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RESEARCH ARTICLE

Strategies for Enhancing Economic Sustainability: Modeling Reduced Bale Handling Costs in Cotton Warehousing

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Abstract

Cotton warehouses face unique inventory management challenges. This research addresses this challenge by proposing innovative strategies to enhance warehouse efficiency. Three key objectives are addressed: modeling cotton bale movements, evaluating an alternative to the current bale handling process, and evaluating an alternative to the current cotton bale marketing system. Results reveal significant cost savings. Changing bale receiving and placement strategy by using gin codes yields a $499,000 per-cycle reduction for an Oklahoma cotton warehouse case. Altering order fulfillment techniques, such as grouping 30 orders, saves $34,000 per cycle. Implementing quality-based bale substitution leads to a $1.3 million saving per cycle.

Keywords: cotton warehouses; Oklahoma; operational efficiency; simulation modeling

JEL classifications: C63; Q13; L81

1. Introduction

Cotton, recognized as one of the world's most vital textile fibers, plays a pivotal role in global industries, accounting for over 25% of the total fiber utilization (Vulchi et al., 2022). The United States, a major player in the cotton sector, stands as one of the largest producers and exporters of cotton worldwide, contributing to roughly one-third of the global raw cotton trade (USDA, 2021). Recent years have witnessed a substantial increase in cotton cultivation, with the cotton harvesting area in the United States expanding from 7.5 million acres in 2013 to 10.3 million acres in 2021 (NASS, 2023). This 27% increase in cultivated area, combined with small improvements in cotton yield, pressures cotton warehouse operations, one of the most important components of the cotton supply chain, to operate with greater efficiency. A crucial step toward meeting this pressing need involves enhancing the efficiency of warehouse logistics by reducing the costs associated with handling cotton bales.

Cooperatively owned cotton warehouses, which are instrumental in the cotton supply chain, have unique logistics management challenges. Unlike many other agricultural commodities, cotton is stored and supplied on an identity preservation (IP) basis. While IP supply chains are employed for various agricultural products, cotton diverges significantly as each sale transaction meticulously designates individual units. These warehouses, distinguished by their atypical operational characteristics (Richard, 2020), receive and place once a year, gradually unloading throughout the marketing season, in contrast to most warehouses which are continually replenished. The layout of cotton warehouses is marked by rows accessible from only one

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direction, necessitating the frequent relocation of non-targeted bales to access specific targeted ones. This process of moving bales, at times exceeding a hundred repetitions before selection for shipment, poses a logistical challenge that is unparalleled in most other supply chains (Richard et al., 2019). Additionally, cotton warehousing is subject to regulations set forth by the U.S. Department of Agriculture's Commodity Credit Corporation (CCC), dictating strict requirements regarding order fulfillment time (Richard et al., 2019). In addition, these warehouses distinguish themselves from typical warehouse operations by incorporating a merchandizing division, connected yet distinct from its core warehousing activities. The distinctive feature of warehouses adds complexity to the already challenging task of managing these cotton warehouse operations. As a result, cotton warehouses face specific logistical management challenges that necessitate innovative strategies for efficiency improvement. Considering these unique logistical challenges, mathematical models and simulation tools are developed and used to evaluate alternative cotton warehouse management strategies.

Previous research, including the works of Brown and Ethridge (1995), Ethridge et al. (1992), Wu et al. (2007), examined the economic value of quality attributes in cotton. Jung and Lyford (2007) introduced the concept of market segmentation based on cotton quality. They evaluated the economic potential of quality enhancements, with a specific focus on shifting harvesting methods to meet evolving market demands. Robinson et al. (2007) introduced the initial framework for analyzing cotton transportation patterns in the United States. Kenkel and Kim (2008) explored how technological advancements and policy changes have influenced the industry's response, particularly in the context of shipping standards. The study emphasizes the need for further research to quantify the costs and benefits of enhanced shipping standards. Griffin et al. (2022) underscored the practical applications of distributed ledger technology within the cotton industry, specifically focusing on issues related to data quality assurance, sustainability metrics, and enhancing supply chain coordination. Additionally, Burinskiene (2011) and Burinskiene (2015) presented generic warehouse simulation examples. Hazelrigs et al. (2017) delved into cotton warehouse operations by exploring alternative stacking and marketing techniques.

