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Analysis of active radio frequency identification systems for maritime vessel security and registration operations

C. Chung[1], L. Schulze[2]

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ABSTRACT

There are approximately 13 million recreational vessels in the US. To operate legally, these vessels must be registered either in their home state or documented with the U.S. Coast Guard.
Registration and documentation typically involves the annual or biannual reissue of a small sticker to be affixed on an external location of the vessel hull. Due to the large number of recreational vessels and the difficulty in visually observing the presence of an unexpired vessel registration tag, many states cannot economically maintain an ongoing registration enforcement operation.
This paper describes the design and analysis of an RFID system for marine vessel registration. With this type of system, for the first time, law enforcement and regulatory organizations such as state fish and game agencies can efficiently and economically determine the existence and currency of vessel registration. Analysis indicates that RFID systems can determine the validity of vessel registration 374% faster and 300% more accurately than visual inspection methods. This allows previously unrealized fees and fines to be more easily recovered from expired vessels. In addition, the system also lends itself to the recovery of stolen marine vessels and the tracking of vessels used in illegal activities.

1. Introduction

The U.S. Maritime Transportation System (MTS) handles approximately13 million recreational vessels, 82,000 fishing vessels, and 100,000 other commercial small vessels in 361 Ports. It is valued in many billions of dollars to the economy. Despite the extent and importance to the U.S., the MTS has very limited regulation with respect to identification and accreditation of <300 gross ton vessels. Currently, no means other than visually acquired hull identification numbers and lettering and registration tags exists for the positive identification of small marine vessels. This situation prevents the government organizations such as the Department of Homeland Security, the United States Coast Guard, and state level law enforcement agencies from cost effectively monitoring the registration and operation of small marine vessels. The presence of unregulated small vessel registration represents the loss of operating capital for government agencies while also leaving a gap in the secure operation of the MTS.

2. Problem statement.

Aside of violation of federal and state maritime law, the loss of registration fees represents a significant capital loss to both Federal and State marine vessel regulatory agencies. Beginning in 2015, all USCG documented vessels must pay an annual fee of $26 per vessel. Similarly, state agencies also charge registration fees. In the state of Texas for example, registration fees vary according to vessel size. Every two years a vessel between 26 and 40 feet in length requires a registration fee of $110. Larger vessels over 40 feet in length is $150. In this study, only 82 percent of the vessels displayed any registration tag and only 56 percent of the tagged vessels observed possessed a valid current State of Texas registration tag. Given the volume of recreation vessels and the degree of non-compliance, this situation represents a significant loss of operating capital.

[1]Associate Professor. Dept. of Industrial Engineering. University of Houston.
[2]Associate Professor. Dept. of Industrial Engineering. University of Houston.

The loss of operating capital in this manner has an interactive effect as, less operating capital further constrains the allocation of resources for the identification of out of compliance vessels and the collection of registration fees.

The second major problem that an ineffective small vessel registration system presents is diminished security to the MTS. Stolen vessels and vessels engaged in illegal activities are more difficult to identify without an effective registration monitoring system. The issues of psychological impact, physical destruction, and disruption of services by small vessels was identified by Croft (2007). In this communication Croft also identified possible countermeasures involving identification and accreditation of vessels. Also in 2007, the DHS National Small Vessel Security Summit discussed and forwarded recommendations for addressing the small vessel security threat. However, it was not until 2008 that a coherent framework was established to improve maritime security. Part of this strategy was to detect, infer intent, and interdict small vessels posing a maritime threat. In 2009 the USCG Commandant stated that the greatest threat to maritime security was due to small unregulated boats (Battle, 2009). The same theme was echoed by Rusling (2009). In 2011, these concerns resulted in the development of the DHS Small Vessel Security Implementation Plan.

By leveraging technology, both the Federal and State regulator agencies can increase their operating budgets while simultaneous helping improve the MTS small vessels security. Technology such as RFID have been identified as a possibility to fulfill these needs. Despite this potential, previous RFID small vessel tests are limited. Two known efforts include Crofts (2007) and Appler (2009). Crofts focused on antenna issues while Appler examined the use of aircraft to detect tagged vessels.

