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Araştırma / Research

MANAGING A RETAIL FASHION PRODUCT WITH RFID-ENABLED INVENTORY VISIBILITY

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ÖZ

One of the main promises of Radio Frequency Identification Technology (RFID) is reduction in inventory record inaccuracy at retail stores, and thus to help achieve inventory visibility in the system. In this paper, we investigate the impact of RFID-enabled inventory visibility for a retailer that sells fashion merchandise, such as trendy apparel. Because the retailer already commits to a total quantity for the item before the season begins, an increase in sales cannot be expected. Here, we formulate the value of inventory visibility as an increase in revenue generated from the product. We characterize the components of this impact and how it changes with respect to the retailer and product characteristics. We also consider the possibility of imperfect performance of an enabler technology like RFID, and analyze how it affects the ROI of the technology.

Keywords: Retail, inventory, RFID, fashion, perishable, imperfect read rate

RFID İLE SAĞLANMIŞ ENVANTER GÖRÜNÜRLÜĞÜ İLE MODA PERAKENDE ÜRÜNÜ YÖNETİMİ

ABSTRACT

Radio Frequency Identification (RFID) teknolojisinin sanayiye sunduğu başlıca değerlerden biri envanter kayıtlarındaki stokla gerçek envanter durumu arasındaki tutarsızlığı yok etmesi, bu şekilde de sistemde envanter görünürlüğünün elde edilmesini sağlamaktır. Bu makalede, hazır giyim gibi moda tarzı ürün satan bir perakendeci için RFID ile sağlanmış envanter görünürlüğünün etkisi irdelenmiştir. Satış sezonu başlamadan perakendeci toplam sipariş miktarını sabitlemiş olduğundan RFID kullanımı satışlarda bir artışa neden olamayacaktır. Bu durumda, erişilen envanter görünürlüğünün etkisi üründen elde edilen toplam gelirdeki artış olarak formüle edilmiştir. Bu etkinin bileşenleri tanımlanmıştır ve perakendeci ve ürün özelliklerine göre etkinin nasıl değiştiği nitelendirilmiştir. Ayrıca RFID teknolojisinin kusurlu performans göstermesi de göz önüne alınmıştır ve bu kusurlu performansın teknolojinin getirisine etkisi incelenmiştir.

Anahtar kelimeler: Perakende, envanter, RFID, moda, ölümlü, kusurlu okuma oranı

1. INTRODUCTION

RFID (Radio Frequency Identification) technology has been described as the “best thing since the barcode” since its rise in 2000s [1]. RFID offers two fundamental advantages over the barcode technology. First, through the simple chip embedded in each RFID tag, it has the capability to carry Electronic Product Code (EPC) and uniquely identify the labeled product - as opposed to a generic one provided by the barcode. Second, identification of a tag does not require line-of-sight; in fact, a sophisticated RFID reader can “talk” with multiple tags through radio waves in a given instant. Thus, when compared to a typical barcode that needs to be individually scanned, RFID

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enables a superior and a more efficient way of object identification and communication. Through this enhanced visibility, RFID presents numerous implementation opportunities and added value across different industries, both public and private, in areas such as inventory management, logistics and transportation, cold chain management, safety, security management, and sales and promotion management (see for example [2], [3], [4], [5], [6]).

Inventory record inaccuracy, which is defined as the discrepancy between the inventory record and the actual inventory level available, is a painful issue for retailers. Due to replenishment errors, transaction errors, employee theft and customer shoplifting, damaged or spoiled goods, incorrect product identification, and incorrect recording of sales, the inventory record and the actual levels start to drift apart over time ([7], [8]). In fact, [9] reports that a global retailer, at the end of the annual physical audit, discovered that in an average store only about 51% of the SKUs had a match between its recorded and actual inventory levels. Furthermore, for only 76% of the SKUs, the record and the actual inventory levels were in the neighborhood of ±5 units. Similarly, [8] found that in a retailer chain of 37 stores, 65% of the inventory records were in fact inaccurate. Faced with a severe problem like this, retailers suffer from stock-outs due to under- or over-replenishment of stores as well as demand forecasting issues. RFID with item-level tagging, by rendering physical inventory audits inexpensive, fast and efficient, makes possible for a retailer to monitor and compare the two inventory levels and correct its records weekly, daily, hourly, and even in real-time if so preferred [10]. Achieving inventory record accuracy through RFID facilitates timely and correct shelf/store replenishment, which in turn is expected to increase availability, and hence sales [11]. This promise has been the major driver of RFID pilots by many retailers in 2000s, and not surprisingly they started with long life-cycle products with stable demand. For example, Macy's started item level RFID trials from "replenishment goods, which are items that are regularly stocked and automatically resupplied when sold to shoppers" ([12], [13]). Wal-Mart similarly started with men's jeans and basics [14]. Today, apparel retail is singled out as the sector with the strongest RFID case and Macy's is leading the way to full RFID implementation with a target of tagging 100% of its SKUs by the end of 2017. Wal-Mart, however, seems to have abandoned RFID roll-out plans in its supply chain and stores, now investigating blockchain for visibility in food tracking and safety [15].

Although Macy's bold move towards a complete item-level RFID roll-out is encouraging, only 4% of apparel retailers share the same vision with the department store chain as of 2016 [16]. Moreover, the leap to tagging all items is generally justified with the rise of omnichannel retailing; because RFID tagging became a "need" for stores' order fulfillment capabilities. This sudden shift in trends and arguments gives rise to the presumption that there is no use/value of RFID if the item is not a basic product, or if the retailer does not have omnichannel aspirations. Some recent articles advocating item-level RFID implementation cite "inventory markdown reduction" or "the correlation between inventory distortion and sales improvement" (see for example [17]) as major factors of value but it is difficult to find an unambiguous business case behind those arguments.

In this paper, we provide the missing link by investigating the value of RFID technology for a short life-cycle (fashion) product from a brick-and-mortar retailer's perspective. As fashion products tend to have a short life-cycle, retailers have to commit on the total (buy) quantity of the items before the selling season, and thus, there is no opportunity for order cancellation or additional replenishment. We show that, although the retailer cannot simply sell more of the fashion product, item-level RFID will still offer value to the retailer. To evaluate the value of RFID-enabled visibility, we characterize the revenue performance of the retailer with and without inventory visibility in its chain. In addition to assessing the significance and magnitude of the value of visibility, we characterize how it changes with respect to the various factors in the problem setting. By a fashion product, we mean an item that has a short life, and that will lose its attractiveness (and hence value) for the consumer over time. In managing a fashion item, the retailer clears away all leftover inventory (if any) at the end of the regular season through markdowns.