The objective of this research is to identify and evaluate cost-saving strategies within warehouses. We first developed a tool for modeling cotton bale movements within a warehouse. Cotton orders are filled by removing bales that are not in the current set of orders to reach bales that are further back in the warehouse and part of a current batch of orders. We then evaluate increasing the number of orders to be filed simultaneously. By pulling bales that fill a larger number of orders simultaneously, the number of duplicate "touches" per bale declines. However, the time to fill a given batch of orders increases as more orders are being filled. Finally, we evaluate the reduction in cost associated with a change in order fulfillment via method that allows warehouses to fill orders with bales that have traits within a given tolerance.

2. Cotton warehouse and market basics

Following the ginning process, cotton bales are graded in a vector of quality traits. A sample from each bale is extracted at the gin and sent for classification at a facility overseen by USDA Agriculture Marketing Service. At this facility, a permanent identification tag, linked to the quality characteristics of each specific bale, is generated. These identification tags are then seamlessly integrated into a variety of digital trading systems (Cotton Inc., 2013). Most U.S. produced cotton undergoes classification and incurs associated fees.

In the first set of simulations, two key variables under scrutiny are the receiving and placement[1] strategy and the number of orders processed concurrently, both of which bear significance in

[1]Receiving and placing bales in a warehouse is sometimes called "loading" in the literature. Similarly, removing bales for order fulfillment is called "unloading."

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Table 1. Summary statistics for cotton bales in dataset

Variables	Mean	Minimum	Maximum	Units
Staple	36.31	28.00	42.00	millimeters
Micronaire	43.59	23.00	59.00	unitless
Leaf grade	2.96	1.00	8.00	class
Uniformity	81.19	73.50	88.80	percentage
Strength	30.23	20.20	38.80	grams per tex
Reflectiveness	77.29	45.80	85.70	percentage
Color (PlusB)	83.96	51.00	160.00	class
Trash	3.68	0.00	32.00	percentage

achieving our research objectives. Under the prevailing operational protocol, warehouse operators engage in the sequential storage of incoming cotton, prioritizing the filling of one warehouse then moving on to the next. While operators lack control over the specific selection of ordered bales, they do possess a reasonable degree of control over the initial storage locations of these bales. To evaluate the cost-effectiveness of various warehousing strategies, our study conducted a series of simulations that replicated the allocation of individual bales based on historical order data. These simulations mirrored the existing order history, allowing for a cost analysis across varying strategies.

In the second simulation, we focus our attention on the largest trading platform facilitating the bulk of US cotton trade, namely The Seam. This platform, specializing in Electronic Warehouse Receipts (EWRs), links each receipt to a specific cotton bale, certifying ownership and quality. With numerous participants on this platform, it serves as an ideal setting for exploring innovative negotiation frameworks. By enabling cotton warehouses to substitute bales of comparable quality for requested ones, the existing identity preserved system can be adapted to potentially enhance operational efficiency by reducing handling costs.

3. Data

This study uses data from a cotton warehouse in Altus, Oklahoma, provided by the Plains Cotton Cooperative Association, encompassing their 2016 cotton crop. Each bale within the dataset is uniquely distinguished by a unique numerical identifier and location parameters, encompassing the warehouse, row, and section numbers. The dataset also includes order numbers and dates. Positions within individual cross-sectional of a row are subject to random allocation due to the absence of documented information within the warehouse's records. Summary statistics on bale quality are given in Table 1.

