID readers placed at the gates. In any case, re-engineering of current processes is necessitated.

<u>Exceedingly time-consuming inspection procedures</u>

The number of containers that are opened at the designated port area in order to be inspected can be reduced. This can be reached if the customs are automatically notified of the status of incoming containers. Interrogators placed at the entry gate and at the bridge can provide the customs and security departments with information about the seal intactness and about any changes in the light, temperature or other conditions of the container. With this information, customs could only inspect containers with atypical suspicious characteristics.

Unsatisfactory terminal productivity

RFID can be a part of the terminal's arsenal to improve their executional excellence. Terminal productivity suffers from mistakes that occur at different parts of container handling, like wrong container identification. Both by reducing human mistakes and accelerating processes (vide, the gate example above) terminal productivity can increase.

Coordination & information sharing problems

Coordination between ocean, rail, and truck carriers, shippers, terminal operators, and customs officials is certainly a convoluted task. Coordination levels below expectations is a cause of poor terminal productivity. The terminal must know with relative certainty the times of arrival of cars, trains, and vessels (and of the containers carried) to optimally allocate its resources. RFID tracking could create traceability even en route. Moreover, the deviation of the times of certain business operations will be reduced. The creation of internet applications where various stakeholders can securely read data obtained from RFID could boost information sharing. In this sense, the port and other stakeholders will be able to more reliably organize their schedules.

Third, reliability of RFID and related technologies is increasing. Research conducted in the last years renders reader and tag collision a rare malfunction. In any case, we can overcome reader collision by careful design, while tag collision is not a common problem in RFID-enabled containers. Other positive news regards reading accuracy, which reaches ca. 99.9%. Moreover, several interoperability bugs have been resolved. These bugs were generated by not proper integration of RFID architecture into other existing IT technologies (like container operations systems, GPS, etc).

Fourth, a driver for RFID adoption is certainly the increasing need for container security. Till 9/11/2001, the container industry was considered a relatively anti-smuggling and secure transportation sector. With less than 2% of the more that ten million containers now entering U.S. and E.U. ports every year undergoing screening, seaports and container transport systems are now considered gaping holes of vulnerability. In tandem, RFID and its auxiliary technologies have proved successful in tackling tampering. However, regulations do not enforce the use of RFID; currently, RFID can assist in reaching regulatory conformity, but is not mandatory. We conjecture that future regulations, probably originating from the US, will enforce the use of RFID. This will lead to the mass adoption of RFID in the OCI.

Fifth, executional excellence, which is so far overlooked, will be forwarded in the next years as competition in the OCI is intense. The outcome of RFID from other industries has proved to accelerate processes and alleviate bottleneck problems. Moreover, RFID can help ocean companies to achieve process standardization and systems integration. In the near past, ocean systems management suffered from obscure ownership of processes, a phenomenon that is a remainder of the traditional, often myopic, management of the industry. RFID offers an opportunity for standardization of processes and integration of systems. These, in turn, can be the basis for operational excellence.

Sixth, another positive indication is the ubiquity of the internet. Not only is the ocean industry familiarized with the internet, but also the internet can provide complementary functions to the RFID applications. The most important thing is that internet can be the user-friendly interface between RFID and ocean stakeholders, who are not experts at IT matters. Often, ocean players are skeptical of RFID as they deem it does not offer simplicity. This can be supplied by the internet. For example, shippers, carriers, terminal operators, etc. can just access over a secure network with a password the status of their shipments and not interfere with the actual RFID actions.

Seventh and last but not least, the cost of tags to the cost of the containers and of their contents ratio is rather low. In this respect, even if the container tags do not get cheaper, this should not be a problem for OCI adoption.

5.2. Paths for RFID adoption

The paths for RFID adoption should be principally traced at the applications. So, we recap and classify the areas of RFID applications.

<u>Container boxes security</u>

Container boxes and their contents security are promoted via a series of RFID-enabled solutions. These include electronic seals, which record if a box has been opened; sensors, which document atypical changes in the environmental conditions of the container; hybrid GPS/RFID systems that constantly track the containers and spot suspicious containers itineraries.

<u>Tracking of container boxes and of container handling processes</u>

- **Container Identification:** It is reported that wrong container identification is often over 10%. This has two primary causes: multiple ID numbers in each container (e.g., one number on the side and one in the end) and wrong manual copying of the container ID by personnel at certain operations. Both can be resolved by RFID tagging, which can automatically spot the identity of a container by means of a unique serial number. Moreover, the location of containers can be tracked.
- **Processes tracking:** Productivity is dependent on activity tracking. Activity tracking provides hints for processes re-engineering and can boost data collection. Via wireless LAN and RFID, the operations managers can supervise day-to-day activities in an efficient way.

<u>Admission Control</u>

- **Worker identification:** Employees can be identified via RFID identification cards. Cards information includes biometric information of the employee and additional data on job details. RFID personnel ID tags provide the advantages that they cannot forged easily and they can additionally record information like attendance, job shifts etc. Additionally, they can be used for purchases within the workplace.
- **Equipment Control:** Equipment management is important not only for executional excellence but also for security purposes. We reviewed applications where RFID enables companies to track their equipment like tractors, trucks, containers, etc and the history of the persons who operated them.