Though RFID technology has the potential to completely eliminate inventory record inaccuracy in any environment for any product type, currently, it is not a perfect technology. In fact, RFID still suffers from performance issues, including reading rates, especially around metals and liquids ([18], [19], [20]). Additionally, in the retail environment, flaws in day-to-day use of RFID could further exacerbate the performance problem. A careless use of the hand-held readers by store employees in a routine physical audit is sufficient to distort the RFID performance and consequently the inventory records.

RFID technology with a perfect performance is a widely used assumption whenever a benefit estimation is done. However, it would not be realistic to expect perfect implementation or use of a new technology like RFID in a retail environment. Here, we also study an imperfect RFID scenario and characterize the impact of technology performance on the estimated benefits.

Our results show that value of visibility is statistically significant and robust across retailers of any size. However, it could present limited value for some retailers. Inventory visibility tends to have a two-fold revenue effect: first through diminished lost sales in the regular season and second through better yield management in the markdown period. The extent of the visibility impact highly depends on various characteristics of the retailer, including inventory record inaccuracy rate, the retailer's competence in forecasting and planning, product life-cycle, product perishability (or fashion-forwardness), and store service level targets.

Our work is mainly related with two streams of literature. One focuses on the inventory record inaccuracy and analytical models to deal with the issue in a retail environment. The second stream focuses on quantifying the value of RFID technology for different parties in a supply chain.

Inventory Record Inaccuracy: Within the operations management literature, there is an extensive body of work which studies the inventory record inaccuracy issue and develops sophisticated models to avert it. [8] demonstrates the severity of the inventory discrepancy through an empirical analysis and highlight the factors that mitigate or exacerbate the issue. [7] develops a Bayesian Update methodology to keep track of the actual inventory level in presence of inventory record inaccuracy. [21] similarly studies an information-sensitive inventory management system for a retailer with inventory discrepancy issues. [22] characterizes the optimal inspection policy that balances the risks and costs associated with inventory discrepancy due to transaction errors with inspections costs. As in all these papers, we study a retailer's performance in the presence of inventory discrepancy issues. However, we specifically focus on quantifying the revenue impact of inventory record inaccuracy in a fashion product environment rather than developing approaches to account for inventory discrepancy under stationary product demand.

RFID Uses and Benefits: An extensive stream of research on RFID benefits studies the implementation of a perfect RFID technology and its impact on businesses through increased inventory visibility or eliminated inventory record inaccuracy. [9] coins the term “frozen inventory.” The paper demonstrates how inventory shrinkage could “freeze” store inventory by preventing replenishment due to a high inventory record when the product is in fact out of stock. RFID technology is proposed as a remedy to avert this issue. Similarly, [23] studies the RFID impact regarding the elimination of inventory discrepancy in a multi-echelon retail supply chain. Cost-savings is the common perspective taken by many papers in this stream (see for example [24], [25], [26], [27], [28], [29], [30], and [31]) As for others, [32] and [33] focus on the profit impact of RFID through a Newsvendor-like setting whereas [34] assesses the profitability impact of RFID in the inventory management of vending machines. [35] and [36] study the use of RFID technology in warehouse and outbound logistics operations, respectively. Our work and all these articles share the common goal of assessing the value of RFID-enabled inventory visibility or traceability. The problem setting we study and our explicit focus on the revenue impact sets our work apart from the rest of the literature.

The more recent articles focusing on the operational value of RFID also take into account the imperfect performance of the technology. For example, [37], [38] and [39] study the shelf-replenishment problem under suboptimal read rates of the technology. As these papers do, our work takes into account the imperfect nature of the technology, and evaluates the robustness of the estimated business value with respect to suboptimal read rates. Our problem setting is focused on a fashion product which loses its attractiveness when its “season” ends. In that, it behaves like a perishable product that never actually expires. The research on the use of RFID technology in perishable inventory management is mainly focused on the availability of product expiration information. For example, [40] and [41] study supply chain problems where RFID technology makes available instantaneous quality and remaining shelf-life information, respectively. [40] focuses on the traceability of contaminated products enabled by RFID in perishable food supply networks. In our problem setting, however, “product expiration” is already uniform across products and only dependent on the amount of leftover inventory in the markdown period. Though RFID does not add any value through “product expiration” information, it is the inventory record inaccuracy eliminated with the technology that makes a difference. In this respect, our work complements this stream of literature with its different perspective on a fashion product in a distribution network.

There are also papers that take an empirical approach to the inventory record inaccuracy problem and RFID's effect on it. For example, [42] estimates the inaccuracy rate from empirical data and demonstrates how inventory and service levels change in a distribution center. [10] shows how RFID technology can in fact substantially reduce inventory record inaccuracy, though with high variability across product categories. In this respect, these articles validate our problem setting and assumptions regarding inventory discrepancy, RFID visibility impact, and subpar read rates.

There is also an extensive literature that studies the RFID investment decisions in a supply chain that consists of more than one party. For example, [43] studies the RFID cost allocation that would maximize the return in a manufacturer-retailer supply chain. [44] similarly studies the incentive conflict in RFID investment in a two-stage supply chain. [45] shows that RFID could also mitigate the double marginalization in the supply chain, and hence a decentralized system could benefit more from the technology. [46] studies the free-rider problem regarding the RFID investment in a supply chain. [47] focuses on RFID valuation and investment decisions under budgetary constraints. This stream of papers studies the inefficiencies in decentralized systems and its interactions with RFID investment decisions. They characterize when and how RFID technology could be a feasible investment in supply chains. Here we study a centralized system with retailer as the sole decision-maker in the system, but we also assess the value of RFID and characterize what kind of technology costs are acceptable for item-level adoption. We refer the interested reader to [48] for an extensive review of the research on RFID and its value.

The remainder of the paper is organized as follows. In section 2, we introduce the model details. We present our findings in section 3; first regarding the perfect visibility in 3.1 and later of the imperfect technology performance in 3.2. In section 4, we highlight our insights and conclude the paper.

