Logistics Cost Minimization and Inventory Management Decision for Yarn Manufacturers in China

by

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ABSTRACT

Logistics efficiency impacts the profitability of manufacturing companies to a large extent. According to IDC Manufacturing Insights Report of 2014, logistics cost makes up 7.87% of sales of the business. Statistics reveal that the carrying cost in China has been increased to over 3.5 trillion RMB in 2016 accounting for 5.8% of the GDP, i.e. 3% higher than the US. In our case study, the spinning mill business in China has experienced over 10% increase in warehouse and transportation costs in 2017. This study shows that by adjusting the replenishment policy and the transportation planning of cottons and yarns according to their seasonality characteristics of supply and demand, 23% of total logistics cost can be saved for the sponsor company. A multi-period Mixed Integer Linear Programming (MILP) model integrating both inventory management and transportation network of a cross region spinning mill infrastructure is developed for logistics cost minimization. Industrial-wise constraints including the cotton import quota, cotton mixing strategies and seasonality of cotton supplies can be adapted to other spinning mill companies for optimization purpose.
Acknowledgements

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1. Introduction

Cotton yarn spinning is a capital-intensive process industry. The cotton cost accounts for 60-70% of the total cost in a spinning mill (Cotton Incorporated, 2011). By mixing cottons with different properties, spinning mills can produce yarns for multiple functions. For example, cotton with high strength shall be mixed to produce woven yarns that is strong enough to sustain the weaving process. Extra-long-staple (ELS) cotton will be the normal choice for this purpose (Cotton Incorporated, 2003). However, the availability of high quality ELS is scarce because its season is short, 4-5 months. Sourcing and replenishing diverse properties of cottons and ensuring their availability for manufacturing consumption is critical for the spinning mill business. The conventional practice is to hold at least 3 months safety stocks plus the forecasted consumption during the out-of-the-season period.

Different economic factors and business considerations affects the replenishment policy of cotton in spinning mills. As an agricultural commodity, the global supply of cotton is subjected to a high level of uncertainty in spot markets. In 2011, the price of cotton raised from 78 cents per pound to 2.27 dollars in one year due to the national reserve policy of China government (OECD-FAO, 2016), the heavy rain in India and the flooding in Australia as well as Pakistan (Ton, 2011). Many spinning businesses ran into bankruptcy during the season due to the difficulties to remain profitable without reserving cotton at reasonable prices. Regarding the demand from downstream, the success of fast fashion business models (Madhavan, 2014) and the change in buying behavior from bricks-and-mortar to online platform (So, 2017) continuously shrinks the production lead time from a year to a quarter along the entire supply chain in the apparel industry. These factors suggest managers to hold high level of materials and products to withstand the volatile business environments.
Holding a high level of inventory, however, has a huge economic implication in the overall logistics network. Logistics cost makes up 7.87% of sales of the manufacturing business (IDC, 2014). In China, for instance, its impact on the profitability of the business is intensified as the logistics cost multiplied in the recent decade. Statistics from the China Federation of Logistics and Purchasing and National Bureau of Statistics reported that the transportation and carrying cost of logistics have grown from 1.1 and 0.6 to 4.4 and 2.9 trillion in RMB from 2001 to 2011 respectively (Wang L., 2014). Research studies also reported that the carrying cost in China accounts for 5.8% of the GDP, which is 3% higher than U.S. The sponsor company has experienced a 10% and 11% increase in its inventory and transportation expenses in 2017 season costing a total of over six million RMB of storage costs and seven million RMB of transportation costs in South China region. Unfortunately, the low price man-made filament such as polyester has made a high pressure in the pricing of natural fiber products in apparel market. The cost increase in logistics is difficult to absorb through marking up the consumer products (Duijn, 2017), which indirectly harms the overall profitability of the cotton products. Cost control in the supply-side logistics becomes a critical element for apparel companies to maintain profitable in the business (Moon, 1999).

