MODELLING AND EVALUATING STRATEGIES TO REDUCE BALE HANDLING COSTS IN A COOPERATIVE COTTON WAREHOUSE

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COOPERATIVE COTTON WAREHOUSE

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I acknowledge there have been many people that played a role in my development as a student and as a person, “It takes a village.” However, I do not want to make anyone feel less important than another, so I have decided to use this space to dedicate my dissertation to one person.

Mom! Wow, wow, wow! Only you and I really know what this PhD really took. Many phone calls you heard me out and listened to everything I was going through. When I struggled in my first year, you convinced me I could finish what I started, against all odds. My orange luggage, however long it lasts, will remind me of how you believed in me even when I was at my lowest. Thank you.

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Abstract: Cooperatively owned cotton warehouses have unique inventory management issues. Unlike some other agricultural commodities, cotton is stored and marketed on an identity preserved individual basis. Unlike other warehouses which are continuously replenished, cotton warehouses are loaded once a year then slowly unloaded 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. All of those factors create unique issues in simulating warehouse operations. The purpose of this study is threefold. 1. Develop a method for simulating activity at a cotton warehouse. 2. Test alternative management strategies for loading and order fulfillment processes. 3. Test a change in the marketing framework the warehouse is managing within by allowing bales to be substituted based on a quality tolerance system. These purposes are important because the warehouse can become more efficient in terms of bale handling costs. A more profitable warehouse, when it is cooperatively owned, will pass savings on to the grower owners. This study begins with a summary of the design of the simulation program. The next step of the research examined alternative warehouse loading strategies. Loading the warehouse according to gin code resulted in the highest cost savings of around $499,000 per cycle. The next research step examined order fulfilment strategies. Changing from fulfilling orders in 20 order groups to 30 order groups saved the warehouse about $34,000 per cycle. The final component of the research examined the effect of allowing the warehouse to substitute bales within a small quality tolerance range. Allowing substitution of bales based on a quality tolerance lead to a $1,300,000 savings per cycle of the warehouse. All these savings contribute to the mission of preserving value for the grower-owner once it passes through the cooperative form of the cotton warehouse.

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CHAPTER I

I. INTRODUCTION

Motivation

Oklahoma State University (OSU) was established on Christmas day in 1890 as a result of the passage of the Morrill Act of 1890. This, along with the Morrill Act of 1862 established what is commonly known as the Land Grant Mission. These legislative establishments of universities for the purpose of agricultural education provide historic motive for why this dissertation's objectives are justified and specifically a justified topic for Oklahoma.

The Land Grant Mission is comprised of three pillars; research, teaching, and extension. As a doctoral student, this dissertation is primarily intended to train me for extension work, because it is my chosen focus of the mission. In agricultural economics, one way extension activities can be planned is to look to industry representatives for their insight into the list of issues imminently faced in the state.

Due to this historic legislature, the mission it started, and the focus on extension work as a future endeavor, this study aims to contribute literature to a current applied problem in agricultural economics in the state of Oklahoma. Another priority of this research is to focus on cooperatives due to the nature of the assistantship funding. One of the more valuable crops in this state is cotton, an industry with a very well developed cooperative to study called Plains Cotton Cooperative Association (PCCA.)

At the onset of this work, PCCA in Altus, OK was approached to determine their insights into an agricultural economics applied research problem. These meetings determined the objectives of this study, and their continued insight as well as contribution of data made the process possible. Hereforeward is a dissertation of an applied cotton warehouse research agenda contributing to the extension pillar of the Land Grant Mission.

Background

Firstly, this section will build the context necessary to understand the contribution this paper makes. This study will focus on cotton warehouse logistics. Logistics in agricultural commodities brings a set of problems similar to logistics in mainstream commercial industries. Additionally, cotton is compared and contrasted with other agricultural commodities. Defining the orientation to other commodities and industries helps validate the contribution made by this study.

The general motivation for this research is straightforward. Improving the supply chain logistics in any agricultural crop can reduce costs and create benefits throughout the supply chain. Cotton warehousing appears to be a particularly interesting example for logistical research because cotton is a high value crop that is stored in large facilities prone to flow-management issues. As we will discuss, the logistics of operating a cotton warehouse are unique relative to the operation of most agricultural product and non-agricultural product warehouses. Additionally, most cotton warehouses are organized as farmer-owned cooperatives. Because of that business structure, any additional cost savings will be passed on to the producer members. Order fulfillment time in a cotton warehouse is regulated by the U.S. Department of Agricultural Commodity Credit Corporation. All of these factors justify additional research into the logistics of cotton warehouse operations.

As stated, the logistics of operating a cotton warehouse are dis-similar to most warehouse operations. Cotton warehouses are loaded once a year, then slowly unloaded throughout the rest of the marketing season. Many warehouses, particularly those used for non-agricultural products are continually restocked. Cotton is stored and sold on an identity preserved (IP) basis. While other agricultural products use IP supply chains, cotton is unique because each marketing transaction identifies specific units. In many other agricultural IP supply chains, specific unit identity information is used for traceability but the market transaction does not specify a particular box or unit. Additionally, cotton warehouses are configured in rows that can only be accessed from a single direction. That necessitates moving non-targeted bales to reach a targeted bale. In some instances, a bale may be moved more than a hundred times before it is selected for shipment.

Finally, the U.S. Department of Agriculture, Commodity Credit Corporation (CCC) specifies requirements for CCC approved warehouses storing and handling cotton.

These requirements, called the cotton shipping standards, basically requires cotton warehouse operators to be able to make 4.5% of their annual warehouse storage capacity to be available for shipment in any given week (USDA AMS 2019). The complete standard is more complex. The compliance standards consider a two week moving average and has provisions for bales made available for shipment but not picked up. The effect of the shipping standard is to create binding constraint on how rapidly orders must be processed. In most other supply chains, the speed of order fulfillment is a strategic or competitive decision and not one mandated by federal regulation. Because of all of these factors, cotton warehouses have different logistical issues relative to most other warehouses.

While there are no other apparent warehouse situation that share all of the operating characteristic of a cotton warehouse, other agricultural and non-agricultural supply chains have some commonalities. Many agricultural commodities, particularly perishable commodities are sold on an IP basis. Apples are IP and are sold based on quality characteristics. Apples are commonly boxed by size and the containers are labeled with information about variety, size, grade, grower lot number and facility for food safety and traceability. Some varieties may have various shades of color, with several grades and sizes for each color shade (WSU, 2020). The inventory in both apple warehouses and cotton warehouses can be traced back to a particular producer. In regard to that dimension they are similar. On the other hand, while an apple warehouse may have dozen or even hundreds of types of apples, order fulfillment only involves selecting from the appropriate category. In that respect, unloading an apple warehouse is very different from unloading a cotton warehouse where a specific bale must be selected from an inventory of 500,000 or 1M unique bales. A review of the literature regarding apple warehouses suggests that the major issues revolve around perishability and quality loss. No studies of loading or unloading strategies could be identified.

Another supply chain business similar to cotton in the nature of its logistics problems is containerized freight. Like cotton, containerized freight is identity preserved and each unit can have a separate final destination. Freight containers are stacked in large units when in ocean transit and may be stored in a concentrated area before or after ocean vessel transport. That can, at times, create situations where some containers may have to be moved in order to get to containers that must be expedited. Containerized freight is dissimilar to cotton warehousing in that it centers on a shipping activity. Most of the logistical activities revolve around continuously moving the entire inventory. A review of the literature on logistical issues involving containerized freight did not reveal any models that would appear to apply to cotton warehouses. However, Luo et. al. 2011 breaks the container logistics literature into three problem types, where "container stacking logistics" is the most relevant to cotton stacking logistics in its objective to minimize object re-handling. Luo et. al. 2011 describes past studies and the nature of the models used to address these logistics problems, and offers that these issues are becoming more popular among academics and practitioners due to the increased demand on terminal yard space.

In summary, while the cotton supply chain has some characteristics in common with other supply chains, it has a unique configuration. Cotton warehouses are loaded once a year and slowly unloaded during the year. Cotton warehouse configuration involves large stacks which are accessible from a single direction. That can create the necessity to move and replace a large number of non-targeted bales to get to a specific targeted bale. Cotton is marketed on the basis of individual unit identification with no substitution within similar types or quality ranges. The logistical challenges of operating a cotton warehouse involve the challenge of locating and removing a small number of specific bales within the bulk stacks of a warehouse holding up to a million bales. In a cotton warehouse it is not unusual to move an individual bale hundreds of times before it is finally selected for shipment. While it is impossible to say that handling situation could not occur in another warehouse situation, it is clearly not typical of the operations in most supply chains.

Objective

The purpose of this study is to identify economic cost savings from reduced bale handling costs at a cooperative cotton warehouse. The sources of these savings to investigate include; alternative loading and order fulfillment strategies as well as alternative marketing rules that allow for bale substitution. The expected findings include a dollar value representing the savings made possible by implementing these strategies and marketing frameworks. The preferred strategy for each element of warehouse operation will be identified by the greatest reduction in bale handling costs, which can be thought of as increased efficiency.