2. MODEL DETAILS

We model a multiple-store (N) distribution system of a retailer who maximizes the total revenue generated from the sales of a fashion product. The retailer manages the stores through a single distribution center (DC) in the presence of inventory record inaccuracy at the stores. After the regular season is over, the product is marked down so that the leftover inventory is all cleared. There is no transshipment among stores. We adopt a periodic-review inventory environment in our model.

We use a linear function to model the periodic demand at store i. It comprises of a deterministic and an uncertain part; i.e., $d_{it} = K_{it} - ap_{it} + \epsilon_{it}$, i=1,…,N, t=1,…,T+1 where ϵ_{it} is independent, identically distributed (iid) across stores and periods, and has zero mean. Here, a represents the price sensitivity of consumer demand. Over the regular season, the product is sold at a previously-set chain-level price p whereas over the markdown period the price is marked down to clear the leftover inventory at each store. A store's demand potential over the regular season is stationary whereas it is possibly lower in the markdown period; i.e., $K_{i,T+1} \leq K_{i1} = \cdots = K_{iT}$. The notation we use in the model is available in Table 1 below.

Table 1. Notation

d_{it}	Demand at store i, at period t, i=1,…,N, t=1,…,T
y_{it}	The order-up-to level for store i, for the beginning of period t, i=1,…,N, t=1,…,T-1
x_{it}	The actual inventory level at store i, for the beginning of period t, i=1,…,N, t=1,…,T+1
z_{it}	The replenishment quantity sent to store i, at the beginning of period t, i=1,…,N, t=1,…,T
$\hat{x}_{it}$	The inventory on record at store i, at the beginning of period t, i=1,…,N, t=1,…,T+1
ϵ_{it}	The random shock on the periodic demand at store i, at period t, i=1,…,N, t=1,…,T+1
θ_{it}	The random variable that represents the periodic inventory record inaccuracy at store i, at period t, i=1,…,N, t=1,…,T+1
K_{it}	The demand potential at store i, at period t, i=1,…,N, t=1,…,T+1
a	Price sensitivity parameter of the periodic store demand
p	The chain-wide regular season product price
p_{im}	The realized markdown price at store i
Q	Total buy quantity of the product

The sequence of events in a regular season period for a retailer without full visibility are summarized below (see Figure 1 for a sketch of the model dynamics):

(1) The retailer checks the inventory record $\hat{x}_{it}$ at store i and creates an allocation order based on the order-up-to level y_{it} at each store. Orders are shipped if there is enough inventory at the DC to satisfy all allocation orders. If not, the retailer determines the shipment quantities to balance out the store service levels as much as possible[1]. The stores are instantly replenished based on the determined shipment quantities (referred to as z_{it}) .

(2) The demand at store i (d_{it}) is realized, and sales $s_{it} = \min(d_{it}, x_{it} + z_{it})$ are recorded. In addition to demand, there is also a random inaccuracy shock θ_{it} on the actual inventory level at the store; i.e., $x_{i,t+1} = x_{it} + z_{it} - s_{it} - \theta_{it}$.[2] The inaccuracy shock being positive translates into shrinkage due to theft, shoplifting, misshipment, damages, and etc. The net inaccuracy shock being negative translates into emerging misplacements, misshipments, misidentifications, and etc. Whenever θ_{it} is positive and $x_{it} + z_{it} < d_{it} + \theta_{it}$, we assume the available inventory is split proportionally between customer demand and shrinkage. Note that, we

[1] At the beginning of period T, which is the last period in the regular season, the retailer ignores the pre-set y_{it} and determines allocation orders to clear away all the inventory at the DC and balance out the expected service level at each store.

[2] θ_{it} can also be described as an “auxiliary demand stream” that may take positive or negative values.

assume θ_{it} is iid across stores and periods, and follows a distribution with mean $\mu_\theta > 0$ and standard deviation $\sigma_\theta > 0$; i.e., inaccuracy shock may be positive or negative but is more likely to be positive than negative. Based on the sales observed, the inventory record to start the next period is calculated as $\hat{x}_{i,t+1} = \hat{x}_{it} + z_{it} - s_{it}$.

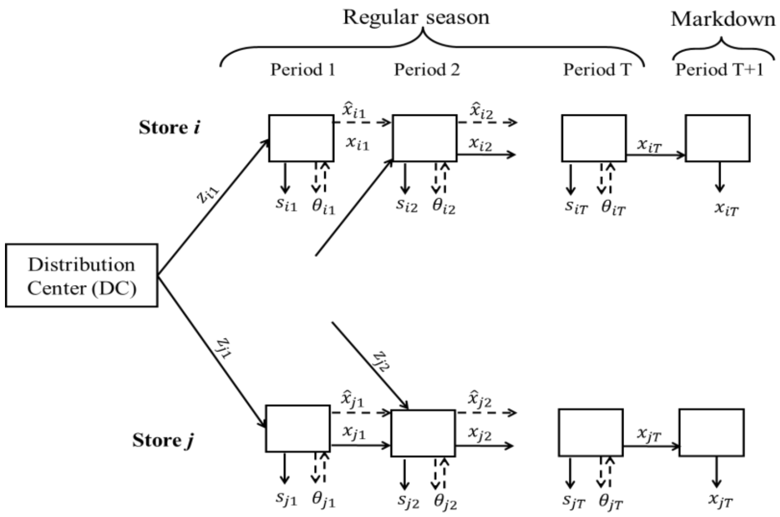


Figure 1. Model dynamics

The retailer has to sell off all units as the regular season ends. Therefore, in the markdown period, it offers price discounts at the store level to generate enough demand to clear away the leftover inventory. Thus, after $\epsilon_{i,T+1}$ is realized, the clearance price p_{im} ($p_{i,T+1}$) is adjusted so that $K_{i,T+1} - ap_{im} + \epsilon_{i,T+1}$ equals/surpasses the available inventory at store i at the beginning of the markdown period. Markdown price cannot be greater than the regular season price and has to be nonnegative.

3. ANALYSIS

In this section, we first introduce the framework we use in our analysis and then share the main insights of our study.

To evaluate the value of inventory visibility in managing a fashion product, we compare two management scenarios for the retailer:

(1) Uninformed Retailer (U): This retailer relies on the current information system, and hence cannot observe the actual inventory levels at its stores. As exactly described in the sequence of events in Section 3, it makes allocation/replenishment decisions based on the inventory on record.