To prepare the data for the simulation, several steps were taken. The first step involved generating an order number based on unique combinations of clearance dates and first merchants. By sorting the dataset using these two variables and identifying changes in them, bales were assigned to specific order numbers. There were 1,091 orders for the 2016 crop, each containing 88 bales or fewer. The data were initially sorted by the order numbers. Following this, it was further organized by shed, row, section, and position, with a descending order of position. This specific arrangement ensured that the simulation program could accurately identify the last targeted bale within a shed-row.

4. Simulating cotton bale movements

The number of bale movements, or "touches," is a critical metric for evaluating the efficiency of the warehouse's operations. A higher number of bale movements corresponds with higher

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Table 2. Alternative receiving and placement strategies

Attribute	Description of strategy
Current	Bales are placed in shed-rows from back to front, bottom to top within each section, as they arrive from the gins, strictly first-in.
Micronaire	Premium mic is placed in one set of shed-rows, then non-discounted mic in the next set, then discounted in the remaining.
Random	Bales are randomly assigned to shed, rows, sections, and positions.
Leaf grade	Grade 1 bales are placed in the first seven sheds, grade 2 bales are placed in the next seven, etc. until grade 8 is placed in the remaining sheds.
Reflectiveness	Lower percentage bales are placed in the first sheds and rows while higher percentage bales are placed in the last sheds and rows
PlusB	Each class group determines which sheds and rows the bales are placed in. Lower classes are placed in first sheds, higher classes are placed in last sheds.
Trash	Bales are assigned to sheds based on trash percentage, where low trash content is sent to the first shed-rows and high trash bales are placed in the last shed-rows.
Gin code	Bales are placed in shed-rows from back to front, bottom to top within each section, as they arrive from the gins, keeping separate gins in separate sheds and rows.
Acct_no. (Farmer ID)	Each farmer's bales are placed in segregated sheds and rows.

handling costs. The program searches each row for bales included in the orders currently being filed. The program counts the number of bales that must be moved to reach each targeted bale in each row. (Targeted bales can be behind or under other bales, which must be moved to reach target bales.) Bales that are removed from rows to reach a targeted bale are returned to the row in their original position. So, removing a non-targeted bale requires two touches. The program continues to search through each row until all the orders being worked on are filled and sums up the necessary touches. The simulation model was programmed using Visual Basic for Applications (VBA) for MS Excel.

5. Alternative warehouse management strategies

We evaluated the impact of three strategic management scenarios aimed at enhancing the efficiency of warehouse logistics. These strategies include receiving and placement, order fulfillment, and marketing.

5.1. Receiving and placement strategies

The first strategy evaluated was a change in how warehouses (sheds) receive and place bales. First actual bale placements from the dataset were used to establish a baseline number of touches and associated handling costs and time-to-order completion. Then, a set of alternative receiving and placement strategies were evaluated. Each shed was allocated bales, with positions assigned according to the chosen quality characteristic, corresponding to distinct receiving and placement strategies. Table 2 explains the receiving and placement strategies.

For example, the micronaire scenario would be sorted such that all the premium micronaire are received and placed first, non-discounted second, and discounted last. Premium cotton might fill the first fifteen sheds, then non-discounted might fill twenty sheds, and the discounted may fill the rest, for instance. This procedure was repeated for each of the receiving and placement strategies generating multiple data sets to evaluate the cost of order completion.

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After determining bale locations for each receiving and placement strategy, the total number of bale movements was determined using the approach described above. The results allow for a comparison of the cost of order fulfillment for a single year's cotton crop.

5.2. Order fulfillment strategies

Following the assessment of receiving and placement strategies, our next endeavor involves the evaluation of order fulfillment strategies within the context of the simulation model. With this objective in mind, we carried out a comparative analysis to ascertain whether there are efficiency advantages when fulfilling a larger number of orders simultaneously, specifically by comparing the simultaneous fulfillment of 20 orders to that of 30 orders. The sample interval begins when the warehouse is full and continues in order until the warehouse is semi-full and then eventually practically empty (only bales in the last order are present). There is a downward trend in efficiency gain potential as we move from a full warehouse to a nearly empty one.