The first step to pursuing these strategies is to model the most important process at the warehouse in terms of cotton flow. “Break-out” is the term used to describe when employees use a forklift to go into a stack of cotton and retrieve targeted bales while moving non-targeted bales to the aisle and then back to the stack at the end of the process. Targeted bales are on the designated pick list, while non-targeted bales are not and can be physically in front of or on top of targeted bales. Chapter 2 will model this process by simulating the representative movements of cotton in the warehouse.

The next step in the research process was to use the model described in chapter 2 to analyze alternative loading and unloading strategies, Chapter 3 focuses on current and alternative loading strategies. It also analyzes current and alternative strategies for order fulfillment (cotton break-out). The loading strategies represent a situation where the warehouse would alternatively determine original locations of the cotton bales based on a quality or other characteristic. For example, if the cotton were sorted based on which gin it came from, and placed into the warehouse in different stacks according to that criteria, this will change the bale handling costs upon break-out. The current or baseline loading strategy is a first-in plan where stacks are built (locations are determined) by timing of when the bales arrive at the warehouse. Each alternative strategy will be compared to the current strategy in terms of the bale handling costs. The bale handling costs are a function of bale movements required to unload the entire warehouse.

In the order fulfillment strategies, the decision variable analyzed was the number of orders processed simultaneously. While fulfilling orders for shipment, the warehouse has a choice of how many orders to fulfill simultaneously. By grouping orders together, working on more than one order at a time increases the probability of finding more than one targeted bale in each stack during order fulfillment. On the other hand, working more simultaneously increases the time needed to work the group of orders. That makes it possible that a particular order will not be completed in the desired time span. It is expected that working a larger group of orders simultaneously will reduce bale handling costs. Conceptually, if all the orders are worked at the same time, each bale has the minimum number of bale movements, one movement per bale. It is expected there is an upper limit however on the number of orders that can be grouped, based on the number of days required to fulfill those orders. More details of this concept and the implementation are found in Chapter 3.

After considering strategies the warehouse can readily implement based on current marketing rules for the industry, the next research question considered whether a different set of marketing rules can lead to greater reduced bale handling costs. Chapter 4 compares bale handling costs under the current marketing framework with bale handling costs under an alternative market structure where substitution based on quality of the cotton is allowed. Under the alternative market structure, a bale within a specified quality tolerance of a requested bale could be substituted when it is in a more advantageous position (location) in the warehouse. The logic is, if a bale closer to the front and/or top is swapped for a bale in the back and/or bottom, but the buyer receives a very similar bale in terms of quality, the warehouse derives an economic benefit from an alteration in the marketing tactics.

Each of these strategies and marketing tactics lead to reduced bale handling costs at the warehouse level in the cotton supply chain. These findings are important because in a cooperatively owned setting, economic savings are passed through to the grower-owners.

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CHAPTER II

II. JUSTIFICATION FOR AND DEVELOPMENT OF A COTTON WAREHOUSE LOGISTICS MODEL

Abstract

Cooperatively owned cotton warehouses have unique inventory management issues. Unlike many other agricultural commodities, cotton is stored and marketed on an identity preserved basis. Unlike other warehouses which are continuously replenished, cotton warehouses are loaded once a year then slowly unloaded 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. Cotton warehouses operate under regulations from the U.S. Department of Agriculture Commodity Credit Corporation and those regulations mandate the maximum order fulfillment time. All of those factors create unique issues in simulating warehouse operations. A cotton warehouse simulation model could be a useful tool in identifying strategies to reduce warehouse costs. Those cost savings would flow through the supply chain and would be beneficial to the cotton producers who own and operate cotton warehouse cooperatives.

This application note presents a computer model, developed in Visual Basic for Applications to simulate bale movements needed to fill a given number of orders. This

manuscript provides a guide to using computer simulation for an applied problem in the agricultural industry.

Introduction

US harvested cotton acreage increased from 7.5 million acres in 2013 to 12.5 million in 2019 (NASS, 2019). This 67% increase in acreage, along with a slight increase in cotton production productivity in terms of increased yields, pressures warehouse operations in the US export-dependent cotton supply chain to be more effective. One important way they can do this is to reduce the number of times a cotton bale must be moved before its sale.

To improve market efficiency by enhancing price discovery, the cotton industry utilizes a digital trading system, The Seam (The Seam LLC, 2020). The Seam system acts as a middleman between buyers and sellers of cotton electronic warehouse receipts (EWRs). Trading on the Seam system is not in physical cotton, but rather EWRs are traded. These are digital documents containing quality and location information for each bale of cotton offered for sale. Information included are location of the cotton warehouse, rates of storage and handling fees, ownership, and a vector cotton quality attributes. Price discovery is efficient because most cotton traded in the US is traded on this system and during this search on the platform, the buyers and sellers remain anonymous. Funds are transferred via The Seam after agents agree on a price.

Because the timing of when a bale is removed from the warehouse is determined by the buyer, efficiency at the warehouse level is mainly dependent on how many times each bale must be physically moved within the warehouse before being staged to complete an order. At the start of cotton harvesting season, storage sheds are empty. Cotton is stacked into the shed back to front, row-by-row as it comes in from the gin. As the warehouse is loaded, each row is filled with 4×4 cross sections of bales and up to 35 cross-sections deep.

Unloading the warehouse starts with orders received on the digital trading system. Each order typically consists of 88 bales which is the amount needed to fill a shipping container. In order to increase efficiency, warehouses typically work a group of orders simultaneously. After receiving the list of group of orders with the targeted bales, employees go to each warehouse row that contains targeted bales and remove non-targeted bales until they reach the innermost targeted bale. As they move bales they distinguish between targeted and non-targeted bales. Targeted bales are removed for transportation. Non-targeted bales are temporarily moved to the aisle, then replaced into the stack after targeted bales in that row are removed. So as each row is processed for an order or group of orders, non-targeted bales are moved twice, once to move out of the way of removing targeted bales and second to restack. The process is repeated for subsequent orders so a bale could be removed and replaced multiple times before it is selected in an order.

To address this problem, my objective is to contribute to the programming literature and document the process from problem identification to completion of a computer program describing and analyzing cotton warehouse management strategies. It is applicable for other warehouse situations where inventory is individually identified and stacked in such a manner that non-targeted inventory must be handled in order to reach targeted items.

The efficiency of the cotton warehouse operation could theoretically be impacted by both the loading and order fulfillment strategies. Organizing the bales on the basis of gin code or quality characteristic as the warehouse is loaded could impact the subsequent efficiency of order fulfillment. However, the potential to improve efficiency through loading strategies is limited because the timing and order bales will be requested for shipment is unknown when the warehouse is loaded. The efficiency of the order fulfilment process is mainly impacted by the choice of how many orders to work simultaneously. That decision also impacts the time required to complete an order. In order to analyze alternative loading strategies and the choice the number of orders worked simultaneously when fulfilling orders, it is necessary to simulate the bale movements over the cycle of warehouse operation. That resulting bale movement information can also be used to estimate the maximum order fulfillment time which creates the upper constraint on the number of orders than can be grouped.

Simulating bale movements and determining the number of bale movements needed to fill each order provides a good metric for warehouse efficiency. More bale movements equates to increased handling costs. That handling cost can be estimated from bale movement data based on forklift speed and operating costs and the length and configuration of the rows in the warehouse. Alternative loading and order fulfillment strategies can then be compared on the basis of cost differences.

While cotton warehouse management has unique processes, the value of developing a program and completing our analyses generates value beyond that particular warehouse situation. As mentioned, the modeling approach is applicable to any warehouse situation involving individually identified inventory which can be accessed only by moving other items. The cotton warehouse case is particularly interesting because most cotton warehouses are organized as farmer owned cooperatives. Any cost savings that can be identified are passed on to grower-owners. Reducing warehousing costs in any supply chain also ultimately benefits the end user, the consumer.

Motivation

The cotton warehouse that provided data and insight for this research has developed the record keeping software to reassign locations for the bale that are moved within the warehouse. This is important because after a stack is worked on, bales could then be reorganized and the location data can be reassigned for easy identification later. The strategy of reorganizing bales is not current practice. Therefore, it makes sense to research whether it could reduce bale handling costs by simulating bale movements. Simulating alternative warehouse management strategies is more cost effective relative to trial-and-error experimentation. A cotton warehouse simulation model can help inform how the warehouse can use their data systems to develop better decision-making systems. All-in-all the ability to test alternative strategies of operations can lead to better informed strategy implementation as well as improved decision systems.

Another application of this simulation model is suggested by Hazelrigs 2016 who identified time and cost savings at the cotton warehouse due to novel bale selection techniques. That study was a response to the National Cotton Council's Vision 21 Cotton Flow study aiming to make warehouses more efficient. Hazelrigs' work and that of other researchers investigating improved cotton flow at the cotton warehouses underscore the need to be able to reliably model cotton warehouse operations.

This programming approach has applications outside of the cotton warehouse industry. Simulation modeling is also justified by logistical issues in other industrial storage and shipping systems. For example, shipping containers are also stored under block-stacking techniques which creates some of the same logistical issues encounter in cotton warehouses. Simulation models have been developed for shipping container applications. For example, Jang, Kim, and Kim, 2013 and Yang and Kim 2006 developed a model which tracks the relocation of containers based on whether the product removed was below the product remaining. The model described here tracks the movement of units in a storage location and could be used to address other logistical issues in the shipping container industry.