(2) Retailer with Full Visibility (F): This retailer, by means of a technology like RFID, has visibility over the actual inventory levels at the stores. At the beginning of each period, it conducts a physical audit at the stores and updates its system with the actual inventory levels observed. It uses these values in allocation/replenishment decisions.

We compare the two scenarios in total revenue generated from the product. Specifically, we seek to evaluate the % improvement in total revenue (Δ) as our primary metric for the value of inventory visibility:

$$\Delta_{F-U} = \frac{\Pi_F - \Pi_U}{\Pi_U} * 100 \qquad (1)$$

where Π stands for revenue. Note that, since the retailer has already committed to a total buy quantity Q and purchased the units, cost is not relevant in our analysis.

We adopt simulation as our analysis methodology, which is not uncommon in RFID-focused research (see for example [23], [35], [36], [37], and [39]). This allows us to avoid simplifications that would otherwise be essential to generate analytical results, observe the magnitude and significance of the visibility effect, and at the same time characterize the impact of various factors on it. Thus, our analysis serves as a decision support tool to help businesses evaluate the value of RFID-enabled visibility in a complex system like a distribution network.

For a given set of parameters, we run 250 replications. For each realization/instance, we calculate the revenue generated by the uninformed and full visibility retailers, and calculate the % gap (Δ_{F-U}). We calculate the 95% confidence intervals for this gap. When we need to present a single value for Δ_{F-U}, we refer to the mean values when the gap is statistically significant; otherwise we record it as zero.

Note that we assume the retailer works with 1 period between reviews and instant replenishment; i.e., zero lead time. Thus, when it sets the order-up-to levels at the stores, it uses a type-1 service level target to cover the exposure demand of 1 period. To mitigate the impact of random effects on our results, we assume no inaccuracy shock occurs in the markdown period; i.e., the actual inventory level ending the regular season gets completely sold in markdown. We also assume there is no discounting due to time value of money across periods.

Under dynamics such as this, an increase in sales cannot be achieved since the total inventory in the system, Q, is already fixed before the season begins. A reduction in average inventory, which is the focus of many studies on RFID, is not possible either. However, the retailer still benefits from inventory visibility in terms of total revenue and markdown performance; first through timely replenishment and reduction in lost sales over the regular season, and second through balanced inventory and better yield management in the markdown period. Although an increase in unit sales is not feasible here, the retailer achieves a higher average margin from the units sold through effective store replenishment. Table 2 provides an example for a 2-store, 4-period season problem. The retailer with full visibility achieves about a 1% higher revenue compared to its uninformed counterpart and achieves a lower average discount in markdown. In Section 4.1 below, we characterize the significance and magnitude of this effect with respect to the various factors in our model.

Table 2. Visibility effect – numerical example (T=4, N=2, Q=570, p=50, Store service level=95%, $K_{it} = 100$ (i=1,2, t=1,…,4), $K_{i5} = 60$ (i=1,2), ϵ~N(0,6) (discretized), θ~N(1,2) (discretized))

	Store 1					Store 2				
	Period 1	Period 2	Period 3	Period 4	Markdown	Period 1	Period 2	Period 3	Period 4	Markdown
y_i	75	75	75			75	75	75		
$\hat{x}_{it}(U)$	0	12	17	7	35	0	19	1	24	38
$x_{it}(U)$	0	11	13	0	28	0	18	0	24	37
$x_{it}(F)$	0	11	14	0	29	0	18	0	25	31
$z_{it}(U)$	75	63	58	93		75	56	74	76	
$z_{it}(F)$	75	64	61	94		75	57	75	69	
d_{it}	63	58	78	65		56	77	51	62	
θ_{it}	1	3	4	0		1	0	-1	1	
$s_{it}(U)$	63	58	68	65	28	56	74	51	62	37
$s_{it}(F)$	63	58	71	65	29	56	75	51	62	31
$p_{it}(U)$	50	50	50	50	50	50	50	50	50	37.1
$p_{it}(F)$	50	50	50	50	48.6	50	50	50	50	45.7
$\Pi_{it}(U)$	3150	2900	3400	3250	1400	2800	3700	2550	3100	1374.3
$\Pi_{it}(F)$	3150	2900	3550	3250	1408.6	2800	3750	2550	3100	1417.1
$\Pi_U(total)$ $\Pi_F(total)$ Δ_{F-U}					27,624.3 27,875.7 0.91%	Avg. Markdown Price (U) Avg. Markdown Price (F)				42.7 47.1

3.1 Value of Full Inventory Visibility (PERFECT RFID)

In our simulation studies, we use discretized Normal distribution to model periodic demand uncertainty (ϵ~ N(0,6)) and inaccuracy shock (θ~ N(1,2)). We use the regular season price p=50, price sensitivity parameter a=0.7, regular season market potential ($K_r = K_{it}\ \forall i, \forall t \leq T$) 100, and markdown period market potential ($K_m = K_{i,T+1}\ \forall i$) 60. Thus, the expected inaccuracy shock in a period is about 1.54% of the expected demand. We conducted experiments with number of periods 4 through 10; number of stores 5, 14, 20, and 40; store service levels 95%, 97%, 99%; and a wide-range of total buy quantity Q. Below we present our main insights regarding the value of visibility and its change with respect to the various factors in our model.

Observation #1: Value of inventory visibility is higher for the retailer, and thus investment in a technology like RFID is more worthwhile, if the unit gross margin percentage is low and if the product price is high.

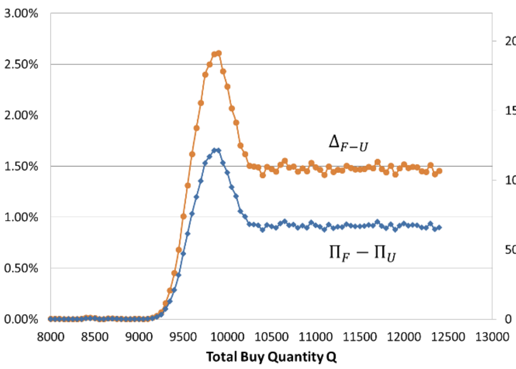
In our studies, value of inventory visibility has been in the range of 1-5% in revenue. Although it is highly sensitive and can increase considerably with some characteristics of the retail environment (e.g. product life, inaccuracy rate, etc.), the current numbers show that inventory visibility has limited returns for a fashion product retailer. Thus, inventory visibility by itself may or may not justify investment in a new technology like RFID. For a major retailer that generates revenue in the order of billion dollars, however, this “limited return” is still quite substantial.