5.3. Marketing strategies

The primary goal of creating marketing scenarios is to determine whether there are economic benefits to be gained by implementing an alternative marketing framework that allows for the substitution of similar quality bales. The procedure for calculating a value from switching from the current marketing framework to an alternative one involves two steps for each potential marketing framework. (Two alternative marketing frameworks are developed in this study, but both are based on the same principles of substitution.) First, a substitution routine determined the new order in which bales will be pulled to fulfill orders. Second, a bale movement counting routine simulated the process of fulfilling orders. This was repeated for the two alternative marketing frameworks. The value of switching to the new marketing framework where substitution is allowed is determined as the difference between the handling costs with and without substitution.

To determine the ranges of quality used to characterize the two alternative marketing frameworks, the minimum and maximum possible values of each quality criterion was determined. A tolerance range for each quality criteria was then assumed and calculated as a percentage of the quality range. This range was included in the substitution routine for each quality criterion. In this study, the two frameworks were: (1) Bales can be substituted only if all quality criteria are within 5% of the requested bale and (2) Bales can be substituted only if color reflectiveness, color plusb, micronaire, and trash are substituted within 2.5% of the requested bale and the remaining quality criteria are within 5%. This means in the first alternative marketing framework, counter-bales are only substituted for the original bales if they are 95% similar. The second scenario is more stringent, where they are 95% the same on most quality criteria but are 97.5% the same on more important quality criteria.

This procedure was performed on only three group orders. They represent the highest, average, and lowest complexity (in terms of bale movements per bale) of orders in the set of orders that are grouped by 20 order sets. (The warehouse currently fulfills 20 orders simultaneously.) The "highest" complexity order is an order where targeted bales are in many different rows and the warehouse is relatively full. In that state, it is highly likely that a bale of very similar quality to a target bale was bypassed in the process of reaching a target bale under the current marketing framework. The "lowest" complexity order would be when the warehouse is empty except for this last remaining order. In that state, there is only one bale movement per bale needed to fulfill the order and no substitution is possible. The bale movements are calculated to identify orders with the highest, average, and lowest complexity.

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Table 3. Average bale movements per bale required to unload the warehouse

Scenarios	Average number of bale movements per bale	Reduction of cost per bale ($)
Baseline	9.22	
Micronaire	8.58	0.13
Leaf grade	6.08	0.63
Color reflectiveness	21.63	2.48
Trash	8.71	0.10
Color plusB	12.31	0.62
Gin code	4.96	0.85
Account number	5.85	0.67

Table 4. Handling costs for order fulfillment strategies

Orders simultaneously fulfilled	30	20
Total bale movements per bale	8,531,572	8,702,268
Average bale movements per bale	14.53	14.82
Total handling cost per “turn”*	$1,706,314	$1,740,454

*Calculated with 587,075 bales and handling cost of $0.20 per bale movement.

6. Results

6.1. Receiving and placement strategies

The eight receiving and placement strategies described above were compared to the baseline in terms of handling cost. The program calculated the total number of “touches” for each of the strategies. This count is divided by the number of bales in that sample to arrive at an average number of bale movements per bale. The resulting averages touches are reported in Table 3. An associated reduction from the current receiving and placement strategy (in cost per bale) accompanies each alternative receiving and placement strategy.

The findings indicate several receiving and placement strategies appear to have a lower fulfillment cost. Arranging the bales based on leaf grade, micronaire, trash, gin code, or account number (farmer ID) led to a reduced number of bale movements compared to the existing receiving and placement strategy. The utilization of gin codes for warehouse receiving and placement resulted in the largest reduction in bale movements, amounting to a decrease of 4.26 bale movements per bale, and consequently, a cost saving of $0.85 per bale. The second lowest number of bale touches was found by receiving and placing based on producer (account number), and the third lowest number of touches was receiving and placing based on leaf grade. These results indicate that a more judicious receiving and placement strategy can reduce warehouse costs.