Materials and Methods

Data on cotton warehouse orders are provided by the Plains Cotton Cooperative Association (PCCA). The PCCA data include cotton quality measured by USDA AMS. Bales are uniquely identified with a number and location, including warehouse, row, and section number. Specific positions within each cross-section of a row are randomly assigned as the warehouse does not record that information. The data also include order number and date. The timing of the order processing was based on PCCA's order records.

Our program was developed in Visual Basic for Applications in Excel. The logic process used to simulate cotton order fulfillment is described as follows:

The first important dissection of the problem was to focus on one row (within a warehouse building) at a time. Later the next procedures are looped over all the rows. The program works through each row determining whether each bale is included in the selected set of orders. The process begins with order number one and then loops over all the remaining orders in the selected group before moving on to the next row.

There are two decisions that need to be made in each row about each bale. The first decision relates to whether the bale is a targeted bale since targeted and non-targeted bales have different implications for the bale movement count. The second decision is whether there are any targeted bales in the row that are located behind the examined bale. This determines whether the bale movement tracking process proceeds to the next row. Those decisions and described in Figure 1, and are determined of each bale before moving on to the next bale, until each bale in the row is evaluated for whether it is in the order of interest. Since the warehouse row is four bales wide and four bales high, the evaluation begins with top layer of the outermost section and then proceeds across the layer before going to the second, third and fourth layer in that section before moving to the next section which is one bale deep in the row.

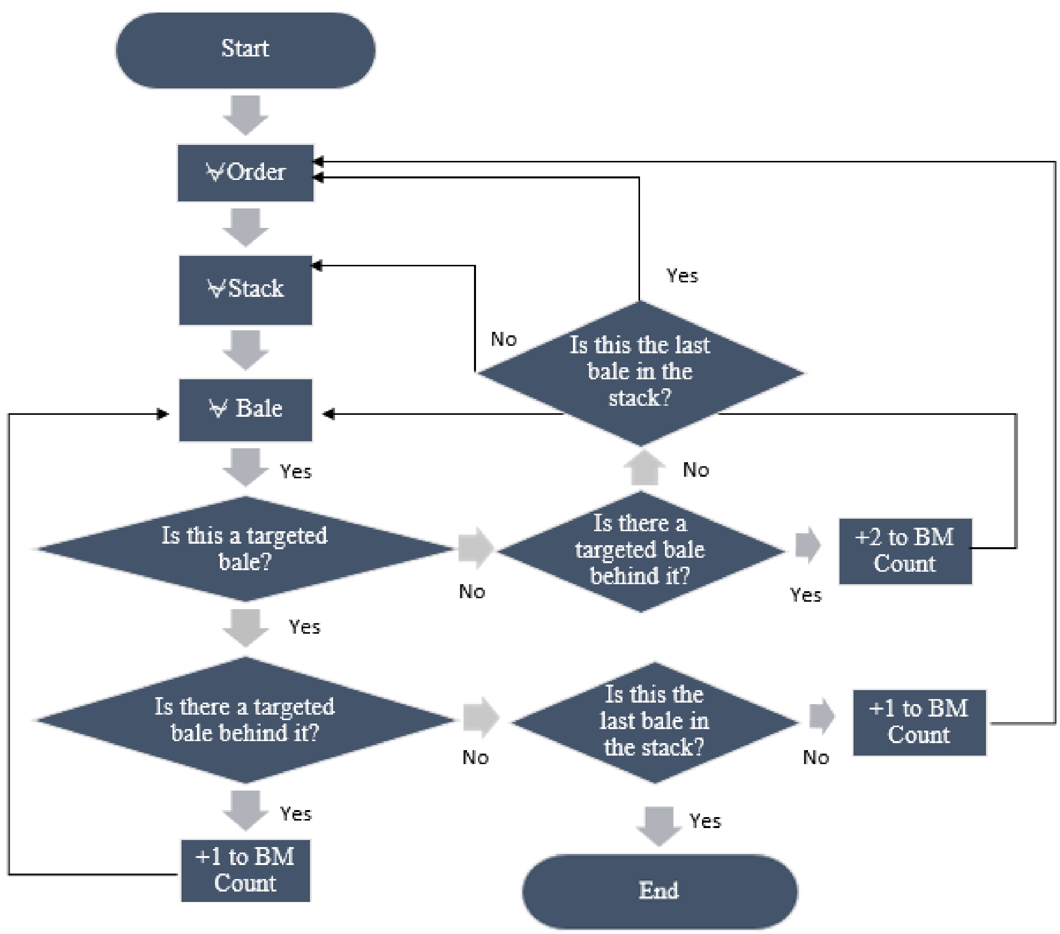

Figure 1.1. Programming Process Flow Chart
*BM denotes Bale Movement

The programming process is a hierarchy where the same set of decisions (represented by the right side of the figure) are made on each bale before proceeding to the next bale. As the computer reads down the lines of code, there are multiple loops for calculating the bale movements for each order in the designated set and within rows.

Traditionally when creating simulation models, validation of the model ensures the results are accurate. For this model, validation was achieved by sampling a random row and order combination. This cross-section of data was manually counted to determine the number of bale movements required to unload that row and order. The model was then run on the same sample to verify if the two totals matched. The model was developed until the model reported the same value as the manual count.

Results and Discussion

The result of this research effort is a unique program simulating bale movements in a cotton warehouse developed in Excel VBA. Executable for alternative sets of orders and rows, the program is flexible enough for applied analysis of alternative warehouse management strategies. Specifically, the program tells the researcher how many bale movements it will take to retrieve targeted bales that are located in a stack that is accessible from only one direction in a warehouse. The program can allow managers to compare alternative loading strategies with the current practice of loading the warehouse in the order that the bales were delivered. The program can also be used to analyze choices in order fulfillment strategies such as the number of orders to work simultaneously.

The program is provided in a GitHub repository (Richard, 2020). Upon execution, the program will tally the number of bale movements for each group of orders, automatically report it in the spreadsheet, and then provide the grand total in a message box. Such an application note as this is useful for future researchers developing warehouse simulations with unique parameters. This method of modelling is interesting for anyone trying to identify cost reducing opportunities in a similar warehouse setting.

Conclusions

This paper identified a gap in the warehouse modelling literature. By outlining the development of a computer program designed to count bale movements in a cotton warehouse, this article contributes framework for conducting applied analysis of current and alternative management strategies. The program is an example and starting point for other programmers developing models for similar warehouse operations. There is currently very little literature modeling warehouses such as cotton warehouses that have a single annual filling cycle, identity preserved inventory and single directional access. This places a higher importance on this contribution and future application notes in the warehouse management literature.

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CHAPTER III

III. COTTON WAREHOUSE APPLIED ANALYSIS OF LOADING AND ORDER FULFILLMENT STRATEGIES

Abstract

Cooperatively owned cotton warehouses have unique inventory management issues. Unlike many other agricultural commodities, cotton is stored and marketed on an identity preserved basis. While other agricultural products use IP supply chains, cotton is unique because each marketing transaction identifies specific units. In many other agricultural IP supply chains, specific unit identity information is used for traceability but the market transaction does not specify a particular box or unit. Unlike other warehouses which are continuously replenished, cotton warehouses are loaded once a year then slowly unloaded 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. Cotton warehouses operate under regulations from the U.S. Department of Agriculture Commodity Credit Corporation and those regulations mandate the maximum order fulfillment time. All of those factors create unique issues in simulating warehouse operations. This study conducts applied analysis intended to identify more efficient loading and order fulfillment strategies using the program developed by Chapter 2. Results suggest the best alternative loading strategy lead to a $499,013.75 per turn of the warehouse (0.85 per bale) reduction in handling costs and the

alternative order fulfillment strategy lead to a $34,139.19 per turn (0.06 per bale) reduction in handling costs. Cotton warehouse cooperatives will pass some or all of these savings through to the farmer-owners.

Introduction

Electronic trading systems have made considerable advancements in the cotton supply chain. TELCOT, a computer based trading system has given rise more recently to an Electronic Title System (ETS) and “The Seam” (The Seam LLC, 2020). Kenkel and Kim, (2008) provide more detail as to how these technologies have impacted the industry. These among other supporting technologies have allowed the merchants to access individual bale characteristics and complete orders electronically. This new ability gives the downstream merchants more information, and the ability to request specific cotton bales. While beneficial for the supply chain as a whole, the electronic trading system also created logistical challenges for cotton warehouse operations.

Cotton warehouse cooperatives are an essential part of the overall cotton supply chain. They administer the beginning of the trading system and facilitate the storage and beginning of the baled cotton shipping system. They perform the challenging function of identifying and retrieving specific orders of bales from a large warehouse system containing 500,000+ bales. This stage in the supply chain is prone to coordination bottlenecks. The cotton warehouse charges a daily storage fee but does not control the storage date or shipping date, and thus the length of storage. All of the logistical costs of warehouse operation are passed on to the grower-owners. If warehouses logistics could be improved to reduce the overall bale movement during the annual cycle of bale delivery and order fulfillment, additional profits could be passed on to the grower-owners. This paper estimates the previously unknown potential cost savings from improved warehouse logistics.