Inventory visibility enables the retailer to sell at a higher average price and thus increases total revenue. Here we compare this increase in revenue to the total revenue generated. This increase will also be directly reflected in the gross margin generated. Especially if the retailer's average unit gross margin rate is low, visibility impact will be even more substantial and can easily pass the 10% mark from a total margin impact perspective. Thus, value of inventory visibility is more significant for a retailer if its average gross margin percentage is low.

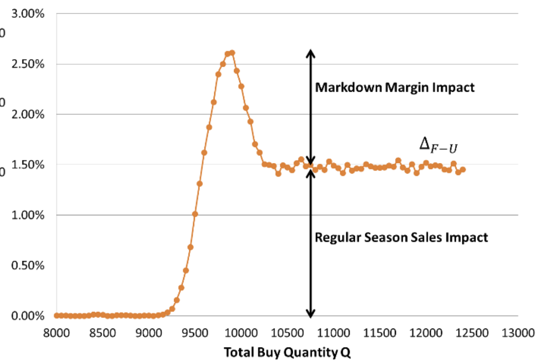
A 1-5% revenue impact also helps depict the cost-return tradeoff for a technology like RFID. In addition to the fixed implementation cost, RFID involves a recurrent tag cost which practically increases the retailer's unit product cost. Based on our current estimations, tag cost will not be deterring if the product price is high enough. If we take a passive RFID tag cost about 5 cents [16], a product price of $5 easily justifies the technology investment.

Observation #2: Value of inventory visibility has two components: increase in regular season sales and increase in margin in markdown sales.

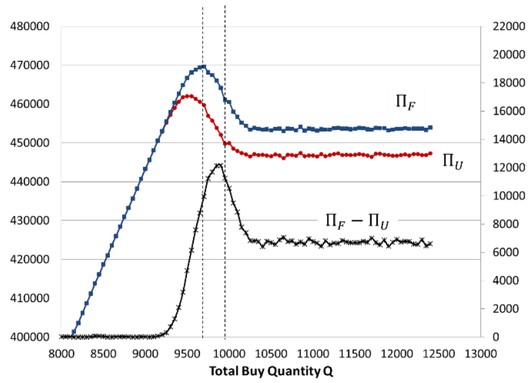
Observation #3: Value of inventory visibility is highest when the retailer is a competent planner but slightly “buys into markdown.”



(a) Δ_{F-U} (primary axis) vs. $\Pi_F - \Pi_U$ (secondary axis)



(b) Δ_{F-U} and its components



(c) Π_F, Π_U (primary axis) vs. $\Pi_F - \Pi_U$ (secondary axis)

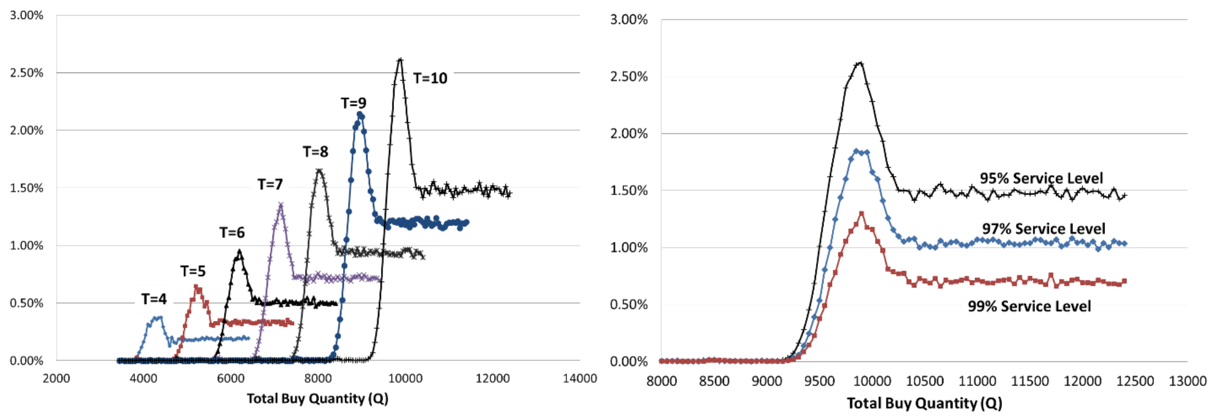
Figure 2. Value of inventory visibility WRT total buy quantity Q in a 14-store chain (Note: The following values were used to generate Figure 2: T=10, N=14, p=50, Store service level=95%, $K_{it} = 100$ ($\forall i, \forall t \leq T$), $K_{i,11} = 60$ ($\forall i$), ϵ~N(0,6) (discretized), θ~N(1,2) (discretized))

Figure 2 depicts the value of inventory visibility with respect to the total buy quantity in a 14-store retail chain. In Figure 2(a), we see that Δ_{F-U} becomes significant only when the buy quantity Q is high enough, reaches a peak as Q increases, and then stabilizes to a certain level as Q increases further. If the retailer does not buy enough units to meet the demand, inventory visibility does not have any return for the retailer. The retailer will sell all units at full price in any case; inventory visibility and better replenishment performance does not generate any additional revenue. If the retailer bought too many units compared to the demand, it will have to offer significant discounts at markdown (practically give the product away for free) irrespective of whether it has full inventory visibility or not. The stabilized level of Δ_{F-U} for high Q values here represents the value saved from regular season lost sales with better replenishment performance (see Figure 2(b)).

Value of inventory visibility is highest when the total quantity bought roughly matches the demand; i.e., if the retailer is competent at forecasting and planning to match the demand. Figure 2(c) shows that inventory visibility brings the highest return when the retailer slightly overbuys compared to the optimal supply required. This practice can also be characterized as “buying into markdown”; i.e., the retailer also plans for the demand over the markdown period or slightly overestimates the total demand. In this range, in addition to a better regular season performance, the retailer with full visibility can now make a difference in the markdown period and achieve better yield management. Here, full visibility enables the retailer to avoid stranded inventory and effectively achieve a balance across store service levels. This is how visibility makes a difference in sustaining high markdown margins. Markdown yield management impact is especially significant when the buy quantity is at reasonable levels but is slightly more than the optimal level required; i.e., when markdown sales is the most sensitive to inventory replenishment decisions.

Observation #4: Value of inventory visibility increases as the product lasts longer; i.e., as replenishment opportunities increase.