3. Objetive.

The primary objective of this paper is to design and analyze the effectiveness of using Radio Frequency Identification Technology (RFID) for small vessel registration applications. This will allow both Federal and State level agencies to determine the benefits of implementing this type of system. It is expected that the increased efficiency and effectiveness of this type of system will increase agency operating budgets while simultaneously helping improve maritime safety.

4. Background technology.

Radio Frequency Identification Technology (RFID) is beginning to permeate many sectors of our society. This includes the manufacturing, retail, service, finance, transportation, and security sectors. Within the next few years, RFID technology may become as prevalent as barcodes.

RFID technology involves the identification, location, and control of various host items using small wireless tags. When activated by an RFID system, an RFID tag emits a radio frequency code. Each tag's code is unique thereby allowing the tagged item to be individually identified. The location of the tagged item is established by the antenna reader that records the tag's identification code. This allows items to be controlled by alerting a host computer as to both the tagged item's identity and its location. The host computer can then match the item's identity and location to a central database to determine further processing. This may include inventory or security access authority functions.

RFID systems are categorized as either passive or active. The following figures illustrate both passive and active tags.

Figure 1: Passive RFID Tag.

Source: Authors.

The passive RFID tag illustrated in Figure 1 - Passive RFID Tag is used for automatic tollway fee collection. It is approximately four inches by four inches. It is deployed by removing the adhesive facing and pressing it against an automobile windshield.

Figure 2: Active RFID Tag.

Source: Authors.

A small active tag illustrated in Figure 2 - Active RFID Tag is manufactured by Wavetrend. It is approximately 86 mm long, 54 mm wide, and 5 mm thick. It weighs 24 grams. This active tag has a specified range of up to 100 meters. It contains a nonreplaceable 3 volt lithium battery that lasts 3+ years.

The difference between these systems is based on the RFID tag's power source. Passive tags do not have an internal power

source. They rely on power transmitted from the RFID reader's antenna to power the tag's circuitry. Conversely, active tags contain a dedicated internal power source. The difference between these two types of tags is significant. Passive tags are more limited in the information that they can store, as well as, their effective range in comparison to active tags. However, the addition of the internal power source with its greater information and range capability also results in significantly increased form factor and expense. For marine based RFID applications, the only feasible option due to range issues is active RFID tags. Since most state governments require registration tags be issued on a two year basis, the limited 3+ year battery life of a typical active RFID tag is not an issue.

RFID technology has been previously used in the marine environment. However, this has been limited large freight shipping containers such as those in the SAFECON program. This program primarily involves the tracking and inventory of containers as they are loaded, off loaded, and stored at marine ports. A variation of the tag illustrated in Figure 2 - Active RFID Tag is used for this purpose. There is no currently known effort underway to assess RFID technology for small vessel maritime security as presented in this proposal.

In this application, the tagged items will consist of small marine vessels which have been historically used in terrorist activities, drug smuggling or illegal alien trafficking. Currently, small marine vessels are identified with either or both state identification tags and United States Coast Guard documentation numbers. Both of these systems require visual line of sight access for vessel identification. Since identification tags are already required for small marine vessels, the replacement of conventional tags with RFID enabled tags offers the opportunity to utilize this technology to improve National security. The following figure illustrates the vessel registration tag currently required by State of Texas law.

Figure 3: Small Vessel Registration Tag.

Source: Authors.

This tag is approximately four inches by four inches. Even under ideal marine conditions, it would be extremely difficult for any law enforcement related vessel to correctly identify the number on this tag. Under normal marine conditions with waves, swells, wakes, salt spray or during reduced visibility, this task would be virtually impossible. Some locations require accompanying lettering as illustrated in the following figure. However, due to hull shapes and the same marine conditions previously identified, it may be similarly difficult to identify a vessel from this lettering. Above all, the relative positioning of the suspect vessel to the law enforcement vessel may also preclude identification of the suspect vessel from either lettering or a registration tag.