6.2. Order fulfillment strategies

The alternative order fulfillment strategies were evaluated in terms of bale movements and handling cost. These results (Table 4) reveal that the order fulfillment strategy analysis also led to potential cost savings of about $34,000 but there is a trade-off. The average number of bale movements declined by about 0.3 touches per bale. However, the simulation resulted in an

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Table 5. Bale movement comparison

	Bale movements per bale		Days to complete group order	
	20	30	20	30
Min	1.00	1.00	1.09	1.63
Max	35.18	34.16	38.18	55.61
St.Dev	10.69	10.47	11.60	17.04

Table 6. Value from substitution marketing framework of 2.5% of color, mic, trash

	High	Average	Lowest
Current marketing strategy BMPB*	48.35	15.92	1.00
Substitution allowed BMPB*	10.83	4.55	1.00
Reduction of bale movements	37.51	11.37	0.00
Value per bale	$7.50	$2.27	$0.00
Value per turn	na	$1,335,086.83	na

*BMPB-Bale movements per bale. (Substitution Rates- Color, Mic, Trash: 2.5%; Leaf Grade, Strength, Uniformity, Length, Staple: 5%).

Table 7. Value from substitution marketing framework of 5% all quality criteria

	High	Average	Lowest
Current marketing strategy BMPB*	48.35	15.92	1.00
Substitution allowed BMPB*	5.04	4.36	1.00
Reduction of bale movements	43.31	11.56	0.00
Value per bale	$8.66	$2.31	$0.00
Value per turn	na	$1,357,421.77	na

*BMPB-Bale movements per bale. (Substitution Rates- Color, Mic, Trash, Leaf Grade, Strength, Uniformity, Length, Staple: 5%).

increased time to complete orders as shown in Table 5. In the worst-case scenario, the maximum days required to complete an or increased from 38 days (baseline) to over 55 days. While there are cost savings associated with this approach, the delay in filling orders may be unacceptable to cotton buyers.

6.3. Marketing strategies

We next evaluated the impact of allowing quality tolerances. Table 6 presents results of allowing the warehouse to substitute bales with ± 2.5% of bale quality criteria. And Table 7 reports similar results for a ± 5% tolerance. This tolerance levels allow the warehouse to pull the first bale encountered that falls within tolerances to fill an order. As is expected, the substitution of bales based on their quality and location results in a reduced number of bale movements per order, leading to a reduction in handling costs.

The findings validate that both examined marketing frameworks result in a decrease in the number of bale movements compared to the existing marketing framework, which involves no substitution. This holds true for both the highest and average order complexities. For the order

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with the lowest level of complexity, which is the final order in the warehouse, there was no potential reduction in bale movements, resulting in a reduction of 0 movements. Assuming a linear relationship between the cost reduction and the complexity state of the warehouse (range from full to empty), the total cost savings per turn are shown in Table 6. That value was calculated by multiplying the cost savings per bale at average complexity by the total number of bales handled over the turn cycle. Under this assumption, it is estimated that approximately $1.3 million could be saved by adopting the substitution-based marketing framework. This result is likely to be compelling for cooperative cotton warehouse members, as they bear the costs of warehouse operation and operate in a low-profit margin environment. The cost savings are considerable in this alternative. With both 2.5 and 5% tolerances, the cost of fulfilling orders declined by over 85%. Interestingly, when compared to the 5% tolerance, the 2.5% tolerance had a slightly higher cost reduction due to the random positioning of bales.