Observation #5: Value of inventory visibility diminishes as the retailer's store service level increases.



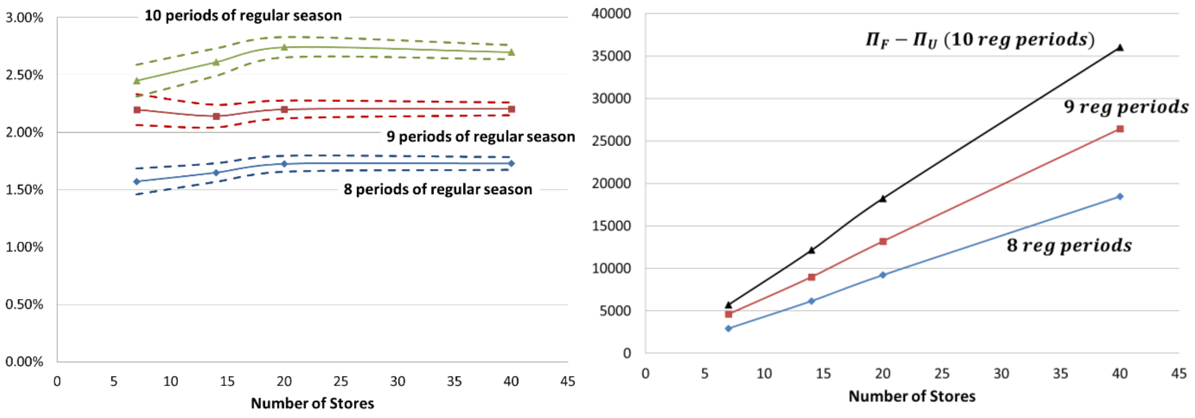
(a) Δ_{F-U} WRT product life (# of Periods in a Season) **(b)** Δ_{F-U} WRT service level

Figure 3. Value of inventory visibility WRT product life and service level (Note: The following values were used to generate Figure 3: T=10, N=14, p=50, Store service level=95%, $K_{it} = 100$ ($\forall i, \forall t \leq T$), $K_{i,11} = 60$ ($\forall i$), ϵ~N(0,6) (discretized), θ~N(1,2) (discretized))

Figure 3(a) depicts the change in the value of inventory visibility with respect to product life; i.e., the number of periods in the regular season. Every period an inaccuracy shock occurs, and the retailer with full visibility enjoys an opportunity to correct its records whereas the uninformed retailer is challenged with the accumulation of errors over the season. Thus, as the product life extends, value of inventory visibility increases.

Figure 3(b) shows that as the retailer's store service levels increase, value of visibility decreases. When the retailer operates with a high service level like 99%, even an uninformed retailer successfully prevents lost sales in the regular season. Additionally, since a high-service retailer has more inventory leftover for markdown, even a balanced inventory across stores - enabled by visibility - cannot sustain high markdown gross margins. Thus, value of inventory visibility is not as high if the retailer already operates with high store service level targets. In fact, the value of visibility (both Δ_{F-U} and $\Pi_F - \Pi_U$) more than doubles between 99% and 95% service levels.

Observation #6: Value of inventory visibility (Δ_{F-U}) stabilizes, and absolute value of inventory visibility ($\Pi_F - \Pi_U$) increases as the retail chain grows.



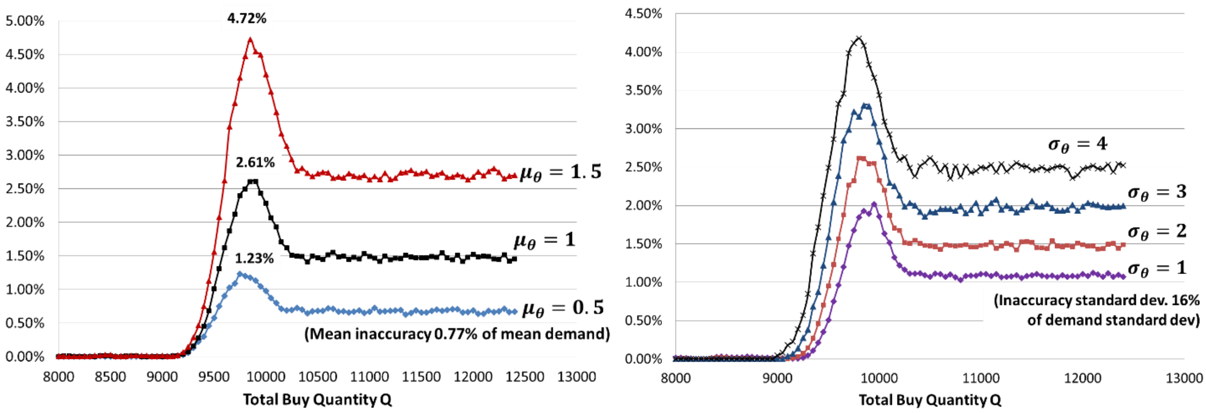
(a) Δ_{F-U} WRT # of Stores (Dashed lines are 95% C.I.s) **(b)** $\Pi_F - \Pi_U$ WRT # of Stores in the Chain

Figure 4. Value of inventory visibility WRT chain size (Note: The following values were used to generate Figure 4: T=10, N=14, p=50, Store service level=95%, $K_{it} = 100$ ($\forall i, \forall t \leq T$), $K_{i,11} = 60$ ($\forall i$), ϵ~N(0,6) (discretized), θ~N(1,2) (discretized))

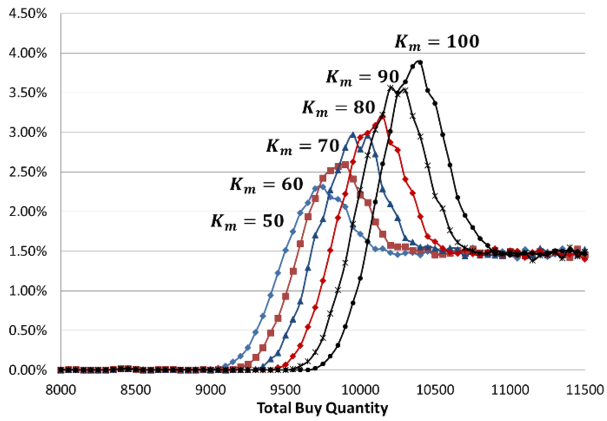
We see in Figure 4 that value of visibility is sustained as retail chain size expands. This means both the regular season and markdown season savings grow proportionally with the network size. Figure 4(a) shows that Δ_{F-U} stabilizes at a certain value as the number of stores increases, and Figure 4(b) shows that the absolute revenue impact grows proportionally with the retail chain size. Thus, a retailer of any size should expect a reasonable return from inventory visibility and an enabler technology like RFID. Size of the retail chain does not affect the tradeoff between the variable costs like item tags. However, major retailers may expect a higher ROI from the enabler technology after taking into account the fixed costs of the investment.

