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# A novel means to address RFID tag/item separation in supply chains

Yu-Ju Tu[a], Wei Zhou[b,c], Selwyn Piramuthu[d,*]

[a] Management Information Systems, National Chengchi University, Taipei, Taiwan
[b] Information & Operations Management, ESCP Europe, Paris, France
[c] MSc Big Data & Business Analytics, ESCP Europe, Paris, France
[d] Information Systems and Operations Management, University of Florida, USA

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ABSTRACT

Automated identifiers such as barcodes and RFID (Radio-Frequency IDentification) tags help with the quick identification of their associated items. When such an identifier is associated with an item, it is generally assumed that these two entities (the identifier and the tagged item) remain inseparable as long as is necessary. However, unintentional or (dishonest party initiated) intentional tag separation may occur, which necessitates an appropriate response before damage is done. We develop a knowledge-based means with cryptography to identify RFID tag damage and/or separation from its associated object. We also consider related security/privacy aspects of the proposed method.

## 1. Introduction

Identifiers play a significant role in today's automated retail environment. From a supply chain perspective, auto-ID (barcode, RFID tag) technology has been used to support logistics services as well as in-store retail operations since such automated identification supports fast and accurate service along with the reduction of lead time and operational and transaction costs. The most commonly used identifier in current retail setting is the barcode. It is hard to imagine a retail setting without barcodes since they facilitate a multitude of applications in retail supply chains that include inventory management and customer checkout.

Barcodes have been the auto-ID technology of choice in retail applications for more than four decades. While barcodes can be used for instance-level unique identification of items, they are commonly used for class-level identification (e.g., any 1 L bottle of brand X water). Although this has sufficed so far in a majority of retail applications, the trend is shifting with the popularity of sensors, block-chain, and other technologies that are being introduced in the retail supply chain. Barcodes have several drawbacks such as sequential (i.e., slow) read, line-of-sight requirement for readability, inability to have a two-way conversation with a reader, and the difficulty in attaching an associated sensor. Moreover, with the increasing move toward remaining shelf-life for perishables [12], RFID (Radio-Frequency Identification) tags are slowly replacing barcodes in a wide variety of retail applications at the pallet-level, if not at the item-level (e.g., American Apparel, Trasluz). In addition to their capability to store and process data, RFID tags can also have a two-way conversation with a reader. This is critical when authentication of the item is involved. Unlike barcodes, RFID tags readily allow for item-level identification due to their unique identifiers, and this property facilitates means to track and trace products in a supply chain [4,6]. While barcodes are cheaper to print vs. unit RFID tag cost, both barcode and RFID tag implementations incur back-end systems and reader cost. When all costs and benefits are considered, RFID tags come out ahead especially given their ability for two-way conversation, ease of associating sensors, batch read speed, no line-of-sight requirement, local storage and processing capability, copy/switch difficulty, among others [25].

RFID offers an efficient and effective means to automatically identify objects. Since a goal of IoT (Internet of Things), which comprises RFID tags, is to connect the physical and virtual worlds by “sensing” different “things” of interest, RFID-based information systems are often considered to be best candidates for IoT-based implementations. This is thanks in part to passive RFID tags that are generally very affordable and function without an external cable or battery as a required source for power, and can be effortlessly deployed to track and trace a large number of objects in a relatively fast and reliable manner.

In today's world, while RFID has been extensively and successfully used in various areas such as wireless token, inventory management, asset protection, and Industrial Internet, all of these RFID applications rely on the premise that the target item is tagged as it should be. As long as the communication between RFID reader and tag is secured and

* Corresponding author.
*E-mail address:* selwyn@ufl.edu (S. Piramuthu).

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uninterrupted, the underlying assumption is that the tagged item will always be identifiable and traceable. In other words, a strict and necessary requirement is that the RFID tag and the tagged item to be identified and traced are constantly bound together. If this condition is not sustainable, almost all contemporary RFID-based information systems will malfunction. However, recent studies have shown that, under many circumstances, RFID tags could be either accidentally or unexpectedly separated from the items to which they are supposedly attached [40]. Consequently, a series of problems may thus arise. For example, when a tag is separated (detached) from a tagged item, the association between that tag and that tagged item disappears. The tagged item's information that is stored in the tag becomes useless. The lost identity problem results from auto-ID technology use (e.g., barcode, RFID tag) as the item's identifier. For example, when the tag of a transportation pass card is lost, the card has no use since the tag represents the identity of the card holder. Relatedly, when an apparel tag is lost, the associated information such as the apparel's normal price and discount information go missing as well. More serious is the faked identity problem, since the separated tag could be easily tampered to impersonate other identities. For example, if the tag of a transportation pass card is pulled out and used to replace the one in another normal transportation pass card, true transportation records with false card holder's identification may thus be forged. In other words, the tag/item separation problem could be addressed with minimal damage to the identified object and with continued trust [15] and reputation [16] for such auto-id technology if there is a general means to immediately detect the tag's separation. From the item-tag combination's perspective, when tag separation occurs, the item loses its identification information regardless of how or why the separation event occurred. We therefore do not distinguish among the specific tag separation causes or processes such as the effect of temperature on the tag's adhesion to its associated item and accidental tag peeling on contact by an external object. Our focus is only on the tag separation event (yes or no) - 'how' and 'why' of tag separation are beyond the scope of this study.