This paper's objective is to model the bale movement during the order fulfillment or "break-out" cycle of a typical cotton warehouse and determine how bale movement is affected by alternative loading and unloading strategies. We then calculate the costs associated with bale movement to determine potential cost savings. Our modeling begins when the warehouse is completely full and continues until all of the bales are retrieved. While there are bale movements associated with loading the warehouse, that process is straightforward with the bales placed into rows in the order of receipt from the gin. In contrast, the order fulfillment process is a particularly time consuming aspect of the overall warehouse operations. During the order fulfillment process, warehouse personnel must move non-targeted bales to reach a targeted bale; then replace the non-targeted bales in their previous position to maintain the inventory location index.

This paper examines two basic research questions. The first research question is whether organizing the warehouse inventory on the basis of quality attributes or gin code can reduce the number of times bales are handled and the associated costs relative to the current first-in loading strategy. If cotton merchants are attempting to assemble uniform lots of cotton as they select the bales in each order, then organizing the warehouse based on quality could place the ordered bales closer together and minimize the handling of non-targeted bales. On the other hand, if merchants or end users are striving for a composite quality by mixing bales with different quality attributes then quality based warehouse strategies may not reduce handling costs. In order to address the first research question, seven scenarios, each based on loading the warehouse based on a separate quality characteristic, are examined to determine the impact on the number of bale movements and resulting costs.

The second research question is whether alternative strategies for order fulfillment could reduce bale movement and warehouse handling costs. The most likely and apparent possibility for reduced handling involves changing the number of orders that are worked simultaneously. As the number of orders being worked simultaneously increases, the number of non-targeted bales among the total bales moved decreases. Cotton warehouses operate under the regulations of the Commodity Credit Corporation (CCC) and must provide a written report to CCC on a weekly basis. As part of that report, the warehouse must indicate whether the bales ordered and scheduled for shipment were either shipped or made available for shipment. The cotton warehouse regulatory environment therefore creates a constraint on the number of orders worked simultaneously. As the number of orders being worked increases it becomes more likely that one or more orders may not be positioned for the scheduled shipment date. In addition to regulatory standards, order fulfilment time is important to the merchant buyers and more rapid fulfilment leads to increased customer satisfaction.

Previous Research

Wu, Gunter, & Shurley (2007), Ethridge, Brown, Price, and Bragg (1992), and Brown and Ethridge (1995) provide examples for examining the impact of quality attributes on economic value, but do not relate this information to warehouse operations. Burinskiene (2011) and Burinskiene (2015) provide generic warehouse simulation examples, providing a conceptual starting point for modelling techniques and the application of Visual Basic for Applications. Hazelrigs et. al., (2017) provides an example specific to a cotton warehouse by examining alternative stacking and marketing techniques, but does not compare the bale movements across quality-determined alternative loading strategies or consider the shipment schedule is not under the warehouse operator's control. The research in this paper is unique because it focuses on cotton warehouse logistic strategies that have not been previously examined.

The remainder of the paper will first establish the conceptual framework, then describe the simulation, present the data, and then the results and proceeding discussion. This work will not only contribute to the field of knowledge of warehouse management but will also be readily extendable to cotton warehouse managers.

Conceptual Framework

Understanding high volume instruments provide accurate reading of cotton characteristics is critical to understanding how the warehouse eventually gets precision information about each bale. A sample of each bale is taken at the gin after ginning and is sent to a classification office managed by the Agriculture Marketing Services (AMS) branch of the USDA where a permanent bale identification tag is generated. This tag is associated with the quality of each individual bale and uploaded to various digital trading systems (Cotton Inc., 2018.) All cotton sold using futures contracts in addition to the Intercontinental Exchange is classified through these offices. In general, most cotton is classified, all classification services are charged fees and there are twelve classification offices throughout the cotton belt. This process is important because the warehouse cannot take advantage of the information until the permanent identification is known by the warehouse.

The loading strategy and number of orders worked simultaneously are the two choice variables pertaining to the objective. In the current protocol, warehouse operators are storing 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. By modelling the break-out of individual bales according to historic orders, each strategy of bale locations had the bale movements simulated, maintaining the same order history, providing means for comparing the costs of various strategies. This process will also be repeated across two order fulfillment strategies where there is a different number of orders to be fulfilled simultaneously.

Data

This study utilizes information from one cooperatively-owned cotton warehouse in Altus, OK. The Plains Cotton Cooperative Association provided data for the entire 2016 cotton crop which is summarized in Table 1. Note some bales were removed from the data set because they occupied positions of another bale, meaning some bales were shipped out and that position was used again within the year.

Table 2.1. Characteristics of Plains Cotton Cooperative Association Cotton in 2016

Variable	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

Each observation provides the individual bale's ID, location (shed, row, and section), the quality attributes, the day it was stored, the day it was moved to the staging area (clearance date for final order), what gin it came from, what farmer produced it, and what merchant bought it. These data are incomplete with respect to the exact position of each bale, which was assigned by a number one through twelve or sixteen depending on how many bales are in that section.

Another step to prepare the data for the simulation was to generate an order number by examining the unique combinations of clearance dates and first merchants. After sorting by these two variables, as either changes, this signals the bale belongs to the next order, and every bale throughout the dataset is labeled with an order number by this method. There are 1,091 orders of 88 bales or less in the 2016 crop. Finally, to prepare the data for the program, it is first sorted by order number, then shed, row, section, and descending by position. This is done so the program can effectively identify the last targeted bale in a shed-row. The data is then ready for the simulation program.

One limitation in our data set was the warehouse sometimes positioned bales that were delivered late in the ginning season into vacant position in existing rows. That resulted in more than one bale occupying a given location. To simplify the modeling, the bales which were placed into previously occupied warehouse positions, were deleted from the data set. Some of the data was lost to this simplification, but programming advantages were significant. Future research could extend our modeling to consider in season re-filling of bale locations.

Procedures

Loading Strategies

First, the possible bale locations from the original data set were sorted by shed, row, descending section, and ascending position, so as to mimic the order in which the positions would be filled as bales arrive. Each shed was "filled" or locations were assigned with bales sorted by the selected data characteristic for each loading strategy. The loading strategies and how they determine the shed, row, section and position are described in Table 2.

Table 2.2. How Alternative Loading Strategies Determine Bale Positions

Attribute Determined	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	Ad hoc scenario where bales are purely randomly sorted into sheds, 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 seven 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 their percentage, where low trash content are 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 different sheds and rows, keeping each farmers set of bales together.

For example, the micronaire scenario would be sorted such that all the premium micronaire appeared first, then non-discounted, then discounted. Premium cotton might fill the first fifteen sheds, then non-discounted might fill twenty sheds, and the discounted may fill the rest, for instance. Bales were located in each row, from the back section to the front section, and the bottom positions to the top positions, before moving on to filling the next row until the shed was full and then moving on to the next shed. This procedure was repeated for each of the loading strategies in order to create multiple data sets on which to perform the applied analysis.

After the warehouse bale locations were determined for each loading strategy, the total number of bale movements was determined. This was performed by the model developed in (Richard, 2020). Each of the loading strategies was analyzed by working all orders (entire shed-rows) for a sample of shed-rows. A sample is justified by the computational burden of modelling the entire warehouse, which became obvious in the early stages of modelling this analysis. Specific details of these limitations are described in the summary and conclusions of this Chapter. Equation 1 describes how the sample size (number of shed-rows) was determined for each loading strategy:

$$n_l = \frac{{Z_\alpha}^2 * {\sigma_l}^2}{{\beta_l}^2} \qquad (1)$$

where n_l is the sample size, Z_α is the confidence level, ${\sigma_l}^2$ is the variance of number of bale movements for that loading strategy, and ${\beta_l}^2$ is the error bound for each loading strategy. Both the variance and error bound for each loading strategy were derived from a small (20 row) sample. The error bound is 10% of the average number of bale movements from the test sample. Equation 1 allows the result to be stated as "We are 95% confident the expected result is X, with an error bound of ±5% of the bale movements per bale."

In terms of warehouse decision-making, the choices of loading strategies are compared side-by-side and selected for the lowest bale handling costs. This decision process can be described by: The warehouse operator's objective function when choosing between alternative loading strategies can be described by:

(3.1) $$\min_{\Omega} C(\Omega)$$

where C is the cost of fulfilling orders, and Ω is each loading strategy.

Order Fulfillment Strategies

Upon interpreting results from analysis of the loading strategies, the analysis was expanded to compare order fulfillment strategies. Specifically, a comparison analysis of fulfilling just 20 orders simultaneously with fulfilling 30 orders simultaneously was conducted to determine if there are efficiency gains by fulfilling more orders simultaneously. This was done by calculating bale movements across all rows for an interval sample of 21 orders. Again, this sample is justified by computational limitations. It takes 24 hours just to run one group order. There are 428 group orders to represent the entire year of this warehouse. In lieu of modelling this analysis for over a year, a strategic decision was made to capture the phases of decreasing overall quantities of bales occupying the warehouse. 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.) This interval approach was taken because a random sample does not have much meaning. There is a downward trend in efficiency-gain potential as we move from a full warehouse to a nearly empty one. Taking this into account, we can instead determine incrementally how much efficiency there is to gain at various stages of fullness in the warehouse.