RFID adoption path in the OCI has its pioneers/leaders and followers. Big ocean liners, which also own the majority of the container boxes, and the biggest container terminals are the pioneers. Feeder service operators, small-to-medium-sized terminals, and inland transport operators are the followers.

Our study suggests is that now is the right time for an ocean company to invest in RFID. To reach this conclusion, we compared RFID with other technologies that initially were evoked skepticism and finally were globally adopted like the telephone, and the personal computer. Specifically, the RFID (beyond the OCI applications) resisted the effects of the technology trigger, the peak of inflated expectations and the subsequent disappointment. Presently, it just began ascending the so-called “slope of enlightenment” and is projected to plateau 5-10 years from now. Thus, a company in the OCI that now invests in RFID will harvest RFID advantages to a full extend. Being an RFID leader can contribute to the company's reputation as technologically advanced, secure, and highly productive.

RFID adoption path should not restrict itself to substituting other technologies. It is important that processes are *re-engineered*. We have already reported that RFID advantages cannot be fully exploited unless the new processes fit the revolutionary RFID attributes.

RFID technology cannot work alone. It should be adopted in coordination with other modern, emerging or not, technologies. WiMax, which stands for Worldwide Interoperability for Microwave Access, is a technology that can beam broadband signals up to 30 miles from a cell tower. The 802.16 standard, which the WiMax Forum industry group is pushing, is designed to operate in unlicensed or licensed frequencies from 2 GHz to 66 GHz. It's being touted initially as a last-mile alternative to DSL and cable modem. Ultimately, WiMax proponents see it as the basis for ubiquitous, continuous mobile wireless connectivity. Moreoer, the ZigBee Alliance is the driving force behind the 802.15.4 technology, which operates in unlicensed spectrum, including the crowded 2.4-GHz band. It can transfer a mere 250K bit/sec of data within a range of 30 to 200 feet.

Finally, we have broken down the industry adoption paths in categories:

a. *Solo*: This path takes place when many organizations invest in the technology, but the benefits are exploited by a single company. This path is happening in the retail sector where retail giants like Walmart obliged their suppliers to use RFID in their pallets and cases. We do not expect it to occur in the OCI.
b. *Single-to-many*: In this case, key investments are made by one partner but benefits accrue to many stakeholders. This path, which has successfully been tested in the semiconductor manufacturer Intel, could be an adoption path in the OCI. For example, if an ocean carrier adopts RFID, the company alone will bear the investments costs; however, many stakeholders –shippers, consignees, terminals, etc- will benefit from increased visibility.
c. *Partnership*: In this path, collectively invest in the technology and share the benefits. The partnership method is very relevant in the ocean industry. For example, coordination between carriers and terminals could promote both terminal productivity and carriers' schedule reliability. We think that this model can work very well in the industry. Partnerships could also exist between companies that provide RFID solutions with companies that offer IT services in the maritime industry. Thus, telecommunications interoperability issues will be addressed.
d. *Closed Loop*: In this path, a single company invests in RFID and harvests its benefits. We reviewed certain applications where this has taken place. We think that this is a very good path for terminals to track their equipment internally (cf., the reviewed example of APL).

5.3. Challenges in RFID adoption

Our optimism does not disregard the open challenges as regards RFID utilization, which have as follows.

<u>Risk aversion of ocean stakeholders:</u> Our participation in RFID projects unveiled us that initially the players were very skeptical of RFID. Specifically, the terminals did not want to permanently put on their equipment (e.g., on the spreaders that connect the straddle carrier with the container) RFID tools. Analogous was the case for carriers regarding their containers. Dissemination actions could assist in overcoming this challenge.

Standardization: Progress in global RFID, e-seals and other seaborne IT standards is long awaited. However, the international EU, US and Asian committees have not yet reached a *modus vivendi*.
Information issues: The *modus operandi* of the ocean industry is not accustomed to the concepts of information sharing and collaborative optimization of processes. Moreover, information ownership and security issues arise and there are certain legislative gaps. Privacy is not expected to be a big problem in this industry.

6. OBSERVATIONS AND SUGGESTIONS FOR CONSIDERATION

In this paper we have, hopefully, accomplished our two-fold objective, which was to describe the status and the perspectives of RFID technology in ocean container transport. To do this, we also reported the problem area, expected changes, RFID and container ID fundamentals. Both RFID status and perspectives appear rosy in the sense that the RFID-maritime applications, which have been completed, are considered successful and simultaneously there is a plethora of factors that catalyzes further RFID adoption.
In such a thriving and continuously evolving environment there could be many research topics abreast of the industry needs. Potential topics can be traced in the open challenges described in §5.3, like standardization and information issues. One particular rewarding topic of research would be the design of incentives for RFID adoption in the OCI. These incentives could mimic the ones devised for supply chain coordination and contracting.

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