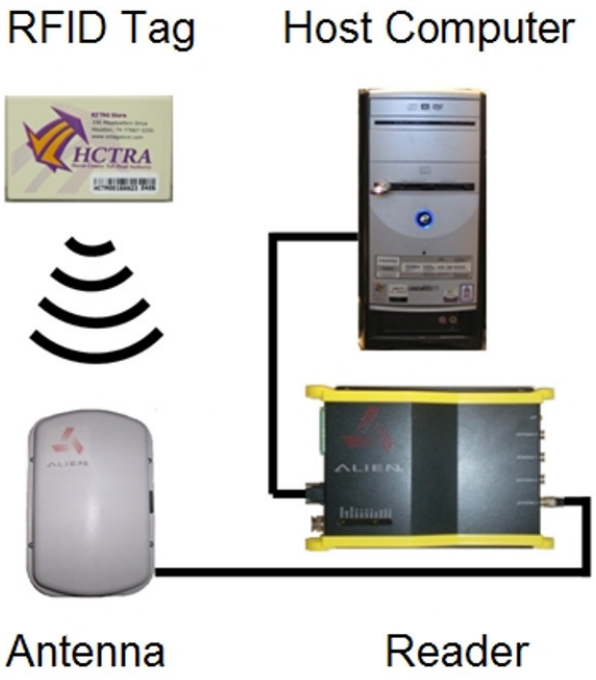
Figure 4: Small Vessel Registration Tag.

Source: Authors.

Since RFID tags do not depend on visual acquisition of lettering or registration tags, they are inherently superior for identifying vessels under both normal and difficult marine conditions. This makes the use of RFID tags, a natural evolution in the effort to properly identify marine vessels. Which ever type of RFID tag that is utilized, it is just part of an overall system that is necessary for information to be generated. A complete system consists of the tag, an antenna, a reader and a host computer. The following figure illustrates an RFID reader / antenna system.

When activated by the antenna, the RFID tag radio frequency signal is transmitted back to the antenna. The antenna then passes the signal to the RFID reader. The RFID receiver interfaces with the host computer. The RFID system described herein was based on Wavetrend, Inc. products. This line of equipment was chosen as it utilizes active RFID tags and the reader antenna operates off of 12 volts DC current. The Wavetrend RFID tag that was used for testing is a 433 MHz tag in credit card size format. The tag is powered by an internal battery rated for a five year service life. The tag is ultrasonically sealed providing sufficient waterproof protection to be used in the marine environment. Each tag transmits a unique identifier code which is received and processed by the reader antenna. The reader antenna was an RX1000 model which contains both the WiFi and the RFID antenna. The system was powered by a small 12 volt Absorbed Glass Mat battery. A Panasonic Tough Book notebook computer was utilized for running the RFID software. Tag read tests were performed using an omni directional antenna to determine the read range of the system

Figure 5: RFID Reader / Antenna System.



Source: Authors.

with tags positioned on a vessel. The following results were obtained.

5. Marine Registration Tag Data Collection.

To assess the effectiveness of the RFID system, a small vessel marina dock with 22 vessels in individual slips was utilized. Of these 22 vessels, a total of 18 possessed State of Texas registration tags. Only 10 of the 18 vessels with tags were not expired. A total of 36 participants were utilized for data collection purposes. The number of vessels, number of tags, and the tag status was not known to the participants prior to the data collection process.

The data collection process consisted of two different runs. The first run consisted of participants traveling down the primary pier and then turning off onto the finger piers which contained vessels. Since there were finger piers on the side of each boat slip, the participants could check for the presence and currency of the registration tags on two boats at a time. The time to complete this entire process was recorded in decimal minutes. The second run consisted of the participants operating in an RFID system mode. In this case, the collection of the registration data only required that the participants walk to the end of the primary pier. Tags are detected by the RFID reader antenna eliminating the requirement to travel down the finger pier to determine the presence and validity of the tax. The exception to this was in the case of the 4 vessels without registration tags. In these situations, the participants were required to visually check for the presence and validity of the tags by proceeding down the vessel's finger pier, as in the first run.