A cost per bale movement was determined by engineering-based estimates of forklift operations. Table 3 provides a detailed step by step calculation of the costs associated with a bale movement. The per-bale costs were multiplied by the number of bale movements to develop resulting cost savings from implementing loading and order fulfillment strategies.

Table 2.3. Determination of Cost per Bale Movement

Calculation of Distance		Calculation of Time		Calculation of Cost per Bale Movement	
Max Sections in Stack	35	Average Forklift Distance (ft.)	30.625	Total Time (hours)	0.0074
	÷ 2	Average Forklift Speed (ft. sec^{-1})[a]	÷ 3.66	Labor with Benefits ($ hour^{-1})	× 25.00
Middle of Stack	17.5	One Way Time per Bale Movement (sec)	8.36	Labor cost per Bale Movement ($)	0.19
Bale Width (ft.)	× 1.75	Time to middle of stack and back	× 2	Total Time (hours)	0.0074
Average Forklift Distance (ft.)	30.63	Time per Bale Movement (sec)	16.73	Fuel & Maintenance ($ hour^{-1})	× 2.28
		Time to Pick-up/Put-down (sec)	+ 10.00	Forklift cost per Bale Movement ($)	0.01
		Total Time (seconds (hours))	26.73 (0.0074)	**Total Cost ($ Bale Movement^{-1})**	**0.20**

[a]Singh et al (2009) utilizes average speed of forklift operations. Here, we average between the minimum and the average speed to account for acceleration and deceleration.

The warehouse follows a slightly different objective function when deciding on an order fulfillment strategy to implement. The warehouse operator must decide what number of orders to group for fulfillment procedures subject to constraints. The warehouse operator's objective function when choosing between alternative order fulfillment strategies can be described by:

(3.2) $$\min_{\mu} C(\mu)$$

$$\text{s.t.}$$

$$M(\mu) \leq n$$

$$S(\mu) \leq p$$

where C is the cost of fulfilling all orders while working various numbers of orders simultaneously, μ is each order fulfillment strategy, M is max days to fulfill a group order, n is the warehouse operator determined max time group orders need to be fulfilled within, S is the required staging area, and p is the limit of available staging area.

Results

Eight loading strategies were developed to test whether an alternative placement of each bale in the warehouse will lead to reduced handling costs for the cooperatively owned cotton warehouse represented in this data set. The program was executed against each loading strategy with differing sample sizes of number of rows; counting the number of bale movements required for all of the cotton bales in each sample to be removed from the warehouse. This count is divided by the number of bales in that sample to arrive at an average number of bale movements per bale, the result is reported in Table

2.4. An associated reduction from the current loading strategy (in cost per bale) accompanies each alternative loading strategy.

Table 2.4. Average Bale Movements per Bale Required to Unload the Warehouse

Scenario	Avg. # 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)

*Denotes a reduction **Denotes the greatest reduction in movements per bale.

The findings indicate the current strategy of loading the warehouse has a fairly low touch count and was actually superior to some characteristic-determined loading strategies. However, sorting the bales by leaf grade, micronaire, trash, gin code, or account number (farmer id), result in a lower count of bale movements than the current loading strategy. Specifically, loading the warehouse by gin code reduced the number of bale movements the most, with a reduction of 4.26 bale movements per bale, and therefore an associated $0.85 cost savings per bale. This results in a $499,013.75 cost savings from reduced bale handling per turn of the warehouse (one complete loading and unloading of the warehouse.) This suggests alternatively choosing and implementing one of those loading strategies will reduce costs, and therefore increase profits.

The order fulfillment strategy analysis also led to identification of potential cost savings for the warehouse. By alternatively fulfilling 30 orders simultaneously, (rather than the current strategy of 20) there is a reduced number of bale movements per bale. However, it will now take longer to complete fulfillment by moving from 20 orders to 30 orders because the bale sets are larger. Figure 2.1 demonstrates the trade-off between bale movement reduction potential and time-to-fulfill potential increase.

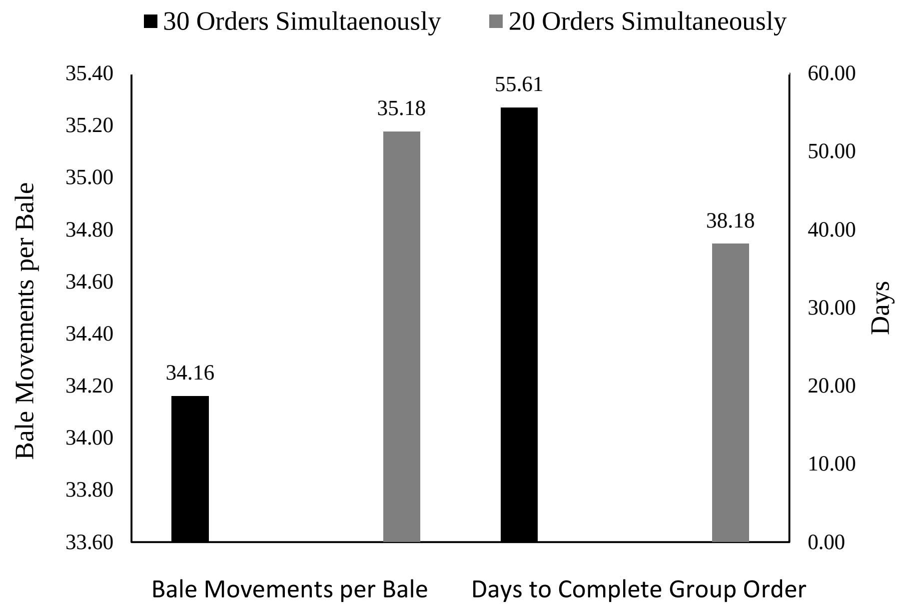

Figure 2.1. Changes in Efficiency & Time by Alternative Order Fulfillment Strategy

Examining the first two bars (corresponding to the primary axis), there are less bale movements per bale under the alternative strategy of fulfilling 30 orders simultaneously. This demonstrates the gain in efficiency from moving to the alternative order fulfillment strategy and this causes a reduction in handling costs. Examining the last two bars, (corresponding to the secondary axis), there are more days to complete a group order under the alternative strategy of fulfilling 30 orders simultaneously. The days to complete a group order is a function of average bale movements per bale, the number of hours per bale movement, and an assumed 12 hour work day. The order fulfillment time shown in Figure 2.1 represents the number of days that elapse before the last bale in the group of orders is retrieved. It therefore represents the worst case scenario that could occur if the last bale in the first order processed was positioned such that it was the last bale retrieved in the group of orders. Upon examining this figure, a warehouse operator could consider the potential reduction in bale movements from working a larger group of orders, while also considering the expanded time to complete that group order set of bales. It is possible that moving to the alternative strategy will cause individual orders to be late. Increasing the number of orders worked simultaneously reduce the average bale movement per bale. However that does not necessarily decrease the time to process an individual order since bales from other orders are being retrieved as the first order is being processed. The maximum possible time to process an order or "worst-case scenario" is likely to be the limiting factor for most warehouses. It should be noted, that while the maximum possible time to fulfill an order increases as the number of orders being worked is increased, many orders will actually be processed faster with larger order groupings due to the reduction in bale movements. Table 5 provides more information about the ranges of bale movements and order fulfillment time when 20 or 30 orders are grouped.

Table 2.5. Variation by Order Intervals

	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

The variation within each grouping assumption is driven by order complexity. That is to say, some orders will have bales scattered among many rows, while other orders will be tightly grouped within a few, or even one row. It is naturally easier to fulfill orders with less spatial complexity, because less non-targeted bales will have to be removed to fulfill the order with targeted bales.

The changes in bale movement that results from changing the number of orders in a group can be converted to changes in handling costs using the procedures previously discussed. The change in handling costs from working 20 versus 30 orders simultaneously is summarized in Table 2.6.

Table 2.6. Handling Costs for Order Fulfillment Strategies

20	30	Orders Simultaneously Fulfilled
8,702,268	8,531,572	Total Bale Movements per Bale
14.82	14.53	Average Bale Movements per Bale
$1,740,454	$1,706,314	Total Handling Cost per "turn"

Note: Calculated with 587,075 bales and handling cost of $0.20 per bale movement

Increasing the number of orders processed as a group from 20 orders to 30 orders results in a $34,139.19 total savings ($0.06 per bale) reduction in handling costs for each cycle of the warehouse. Warehouse managers will need to decide whether this cost savings justifies the increase in maximum time to complete a group order.

Loading the warehouse based on gin code generated the greatest reduction in costs from the baseline first-in loading strategy. The order fulfillment strategy of working 30 orders at a time presents a trade-off between a reduction in the cost of bale handling and the time it takes to complete the fulfillment process for a set of orders.