Observation #7: Value of inventory visibility increases as inaccuracy increases in terms of mean or variance.

Observation #8: Value of inventory visibility decreases as the product becomes more perishable (fashion-forward).



(a) Δ_{F-U} WRT inaccuracy mean **(b)** Δ_{F-U} WRT inaccuracy standard deviation



(c) Δ_{F-U} WRT product perishability

Figure 5. Value of inventory visibility WRT inaccuracy and product perishability (Note: The following values were used to generate Figure 5: T=10, N=14, p=50, Store service level=95%, $K_{it} = 100$ ($\forall i, \forall t \leq T$), $K_{i,11} = 60$ ($\forall i$), ϵ~N(0,6) (discretized), θ~N(1,2) (discretized))

Figures 5(a) and 5(b) show that value of visibility increases with inaccuracy; both its mean and standard deviation. As the mean inaccuracy increases, inventory shrinkage tends to dominate and the actual and recorded inventory levels start to drift apart even faster. An increase in the inaccuracy variance can both amplify the shocks a store faces over a horizon and distort the balance of inventory across stores more effectively. In either case, it becomes even more critical for the retailer to have inventory visibility and replenish responsively to manage its sales.

Figure 5(c) characterizes the value of visibility with respect to the product's markdown demand potential K_m. When the markdown demand potential is low compared to that in the regular season, this means the product gets obsolete and loses attractiveness fast. High "perishability" can be commonly observed in seasonal/trendy apparel. We see in Figure 5(c) that value of visibility drops as the product becomes more "perishable". Although the increase in regular season sales is sustained for all cases, markdown yield management suffers because of the depressed market potential, independent of whether the retailer has inventory visibility or not. Thus, retailers with highly seasonal or trendy products should expect modest returns from inventory visibility compared to others.

3.2 Value of Imperfect Visibility (IMPERFECT RFID)

The retailer with full visibility, by means of a technology like RFID, can conduct a physical inventory audit at the beginning of each period and update its information system with the actual levels observed in the audit. Thus, we assume the retailer has access to the perfect inventory information in this case. However, the enabler technology RFID, like many others, does not demonstrate perfect performance. In fact, it is widely known that RFID technology has imperfect read rates; i.e., not all RFID-labeled products will be identified by the RFID reader in a given space ([20], [39]) Thus, a physical audit conducted by means of RFID will tend to miss a few items and therefore underestimate the actual inventory available in a store. This means that in practice the retailer will not have access to perfect inventory information, but mostly an underestimated version of it.

In this part, we investigate the value of inventory visibility in a more realistic environment; i.e., by taking into account the imperfect RFID read rates. Here, we define a third management scenario that reflects the imperfect RFID technology and assess its impact compared to the full visibility case. Accordingly, we define:

Retailer with Imperfect Visibility (I): This retailer, as in the full visibility case, conducts a physical audit at the stores at the beginning of each period and updates its information system with the inventory levels observed. However, the observed values do not necessarily match the actual inventory levels due to imperfect RFID. Nevertheless, the retailer assumes these are actual values and makes allocation/replenishment decisions based on these observed values.

We refer to the observed inventory level at store i at the beginning of period t as x_{it}^r; where $x_{it}^r = R_{it}x_{it}$, i=1,...,N, t=1,...,T. The random variable R_{it} reflects the imperfect read performance of RFID and its uncertain nature during the inventory audit. Here we assume that R_{it} is iid across stores and periods, and takes values between 0 and 1. Thus, we assume that retailer with imperfect visibility may underestimate the actual inventory levels due to imperfect read rates, but will never overestimate them. In our simulations, we assume the read-rate R_{it} is normally distributed with parameters (μ_R, σ_R), 0.4<μ_R<1, and we truncate the values to the interval [0.4,1].

Imperfect RFID technology introduces errors in the inventory records in the system, though with a different nature from inventory record inaccuracy. Every period, the recorded inventory levels in the system are refreshed with the observed values in the audit. Thus, the errors due to imperfect RFID do not accumulate as inventory inaccuracy does for the uninformed retailer. Imperfect read rates encourage the retailer to over-replenish, and thus even decrease the risk of lost sales in the regular season. However, with this replenishment strategy, the retailer may push inventory to stores too early, and sometimes end up with too much inventory at some stores. We refer to this as stranded inventory. The former effect may boost the regular season sales whereas the latter may deteriorate the markdown margins and thus total markdown revenue. Table 3 shows an example scenario for the retailer with imperfect visibility using the same demand and inaccuracy realizations as in Table 2. Here, we see an increase in the retailer's regular season sales performance coupled with a drop in the average markdown price compared to the full visibility case (see Table 2). Nevertheless, the retailer with imperfect visibility still generates more revenue compared to the uninformed retailer, but now less than the full visibility scenario.

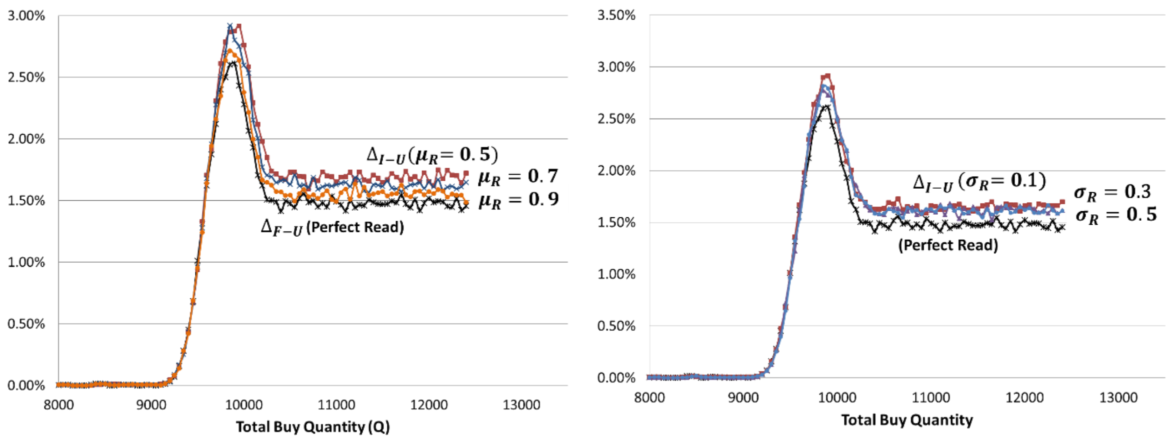
Table 3. Visibility effect with imperfect RFID – numerical example (T=4, N=2, Q=570, p=50, Store service level=95%, $K_{it} = 100$ (i=1,2, t=1,…,4), $K_{i5} = 60$ (i=1,2), ϵ~N(0,6) (discretized), θ~N(1,2) (discretized), Read-rate in [0.4,1])