Table 1: Active RFID Tag Read Performance.

Reader Antenna System	Omnidirectional Antenna
Percent Reads at 100 yards	100
Average Distance Read Yards	119.7
Standard Deviation Distance Read Yards	10.5
Sample n	20

Source: Authors.

6. Marine Registration Tag Results.

The following table provides summary statistics for the registration tag data collection process.

Table 2: Summary Statistics for Time in Decimal Minutes to Complete Data Collection.

	Visual Observation	RFID System
Average	13.98	3.73
Standard Deviation	2.40	0.30
Sample Size	36	36

Source: Authors.

The summary statistics indicate that under the same data collection conditions, the RFID system is capable of completing the data collection process approximately 374% faster than the traditional visual observation method.

6.1. Paired T Test Results of Registration Tag Times.

Since the participants were involved in both the visual and RFID tag determination modes, it is possible to perform a Paired T-test comparison between the processing times. The following section summarizes the results of the test run at an alpha level of 0.05.

Ho: No difference between the population means
Ha: Difference between the population means
Level of Signficance: alpha=0.05
Critical Value: t for n-1 or 35 degrees of freedom = ±2.03
Test Statistic: t= - 26.31 calculated using:

$$t = \frac{\overline{D} - \mu_D}{S_D / \sqrt{n}} \quad (1)$$

Where *D* is the difference between the processing mode participant times, the hypothesized mean difference *D* ??is 0, SD is the standard deviation of the difference between the processing mode participant times, and n is the number of paired observations, which is 36.

Decision: Reject Ho at an alpha level of 0.05

The null hypothesis is that the times between the two methods visual versus RFID processing is equal. The alternate hypotheses is that there is a difference between the two times. The alpha value is set at 0.05 for the equivalent of being 95% confident of the results. The critical value for the alpha level using the t distribution for a two sided test is + or - 2.03. The calculated test statistic for a paired t test is -26.31. Since -26.21 is less than the negative critical value of -2.03, the null hypothesis must be rejected. This means that there is evidence to support the claim that the shorter processing time using the RFID mode is statistically significant at an alpha level of 0.05.

Aside of the statistically significantly faster processing time, another issue is the accuracy in which the data can be collected.

Table 3: Summary Statistics for Accuracy of Observations.

	Visual Observation	RFID System
Percent accuracy in observing presence of all present registration tags	11%	100%
Percent accuracy in observing validity of observed registration tags	25%	100%

Source: Authors.

Only 11 percent of the participants correctly visually recorded the presence of all of the registration tags. The remaining 89 percent recorded fewer than the actual number of tags. The relatively small percentage of complete observations is possibly due to the fact that the registration tag is positioned somewhat differently on each vessel according to the hull shape and other physical factors. The distance between the end of the finger pier and the tagged hull also undoubtedly contributed to the small 25% accurate determination of whether the tag was current or not.

As indicated in the RFID system read tests, 100 percent read accuracy is attained at distances less than 100 yards. Similarly, since the presence of the tag is associated with its registration status, the determination of currency is 100% barring an error in the registration database.

Conclusions

The use of RFID technology offers both Federal and State marine vessel regulatory agencies with the opportunity to operate a more efficient and cost effective registration system. The analysis indicates that the presence and expiration status of registration tags can be completed approximately 374% faster than visual observation methods. At the same time the RFID system can be operated with 100 percent accuracy. Further time savings are actually achieved as the automatically collected RFID data could also be interfaced with an electronic ticketing / notification system whereby the registration violator would be notified.

The implementation of this type of system will result in additional previously unrealized operating capital for any marine vessel regulatory agency. It is unlikely that any marine law enforcement system conducts 100 percent compliance checks. The use of RFID technology will help make this an achievable goal. In addition, the system will also allow for the immediate identification of stolen vessels and vessels engaged in illegal activities which is not now currently possible using visual observation methods.

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