Summary and Conclusions

This study examines current and alternative loading and order fulfillment strategies in a cooperative cotton warehouse. Loading the warehouse based on gin code generated the greatest reduction in costs relative to the baseline of current practices. Increasing the numbers of orders worked simultaneously achieved a smaller cost savings. The resulting calculation of reduced handling cost was $499,013.75 and $34,139.19 savings per turn of the warehouse due to the optimal order loading and order fulfillment strategy, respectively. Fulfilling group orders of 30 individual orders simultaneously (as opposed to the current strategy of only 20) lead to the stated reduction while, at the same time, increasing the maximum possible time to complete a group order by 17 days. Loading strategies based on account number, micronaire, trash or leaf grade yielded cost reductions relative to the current baseline but were inferior to the optimal loading strategy; gin code.

Note this research only considered loading strategies based on a single quality factor. It is possible that cotton merchants consider a combination of quality variables when they decide which bales to order and therefore more complex characteristic-driven loading strategies could yield higher cost reductions. While this may seem like a limitation of this study, it is more of a nuance of each individual warehouse.

While our results did not indicate loading by any of the quality attributes resulted in the largest cost savings, we should point out the challenges in implementing any quality characteristic-driven warehouse loading strategies. The classification information is not known at the time the warehouse is being loaded. The time delay in receiving quality information varies across the ginning season and also likely varies across warehouses. Additional research is needed to consider the additional costs and warehouse space needed to stage cotton while waiting for grade information. However, this study’s findings do provide motivation to reduce the time delay in providing quality information to the warehouse. Loading warehouses according to quality information should be considered as a future opportunity for cotton warehouse management once the delay has been reduced.

Another practical issue with characteristic-driven based warehouse loading 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. Additional research characterizing the distribution of characteristics of bales delivered to a cotton warehouse would address that issue.

Order fulfillment strategy results suggest warehouse operators should fulfill as many orders simultaneously as possible, up to the point where order fulfillment times become unacceptable. Our research considered a sample of orders spread across the operating year as the warehouse transitioned from full to empty. Our results on the maximum time required to complete an order were therefore driven by the bale movements when the warehouse was relatively full. Since the ratio of targeted to non-targeted bales improves as the warehouse is emptied it is likely that a warehouse could increase the orders in a group as the warehouse becomes more relatively empty without increasing the maximum order fulfillment time. Bale movement per order also improves as the warehouse empties so the cost savings from increasing the order grouping as the season progresses could be limited. Future research could examine the dynamics of optimal order grouping over the warehouse turn cycle.

Additionally, the sampling necessary in this study for both the order fulfillment and loading strategies can be circumvented with a more sophisticated model. The computational limitations of this study justified a sampling scheme for both types of applied analysis. For example each row and all orders set for each loading strategy took an hour and a half to complete, and each order and all row set for each unloading strategy took a full day to complete. This limitation prevented further investigation of more order fulfillment strategies where the number of orders grouped is higher. Ideally, a mapping of that curve starting at 20 and ending at 428 (max orders for this warehouse's year) would be generated to see where the peak trade-off between reduced bale movements and increased time to complete lies.

Recommendations to warehouse operators from this research include a choice of focusing on loading or order fulfillment strategies. Both processes have alternative strategies leading to reduced bale handling costs. Within the loading strategies considered, the optimal strategies involved gin code and farmer ID, information that is available at the time of bale delivery to the warehouse. Warehouse managers should be able to implement either of those strategies with little additional costs since bales could be placed directly into position (determined by gin code or farmer ID) as they are delivered. There would be minor issues in allocating warehouse space but those could likely be addressed with available information on anticipated production from gins and producers. Managers should plan to work on as many orders simultaneously as they can, given their comfort level with maximum possible time for order completion.

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CHAPTER IV

IV. REDUCING BALE HANDLING THROUGH AN ALTERNATIVE COTTON MARKETING FRAMEWORK

Abstract

Cotton warehouse management research advances the value captured by agricultural cooperatives, critical to the cotton supply chain. Other research in this project examines management strategies at the warehouse level for improving efficiency of bale handling. This research focuses on a more forward-thinking question of "How would overall efficiency of the supply chain change if the strict identify preserved marketing was relaxed?" More specifically, we examine the impact of substituting a bale of similar quality for the originally targeted bale when it is advantageous in terms of warehouse location. This study used data from a cooperative cotton warehouse to examine the economic benefits of substituting bales within a quality tolerance. Expected results include evidence there are economic benefits to adopting a marketing system allowing for bale substitution based on quality and location within the warehouse.

Introduction

Cotton warehouses have unique inventory management issues. 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 other warehouses which are continuously replenished, cotton warehouses are loaded once a year then slowly unloaded 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. Cotton warehouses operate under regulations from the U.S. Department of Agriculture Commodity Credit Corporation. Those regulations, referred to as the "Cotton Shipping Standard" mandate the maximum order fulfillment time. As part of the Cotton Shipping Standard, cotton warehouses must provide weekly reports indicating the specific bales that have been ordered and the specific bales made available for shipment. All of those factors create unique issues in simulating warehouse operations. Warehouse managers respond to orders on individual bales with no negotiation. Any given bale may be located in the very back and bottom of a given stack of cotton, with no other bales in that stack as part of that or other orders ready to go to the staging area. This means many bales will be handled multiple times before ever leaving the stack for final staging. This repetition of handling causes inefficiency.

To combat this inefficiency, forthcoming literature in the cotton warehouse management field investigates the changes in efficiency due to choosing alternative loading and order fulfillment strategies under the current market structure. Chapter 3 examines the economic benefits of implementing these strategies, while Chapter 2 provides a computer program to enable the applied analysis to be performed. Combined, these studies advance understanding of potential strategies in the cotton supply-chain management field beyond what is currently implemented in all cotton warehouses.

To continue with the theme of identifying strategies that introduce greater efficiency to the warehouse step in the supply-chain, the implications of a slight change to the cotton marketing system is examined. This study investigates the research question: “What would be the cost savings from allowing cotton warehouses to substitute bales within a given quality tolerance?” It is recognized that the realization of any identified savings would require changes in the cotton marketing system and in associated federal programs.

Quality is generally important to merchants of cotton because textile millers and end-users have preferences and specifications in the characteristics of cotton they buy. Due to the processes cotton goes through to become a final product, specific characteristics are important in the supply chain beyond the warehouse. The following discussion will start with the general case for why cotton quality cannot be ignored, and then move into specific reasons and an example for why merchants look for specific bales.

Cotton quality affects the marketability and value of bales in the supply chain. Marketability suggests some cotton may not be able to be sold due to poor quality. There is at some point, some minimum quality each bale must meet in order to get any buyers interested in purchasing it. Value is then considered to be a function of how far above that minimum quality a bale is. There are also numerous dimensions to cotton quality and the relative importance of quality attributes varies across end users. Bales with more desirable properties will be higher priced, bringing more value for the grower, and hopefully bringing more value to the end user, and therefore the merchants and processors.

Ladd and Suvinnunt 1976 begin a long dialogue of the origins of why characteristics that represent quality in goods is important. Specifically, they develop an application for how the consumer goods characteristics model can be used to determine expected price of a good based on the qualities it has. They argue any good's price paid by the consumer is equal to the sum of the marginal monetary values of the product's characteristics; the marginal monetary value of each characteristic equals the quantity of the characteristic obtained from the marginal unit of the product consumed multiplied by the marginal implicit price of the characteristic. In the case of cotton's first sale, each bale's price is a function of its color, micronaire, staple, etc. and therefore merchants desire to acquire cotton of a specific price according to those traits. Bowman 1989 and Chen 1995 both analyze characteristics of cotton that explain and determine prices, citing Ladd and Suvinnadt 1976 as a foundation for them to do their work.

This theory for price as a function of characteristics becomes important when arguing for a marketing framework that allows quality-based substitution. Quality is important to merchants, critical even, however, compromise within a very small interval may be possible, especially in the case of offering a discount for the amount of compromised quality. Before investigating the rational quantity of a discount, establishing whether the marketing framework has any upstream value must happen first.

Additionally, in order to determine that value, it is necessary to understand the mechanism merchants use to select the quality of cotton they purchase. The textile millers whom merchants are buying on behalf of have specifications of each characteristic because the quality affects the ease of cotton processing as well as the quality of the end product. The merchants know these specifications and have a software called MillNet which selects a mix of bales that when blended together, meet a specific minimum target of quality. There may be other bales that also help meet that target mix.

Merchants are buying for different end products sometimes. In the case that one merchant is buying for a miller making socks and another is buying for a miller making dress shirts, the first miller is going to be less stringent about color than the second one. This is another reason flexibility of substitution may change based on what the merchants objective is. Different end users may also have difference tolerances relative to the variation they can accept from their desired quality parameter.

The concept of establishing allowable tolerances is widely applied in manufacturing. As a simple example, manufacturers of nuts and bolts specify the pitch diameter tolerance, the internal thread diameter tolerance and the external thread diameter tolerance for each category of nut or bolt. It is possible to purchase the same diameter nut or bolt with more stringent or less stringent tolerances (Fastenal, 2020). When a buyer purchases a 10mm diameter bolt, they are actually purchasing a bolt guaranteed to be within some tolerance of 10mm.