	Store 1					Store 2				
	Period 1	Period 2	Period 3	Period 4	Markdown	Period 1	Period 2	Period 3	Period 4	Markdown
y_i	75	75	75			75	75	75		
$\hat{x}_{it}(U)$	0	12	17	7	35	0	19	1	24	38
$x_{it}(U)$	0	11	13	0	28	0	18	0	24	37
$x_{it}(I)$	0	11	17	0	23	0	18	0	25	32
$x_{it}^r(I)$	0	8	14	0		0	16	0	19	
$z_{it}(U)$	75	63	58	93		75	56	74	76	
$z_{it}(I)$	75	67	61	88		75	59	75	70	
d_{it}	63	58	78	65		56	77	51	62	
θ_{it}	1	3	4	0		1	0	-1	1	
$s_{it}(U)$	63	58	68	65	28	56	74	51	62	37
$s_{it}(I)$	63	58	74	65	23	56	77	51	62	32
$p_{it}(U)$	50	50	50	50	50	50	50	50	50	37.1
$p_{it}(I)$	50	50	50	50	50	50	50	50	50	45.7
$\Pi_{it}(U)$	3150	2900	3400	3250	1400	2800	3700	2550	3100	1374.3
$\Pi_{it}(I)$	3150	2900	3700	3250	1150	2800	3850	2550	3100	1417.1
$\Pi_U(total)$ $\Pi_I(total)$ Δ_{I-U}					27,624.3 27,867.7 0.88%	Avg. Markdown Price (U) Avg. Markdown Price (I)				42.7 46.7

In this section, we aim to test the robustness of value of inventory visibility to imperfect RFID performance. To do this, we simulate the performance of the retailer with imperfect visibility for the same instance studied for the full visibility scenario. We calculate the value of imperfect visibility Δ_{I-U} and compare it with Δ_{F-U} under the same setting and parameters we used in section 4.1. The gap between these two levels as well as the values that Δ_{I-U} takes should enlighten the retailer about whether inventory visibility is worthwhile - though imperfect it may be.

Observation #9: Value of inventory visibility is robust to imperfect read rates.

Figures 6(a) and 6(b) (below) compare the value of imperfect visibility with the full information scenario. Both figures plot the value of imperfect visibility (Δ_{I-U}) together with the value of full visibility as a baseline (Δ_{F-U}). Figure 6(a) characterizes the impact of read rate means, and Figure 6(b) the impact of read rate standard deviation on the value of imperfect visibility. We observe that imperfect RFID performance does not deteriorate the value of visibility. On the contrary, we see a slight rise in the value of inventory visibility. The boost in the impact of regular season sales, as expected, is clearly observable at high levels of total buy quantity. Interestingly, this boost is mostly sustained for moderate levels of total buy quantity as well - when markdown yield performance makes a difference for the retailer. Here, the potential loss due to stranded inventory is compensated through increased regular season sales which also alleviates the need to discount with fewer items left for markdown. Thus, a retailer should not hesitate in investing in RFID technology just because of imperfect read rates.



(a) Δ_{I-U} $(\sigma_R = 0.2)$ vs Δ_{F-U} (b) Δ_{I-U} $(\mu_R = 0.7)$ vs Δ_{F-U}

Figure 6. Value of imperfect visibility (Note: The following values were used to generate Figure 6: T=10, N=14, p=50, Store service level=95%, $K_{it} = 100$ $(\forall i, \forall t \leq T)$, $K_{i,11} = 60$ $(\forall i)$, ϵ~N(0,6) (discretized), θ~N(1,2) (discretized), R~N(0.7, 0.2) in [0.4,1])

4. CONCLUSION

To our knowledge, this is the first study that focuses on RFID-enabled inventory visibility in managing a fashion retail product. Here we first present an analysis framework based on the revenue impact for the retailer. We find that value of visibility has two components: growth in regular season sales and improved yield management in the markdown period. Through extensive numerical simulations, we show that value of inventory visibility is robust across retailers, but could be limited depending on the retailer characteristics. Thus, return-on-investment in an enabler technology like RFID needs to be carefully evaluated by each individual retailer.

We find that retailers that sell products with prices above the $5 mark, that carry products with relatively long life-cycles, that operate with relatively low service levels, that face relatively high or variable inaccuracy, and that plan its sales well or even “buy into markdown” enjoy higher returns from inventory visibility.

RFID technology is the best candidate so far as an enabler technology of inventory visibility in a retail environment. However, it is not perfect and it is still developing. Depending on the environment, the presence of metals or liquids, the spacing between RFID tags in a stack, and etc. an RFID reader may fail to identify all the tags in a given space. Thus, the inventory levels observed through an RFID-enabled audit may underestimate the actual levels in the store. In this study, we also test our findings by simulating an imperfect visibility scenario. We find that value of inventory visibility is sustained even with an imperfect RFID performance. Thus, retailers should not be deterred from investing in the technology because of imperfect read-rates.

In this study, we analyze the value of inventory visibility for a retailer that manages a fashion product. Our current findings suggest further extensions, especially regarding the retailer's planning activities and the chain structure. One wonders how value of visibility would change if the retailer updated its forecast and inventory targets dynamically based on observed sales, or if the stores in the chain were not identical as we assumed here. One would also wonder the interaction of inventory visibility with mid-season price promotion decisions and its overall impact for a retailer. These settings could further help characterize the value of inventory visibility in a fashion retail environment.

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