In the retailing context, an item with a damaged or separated barcode necessitates manual identification of its stock keeping unit (SKU) and/or universal product code (UPC) as well as other related information that include the item's unit price. Such manual look-up necessarily causes avoidable process delays that disrupt automation. While it may be possible to manually retrieve associated SKU and/or UPC for a majority of items, it is certainly not a guarantee. When the identification information cannot be retrieved for whatever reason (e.g., last item of that type in the store), it could lead to loss in sale of that item as well as inventory shrinkage where an item is in stock but due to its missing identity the item is invisible to the (inventory management, checkout) system.

To the best of our knowledge, there is only one published research paper on identification separation in a supply chain context. Zhou and Piramuthu [40] consider identification shrinkage from an inventory management perspective with RFID as the identifier of interest and ticket-switching as the specific issue. Ticket-switching [37–39] is the intentional act of switching identifiers between two items in a retail setting that allows for the possibility of paying the lower item's price for the higher priced item.

Although there exist a few de facto ways to prevent items from being shoplifted, such as the use of electronic article surveillance (EAS) system or ink tag, these means are either unable to detect the unexpected identifier (e.g., ink tag) separation immediately or limited to only very specific separation cases. The primary motivation of this study is to find a general solution for addressing the tag/item separation problem. The few existing solutions to the tag separation issue are very application-specific which preclude their use in the general context. For example, NASA recently proposed a solution by using a passive RFID tag to detect tag/item separation [19]. However, NASA's approach is mainly designed for detecting whether a given bolt is torqued properly. Moreover, it needs an additional device that can mechanically operate on the tagged item and thus may not be universally suitable for general RFID-tagged items such as apparel or package. Such a solution does not address the issue that is critical to any RFID-based information system that includes security management. These facts reflect the pressing need and timeliness of this study. Based on our experience addressing related RFID-based issues, we propose the use of ambient conditions and intelligent learning for addressing the tag/item separation problem.

The contributions of this study are three-fold. This is the first research study that systematically investigates the problem of RFID tag separation. It is an ongoing trend that many firms are preparing themselves for making decisions based on the item-level information and the overall value of such information may amount to billions of US dollars [9,11]. However, such a trend and the associated value can hardly be sustained if items are mistakenly identified or tracked due to unexpected separation. This study highlights the importance of constantly watching the state of RFID tag attachment. Second, this study is the first to provide a solution to detect RFID tag separation. More importantly, this signifies that this study is complementary to the entire set of existing literature on RFID identification and tracking since such studies are reliable and valid only when the inseparability of RFID tag and the tagged item is guaranteed. Third, while this study is not the first to propose lightweight RFID authentication means, it is the first to consider the use of ambient condition to achieve both mutual authentication and tag separation detection. Moreover, the method proposed in this study is not designed for a very specific context such as a customized RFID tag with a rewired antenna, etc. Rather, it is very general because it is based completely on information with no reliance on mechanical means. For instance, the proposed method can be easily applied to any passive RFID tag that follows ISO EPC C1G2 standard.

The remainder of this paper is organized as follows: Since there is really no published research literature that addresses the RFID tag separation issue in a supply chain context [5,14] other than Zhou and Piramuthu [40], we briefly review this paper along with a few other tangentially related papers and also consider the current state-of-the-art to handle RFID tag separations in Section 2. We consider a few different means to address the tag separation issue and discuss these in Section 3. We follow this with a brief discussion on the potential use of sensors in these applications and then present the proposed associated cryptographic protocol in Section 4. We also include security analysis of the proposed protocol. We provide experimental results using the considered frameworks and also discuss performance results using the different frameworks in Section 5. We then conclude the paper with a brief discussion in Section 6.

## 2. Literature review and current state-of-the-art

Unexpected RFID tag separation can be a devastating threat in all current RFID-based information systems. Tag separation often denotes the loss of item information and thus in turn incurs additional labor and other (e.g., computational, customer goodwill) costs for recovery only if the tag separation is detected. Moreover, the additional cost could be very hard to tolerate, considering the thin margins in some (e.g., retailing) applications. More seriously, tag separation often signifies the loss of item control when the tag separation incident goes undetected. Nowadays, some retailers use RFID tags as their items' identifiers to automatically (e.g., inventory) manage these items. However, when a tag is separated from its tagged item either intentionally or accidentally, its identification information is lost and thus the item would be out of control. For instance, a culprit was caught at a Target store for removing the price tag from a cheap item which was then switched with that from an expensive item in order to pay less for more [18]. In another incident, a student was caught using the tag that is originally meant for a very cheap gadget for checking out with an iPod that costs more [42]. Similarly, several people were caught at a Walmart store for switching the price tags on many valuable items and returning the items without the tags to the store for refund [27]. There have been several