Theory

The identity preserved system would not have to be abolished in order to consider changing the marketing framework of the cotton industry. Rather, focusing on the largest trading platform handling the majority of the cotton traded in the US provides a starting point for considering new negotiation frameworks. The Seam handles trading of Electronic Warehouse Receipts (EWRs) which are traced to an individual bale at the warehouse, declaring the ownership and quality of the bale. Many buyers and sellers convene on this platform to make sales of cotton, justifying this as a place to target for potential negotiation constructs. This system allows cotton end users to purchase and assemble an inventory of cotton bales that can be blended to meet their individual quality requirements.

The existing identity preserved marketing system could be modified to allow the cotton warehouse to substitute a bale with similar quality characteristics for a requested bale. The cotton warehouse would be interested in making the substitution when the substitute bale was located in a more accessible position within the warehouse, resulting in lower handling costs. In order for the industry to make the change in the marketing system, the associated cost savings would have to be split between the cotton warehouse and cotton end user. It might also require some accommodation for the cotton producer. In most years, over half of U.S. cotton is marketed through cotton marketing pools. For example, survey research by Pace and Robinson (2012) found that 55% of Texas cotton was marketed through a cotton marketing pool. Under the pool structure, each producer receives the average price for all cotton of similar quality that was sold by the pool during the marketing year. Because of that averaging, both the marketing pool administrator and the producers marketing through the pool should be indifferent as to whether a similar bale of cotton was substituted for the bale submitted for sale. Bales of cotton placed on the electronic trading platform by individual producers would be more problematic. In that case, substituting a very similar bale for the targeted bale could involve shifting the sale from one producer to another which would change the market date and likely the market price for both producers. Cotton producers might therefore need some sort of incentive system before they would accept the change. A change that allowed substitution of bales within a quality tolerance range would also require changes in the Cotton

Shipping Standard. All of the participants in the supply chain would have to realize sufficient incentives to motivate them to accept the modified system.

It is important to note the decision rules that cotton buyers use when selecting bales are not known. It is widely speculated that cotton buyers use linear programming based approaches to identify the least cost set of bales that satisfy their particular quality requirements. If that is the case, their selection criteria does not consider the warehouse handling cost (based on location) and could therefore be sub-optimal in terms of the entire cotton marketing chain. The question of whether it is useful and possible to correct that marketing chain inefficiency depends in part on the potential cost savings of substituting bales within a small quality tolerance.

This study's null hypothesis is there is no economic benefit to be gained by an alternative marketing framework which allowed substitution of similar quality bales. The test hypothesis, or the alternative hypothesis, is: there is some economic benefit to the implementation of an alternative marketing framework in the cotton industry. The purpose of this study is to identify the amount (if any) of economic benefit from substituting similar quality bales for specific bales identified by the cotton buyers.

While identifying economic benefits is critical, it is useful to think of this problem in terms of the warehouse's decision. Should the warehouse participate in an industry wide substitution-allowed marketing framework or not? The warehouse operator's objective function when choosing between alternative marketing frameworks can be described by:

(4.1) $$\min_{\delta} C(\delta)$$

s.t.

$$q_L(\delta) \leq \text{Q} \leq q_U(\delta)$$

where C is the cost of fulfilling all orders when 20 orders are fulfilled simultaneously, δ is each marketing framework, Q is the quality of the targeted bales, and q_L and q_U are the lower and upper bound quality tolerance of the bale to be substituted for the targeted bale for that marketing framework respectively. Future research may need to develop an understanding for the challenges to implementing such a policy decision. These challenges include: How can trade organizations incentivize the switch to the alternative marketing framework? How can the negotiation mechanism be built into The Seam? What kind of system change needs to happen such that location data is available from the warehouse to The Seam?

Data and Methods

In order to investigate the implications of an alternative marketing framework, it is important to understand the population data set. The population data set is one that includes all cotton bales traded on The Seam, their quality, and handling costs associated with their location, in addition to a list of historic orders transacted on this digital trading system. While obtaining this data set in its entirety may be challenging, sampling from it can provide a first look at the possible value of an improved marketing framework.

Data for this study was obtained from Plains Cotton Cooperative Association in Altus, OK. It represents 587,075 cotton bales handled in the year 2016. Bales are uniquely identified, location includes warehouse, row, and section number where specific positions within each section of a row are randomly assigned as the warehouse does not record that information. Quality, gin, ownership, and sale data are known. Bales that were placed in a position that had already been occupied were removed from the sample data set so as to keep the analysis to one turn of the warehouse. One turn is one complete loading and unloading of the warehouse.

One remaining data series is critical to this study. Handling costs for each position, conditional on remaining bales in front of that position needs to be calculated for estimating the results of this study. This is calculated by the routine designed in Chapter 2.

The procedure for calculating a value from switching from the current marketing framework to an alternative one involve 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 is run to determine the new order in which bales will be pulled out of the stacks to fulfill orders. Second, a bale movement counting routine is run on the new order to simulate the process of fulfilling orders. This is repeated for each of the two alternative marketing frameworks. The value of switching to the new marketing framework where substation 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 criteria is determined. A tolerance range for each quality criteria is then assumed and calculated as a percentage of the quality range. This range is included in the substitution routine for each quality criteria. In this study, the two frameworks are: (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% the same. The second scenario is more stringent, where they are 95% the same on most quality criteria, but are 97.5% the same on the more important quality criteria.

To explain the substitution routine in greater detail, a program developed in Visual Basic for Applications where two bales are considered on each iteration. The routine examines every bale in the sample order, and compares that bale to every other bale in front of it looking for a bale within the quality range desired. This program is provided as another Github repository (Richard, 2020b).

Finally, the bale movement simulation from Richard 2020 (Chapter 2) is utilized to calculate the count of bale movements under the two new alternative marketing frameworks. The exact same routine is run, but now the order in which bales are pulled (based on the substitution routine) is different. This is then combined with the results from Richard 2020b to compare handling costs and calculate a reduction in handling costs from switching to each of the two alternative marketing frameworks respectively.

This procedure is 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 and this is why the individual orders are grouped into sets of 20 for these bale movement comparisons. An explanation of the complexity of order fulfillment is as follows. The "highest" complexity order is an order where the bales are in many different rows and the warehouse is relatively fuller. 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 1 bale movement per bale needed to fulfill the order and no substitution is possible. The bale movements calculated from our previous analysis of warehouse efficiency (Chapter 3) were used to identify orders with the highest, average, and lowest complexity. The justification for this sampling mechanism is based on the principle that an initial economic benefit only needs to be an estimate, and a range provides more meaning to that estimate. If the alternative hypothesis is supported by this initial estimate, further sampling and scrutiny can be pursued.

Results

This study finds potential savings to the cooperative warehouse for implementing the new marketing framework involving substitution of cotton bales previously described. By allowing some bales to be substituted for others based on quality and location, there are less bale movements per bale in an order and thus handling costs are reduced. Table 3.1 describes the range of reduced handling costs under a substitution rate of all criteria at 5%. Table 3.2 describes the range of reduced handling costs under a substitution rate of 2.5% for the most important criteria and 5% for all remaining quality criteria.

Table 3.1. 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%)

Table 3.2. 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%)

Both tested marketing frameworks lead to a reduction of bale movements from the current marketing framework of no substitution. This is true at the highest and the average complexity of order. The lowest complexity order represents the last order in the warehouse and therefore the potential reduction in bale movements was 0. One would expect a linear relationship between the cost reduction and the complexity state of the warehouse (range from full to empty) so the total cost savings per turn shown in the center bottom row of Table 3.2 is likely representative of total savings that could be expected. That value was calculated by multiplying the cost savings per bale when the warehouse was at average complexity by the total number of bales handled over the turn cycle. Under that assumption, around $1.3 million could be saved from adopting the substitution based marketing framework. This finding should be hard for cooperative cotton warehouse members to ignore since they ultimately bear the costs of warehouse operation and they operate in a low profit-margin environment.

Discussion

The cotton supply chain has potential to preserve more value by adopting a systemic marketing framework 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 actually been traded) was taken to determine the range of this economic benefit.

The economic benefit of adopting the alternative marketing framework is determined to be $1,357,421.77, or the benefit from the average order multiplied across the total number of bales handled across the whole turn cycle. (This is for the all criteria substituted within a 5% range scenario.) The value per turn of the warehouse in the second scenario where 2.5% is the substitution rate for color, mic and trash, and all remaining criteria is substituted at 5% is $1,335,086.83. These benefits are passed through to the grower-owners based on the collective decision made by the cooperative.

Understanding the limitations of this study directs the next steps to investigating and developing a formal proposal for this new marketing framework. Limitations to implementing this marketing policy include: the possibility the original bale ordered and the one offered as a counter are owned by two different growers. This causes a "winners and losers" scenario where some growers may be more greatly affected by the marketing framework than others. Perhaps one grower is consistently substituted away from because their bales happen to have poor locations in the warehouse as a function of variables that are not in his control. Discussion around how to address this potential problem is necessary on the front end of attempting to adopt this new marketing framework.