7. Discussion and conclusions

Cotton warehouses have unique logistical management challenges that necessitate innovative strategies for efficiency improvement. Currently, the cause for logistic inefficiency in terms of bale handling costs is mostly derived from the identity preserved system of marketing cotton bales by the individual bale. Also, unlike typical warehouses which are continuously replenished, cotton warehouses are filled once a year then slowly emptied as orders for specific bales are received. The warehouse is configured in rows that can only be accessed from a single direction which necessitates moving non-targeted bales to reach a targeted bale. In the current protocol, warehouse operators store the cotton as it comes in, filling a warehouse before proceeding to the next. Although operators have no control over which bales are ordered when, they do have a reasonable amount of control over where the bales are initially stored, which can reduce bale handling costs. Additionally, cotton warehouses operate under regulations from the U.S. Department of Agriculture Commodity Credit Corporation, known as the “Cotton Shipping Standard,” which mandates the maximum order fulfillment time. This regulatory framework creates a binding constraint on the speed at which orders must be processed, distinguishing cotton warehouses from most supply chains where order fulfillment speed is typically a strategic or competitive decision and not mandated by federal regulation. These regulations significantly impact the efficiency of the order fulfillment process in cotton warehouses.

Our purpose was to evaluate the impact of alternative cotton warehouse management and marketing strategies on handling costs. Three alternatives were examined here. First, alternative warehouse receiving and placement strategies were considered including sorting based on quality traits, gin code, and producer. Second, the number of orders filled simultaneously increased from 30 to 20 orders. Finally, a bale fulfill strategy was evaluated allowing the warehouse to substitute a bale that has quality traits within 2.5 or 5% of the ordered bale.

The warehouse receiving and placement strategies showed substantial savings in handling costs. The largest savings was found using gin code to fill warehouses, resulting in almost $1 million in reduced handling cost. Significantly, gin code is known at receiving.[2] Several other quality-based receiving and placement strategies also resulted in lower handling costs. However, there is one critical impediment to this receiving and placement strategy. Under the current system, classification information is unknown at the time of warehouse receiving and placement. The time delay in receiving quality information varies across the ginning season. One potential avenue for overcoming this challenge involves the adoption of gin-based sampling/grading technology. Implementing such technologies could enable a near-real time analysis and reporting system, thereby decreasing system costs and enhancing the effectiveness of quality-based receiving

[2]Farmer identification (account number) is also known at receiving. Our simulation showed a $0.67 per bale improvement in costs when using farmer identification to place bales in sheds.

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and placement strategies. Future research could explore the development and the economic implications of these systems within the cotton supply chain. In the absence of technological advancements, additional research is needed to consider the additional costs and warehouse space needed to stage cotton while waiting for grade information. The modification of the cotton warehouse system to allow for bale substitution within a quality tolerance would require the approval of growers, warehouse operates, and cotton merchants as well as regulatory changes.

Another practical issue with characteristic-driven based warehouse receiving and placement is determining how much warehouse area to assign to each level of the characteristic. The distribution of bales across characteristic levels is not known until all bales are delivered, making it difficult for warehouse managers to allocate warehouse space across the levels. However, historical quantities of bales for each characteristic, i.e., number of bales from each gin, are known and could provide an initial estimate for determining how much warehouse space will be needed for each level or group.

Increasing the numbers of orders worked simultaneously achieved smaller cost savings. By increasing the number of orders processed simultaneously from 20 to 30 orders, we achieved a cost savings of $34,139.19 per turn of the warehouse. However, there was a trade-off. Fulfilling group orders of 30 individual orders simultaneously (as opposed to the current strategy of only 20) increased the maximum time to complete a group order by 17 days.

Our results indicate that the cotton supply chain has potential to decrease costs by adopting a marketing systemic which allows cotton warehouses to substitute similar quality bales for requested bales. This study examined the economic benefit from the adoption of this alternative marketing framework. A sample of orders (historic set of bales that have been traded) was taken to estimate this economic benefit. The cost savings of adopting the alternative marketing framework was over $1.35 million when a 5% tolerance is allowed. When a 2.5% tolerance is allowed, a similar saving of nearly $1.34 million.

With the recent integration of intermodal shipping capabilities at the examined warehouse, a factor not previously accounted for in our modeling, there is the potential for significant changes in bale handling costs. Consequently, it is crucial to assess alternative strategies to enhance warehouse efficiency considering these changes. This underscores the importance of future studies delving into the specific implications of evolving transportation methods within the established framework of this research.

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