Limitations also include the need to develop a new feature of The Seam that acts as a mechanism for automatically counter-offering bales of a similar quality but more preferred location. It is possible this is a very involved process with heterogeneity across warehouses in terms of how difficult this is to do or how much investment it would take to get each warehouse online. Adjustments would also have to be made to the Cotton Shipping Standard to allow a cotton warehouse to reflect substituted bales in their reports on orders and bales made available for shipment. In conclusion, there are initial reasons to believe further pursuit of an alternative marketing framework involving substitution of bales based on quality and location data is worthwhile. Economic benefits could be realized industry-wide and have a much greater impact than the estimates provided in this analysis because just one warehouse is represented in this sample.

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CHAPTER V

V. CONCLUSIONS

Summary

This chapter provides a summary of the procedures, results, and implications of the research. Cotton is an important crop in the U.S. and an important part of Oklahoma's agricultural economy. This research has focused on warehouse operations in the cotton supply chain. The goal of the research was to identify strategies to reduce warehousing costs. Because most cotton warehouses are organized as farmer owned cooperatives, the identification of potential cost savings could directly benefit the warehouse's grower-owners. This research has examined both potential changes in warehouse operations and changes to the cotton marketing framework.

The cotton supply chain has some characteristics in common with other supply chains but faces some unique logistical challenges. No other supply chain that we can identify has the structure where a particular unit may have to be removed and replaced over a hundred times before it is ultimately selected for removal. That logistical challenge was the focus of this research. While this study's modelling approach was focus on logistical challenges unique to cotton warehouses, there are aspects of the study, including the computer modelling of bale movement which applies to that of other warehouse situations.

The objectives of this study were to identify economic cost savings from reduced bale handling costs at a cooperative cotton warehouse. The sources of these savings were found to include; alternative loading and order fulfillment strategies as well as alternative marketing framework that allow for bale substitution.

The remaining sections of this chapter summarize the specific findings of the research, discuss the conclusions to be made from those findings, and suggest avenues for future researchers in this field to continue efforts related to cooperative cotton warehousing.

Findings

The research had three basic sections. First, Chapter 2 provided a method for modelling activity at the cotton warehouse during order fulfillment. Secondly, Chapter 3 evaluated internal management strategies the warehouse could implement, including loading and order fulfillment methods. Lastly, Chapter 4 tested the impact of allowing substitution of cotton bales based on their quality and location in the warehouse in the marketing framework. Each of these sections has a unique contribution to academic understanding of logistics studies as well as impact for the cooperative cotton warehouse.

Chapter 2 developed a program that simulates the order fulfillment process at the warehouse. Bale quality, ownership, and location data are retrieved and stored in Excel. The described VBA for Excel program accessed that data and yields a count of bale movements needed to break bales out of all the designated stacks and orders. The development of this original program took into account warehouse dimensions and processes and was validated to ensure accuracy.

Chapter 3 identified gin code as the optimal loading strategy, resulting in a $499,013.75 reduction in the cost of handling bales for one full cycle of the warehouse. In terms of order fulfillment, working a larger number of orders simultaneously was shown to reduce costs but also increase the maximum possible time to complete a particular order. The strategy of working 30 orders simultaneously results in a $34,139.19 reduction in bale handling costs relative to working 20 orders at a time. Increasing the number of orders worked simultaneously from 20 to 30 orders also increased the maximum number of days to complete and order from 38 to 56 days.

Chapter 4 tested two different tolerances for quality range allowance when substituting bales. When all criteria of bale characteristics are within 5% of the original bale ordered, a savings of $1,357,421.77 per cycle of the warehouse was found. This means every quality metric of the substituted bales were within 5% of that of the original targeted bale. Next, when the substitution rate for color, mic and trash was within 2.5% and all remaining criteria are required to be within 5%, the cost reduction per turn of the warehouse was $1,335,086.83. This represents a more strict tolerance on quality, but results in a very similar savings to the warehouse.

Altogether, this study not only advances the logistics literature, but also provides evidence to the cotton warehouse in favor of implementation of alternative management strategies and marketing frameworks.

Conclusions

There are some key implications of this study for the cotton supply chain. Cooperative cotton warehouse operators should load their warehouse according to gin code. This strategy results in tangible economic benefits in the form of costs savings derived from reduced bale handling costs. Warehouse managers should also strive to fulfill orders in 30 order groups rather than 20 order groups. This research did not consider every possible strategy for loading and order fulfillment so it is possible that future research will uncover even better strategies. However, both of these recommendations represent a cost savings over current practices.

The current marketing framework in the cotton industry dictates that when a bale is sold on the trading platform, that bale is picked out and shipped from the warehouse. An alternative to this was investigated where substitution of bales based on quality tolerance is allowed. The results indicated substantial cost savings of over $1.3M per warehouse turn which far overshadowed the possible cost savings from alternative loading and order fulfillment strategies. 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. Despite the potential roadblocks, these research results suggest there could be substantial savings from a substitution based framework.

Future Research

There are numerous opportunities to expand this research on improving the efficiency of the cotton marketing chain. Future research on this or similar topics could be greatly enhanced by translating the programs used in this study into another software that can handle greater data processing. An improved programming language, along with enhanced computational power could eliminate the limitation of having to sample from the warehouse but could instead, calculate total bale movements on the entire cycle's worth of data, rather than the single year data used in this study.

Another avenue for future research would be the investigation into how warehouse space should be allocated, given the implementation of alternative loading strategies. This objective dictates how the warehouse should determine how much space is needed per category as well as how many categories are needed for a given criteria. For example, since loading the warehouse based on gin code created the greatest cost savings among the strategies considered in this research, further research is needed to address how much space on the floor of the warehouse to allow for each gin, such that if bales from different gins arrive at the same time, the separate stacks for different gins remain separate throughout the loading process. This could be detailed by using historic data of how much cotton came from each gin.

Also for the loading strategy analysis, future research could investigate the combination of two criteria to determine bale location upon loading the warehouse. For example, loading the warehouse by gin code, but then organizing each gin code section by account number (producer ID) is an alternative strategy that has not yet been investigated. This can be analyzed with this model, but development of the rationale for which attributes should be combined as sorting criteria needs to be done.

For the order fulfillment strategies, a mapping of the trend line starting at 20 orders simultaneously and ending at the 428 orders fulfilled simultaneously could be developed. This study examined both bale movement counts when 20 and 30 orders were grouped for fulfillment. Further testing to determine how much of a reduction in bale handling costs 40, 50, and 60 orders all the way up to working all the orders at once would be beneficial. This is important because then a trend line could be mapped across all possibilities instead of just the two data points identified here in this study. Ideally, after this is done, the trade-off between reduced bale handling costs and time required to fulfill group orders would be understood across all the possible order fulfillment strategies.

Also pertaining to order fulfillment, future research has the ability to make flexible the number of orders to work simultaneously based on how full or empty the warehouse is. This is a logical investigation piece because when the warehouse is more full, the difficulty of fulfilling orders is greater as compared with a less full warehouse. The time required to fulfill orders will change with degrees of fullness, and therefore the optimal number of orders to group while fulfilling should change with that. This idea proposes a more dynamic model where more factors are changing at once.

The last extension of the order fulfillment study is to consider prioritizing the rows entered first upon order fulfillment. In this study, the warehouse was picked through systematically starting with the first row, the second, through to the last row, based on location. Instead, a program and system where certain rows are prioritized and picked from first because individual orders can be filled sooner under this system could exist. This case is where the warehouse is operating strategically to meet shipping standards that are mandated and to keep customers happy. Because there is a real perceived benefit to fulfilling orders this way, a computer model of the problem and strategies could address this nuance.

In order to expand the marketing framework allowing for substitution of cotton bales, more quality tolerance scenarios could be investigated. The scenarios could be more tolerant or less tolerant by changing the range of quality allowed. One scenario in particular could rapidly advance the dialogue of implementing this marketing framework. This is that a quality tolerance of 0% for all quality criteria, or identifying identical bales for substitution may still lead to reduced bale handling costs. This is based off the logic that some bales come from the same module but may end up in different locations, allowing for a difference in handling costs. Also, the quality range could be restricted to one direction. In other words, it could be tested whether a bale is only substituted if it is the same or better quality, how would this impact bale handling costs?

To expand the marketing framework discussion, this study did not consider any specific policy changes that would encompass this substitution-allowed framework. Further development around the specific policy needed to encompass the substitution mechanisms pushes this idea towards a real means of operating the cotton supply chain. Along with that, the means of distribution of costs savings needs to be researched and discussed. If an alternative marketing framework generates or preserves more value from the end consumer for the actors in the cotton supply chain, the distribution of value throughout the chain needs to be well understood before haphazardly adopting, unknowingly creating much more value for some than it does for others.

One additional way this study could be extended is to test what impact reorganizing the bales back into the stack after they have been moved to the aisle based on when they are ordered next has on bale handling costs. The logic behind this idea is when orders are being fulfilled, it is known when the next few orders will be needed, and if sooner order bales are placed towards the outside while later or unknown order bales are placed towards the inside, the stack will then be more organized for the next time it is worked. This greater organization leads to greater efficiency in terms of reduced bale handling costs because you may have to move less non-targeted bales as compared with if the stack were not reorganized according to order dates. All these ideas for future research will enrich the understanding of cooperative cotton warehouse logistics and logistics at large.

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