Given the aforementioned challenges in demand uncertainty, cotton supply scarcity, yarn manufacturing complexity and the high pressure in the pricing of yarn products, the objective of this research is to study the optimal replenishment strategy and transportation planning for spinning mill companies in China to minimize the overall logistics cost according to the seasonality characteristics of different types of cotton. We developed an integrated MILP model for the logistics network among a group of spinning mills with industrial specific constraints such as the international import quota of cotton, yarn production capacities, cotton mixing strategies and seasonality of cotton supplies to ensure its practicality and adaptability in the case studies. To our best knowledge, there is no supply-side logistics optimization model proposed in prior literature.
for the spinning industry. The optimized solution found a 23% potential cost saving for the sponsor company in the season 16/17.

The structure of the study is as the following: In Chapter 2, we provide a literature review on the relevant research work in logistics optimization done in different industries. We present the methodology in Chapter 3 to describe the approach employed in this work. We describe the process mapping of the spinning industry and the data collection and preprocessing work made on the gathered corporate data. The optimization model is presented with detailed description on the objective function and the industrial specific constraints formulated. We conduct a case study in Chapter 4 to show how the model saved 23% of the logistics cost of the sponsor company. Sensitivity analysis is conducted in Chapter 5 to exam the impact of spot-prices to the overall logistics cost of the network. Managerial insights and conclusions are provided in Chapter 6.
2. Literature Review

Logistics network optimization considered the inbound logistics of raw materials to warehouses and manufacturers, the quantity consumptions during the transformation process from raw materials to products, and the distribution of products directly from manufacturing plants or finished goods warehouses to customers. There is literature in logistics cost minimizations integrating transportations and inventory management in blending products industries. Koopahi & Kiani (2006) developed a linear programming model for a material replenishing, manufacturing and distribution network to obtain the optimal transportation pattern for a food processing company with the objective to minimize the transportation cost of its supply chain. Farahani, Asgari, Hojabri, & Jaafari, (2009) developed a network optimization model which adds storage expenses into the cost minimization objective. Asgari, Farahani, Rashidi-Bajgan, & Sajadiehd (2013) applied Genetic Algorithm (GA) to solve the linear integer model of a logistics optimization problem for a real-world case which is too large to resolve in a reasonable time in practice. Mogale D. (2017) suggested the Chemical Reaction Optimization algorithm to resolve a large scaled MILP problem for a complex Indian food distribution network. In a manufacturing industry which consumes seasonal crops like yarn manufacturing, the spot market prices of the materials and the opportunity costs of storage spaces are two critical elements affecting the economic value of the overall logistics solution. In this study, we add these two factors into the formulation of our minimization objectives.

The cotton mixing techniques for economy production has been actively studied in textile industry. Zhang, et al., (2011) proposed a multi-objective optimization model to find the optimal blending ratio of cotton in yarn production. Das, Ghosh, & Banerjee (2013) developed a fuzzy optimization model to maximize the strength of yarn with minimum quality of cotton for economic considerations. Sharma (2014) suggested the empirical formula to mix cotton for the optimal yarn
quality. However, the works reviewed before merely focused on specific properties of yarn that could not cover a wide spectrum of products we needed in this study. In practice, the considerations in cotton mixing are much more sophisticated that properties such as the color grade, maturity and also the production routing cannot be ignored. While the deduction of mixing formula is not the focus of this study our model formulates the mixing ratio of cottons in different yarn products into linear constraints for optimization purpose without exploiting the detail correlations of yarn and cotton properties. To handle the high volume of production recipe and product catalogs, we group the products into 17 classes and 48 sets of cotton mixing recipes based on their compositions to minimize the problem space.

Optimizing the logistics network of the yarn spinning industry requires a thorough consideration to all business constraints along the material flow. These constraints include the cotton procurement, domestic policies in cotton trading, the cost structure of warehouses and transportation, the consumptions of cotton in yarn production, the capacity of the logistics infrastructure and finally the downstream demand of yarn along the season. The main contribution of this work is to fill the gaps between prior logistics optimization research with the industry-specific policies and considerations to make the optimization result applicable to the spinning industry in China. Such gaps include the spot prices of cotton, the import quota of the Chinese government, the rules of cotton mixing in spinning process and the opportunity costs of cotton inventory. The optimization framework can be used as a tool to guide the replenishment decision of the cotton sourcing personnel in practice. In the next chapter, we describe the methodology of this work.
3. Methodology

3.1 Overview

This section gives the overview of our research methodology. Although our study was conducted in the sponsor company, discussions with the interviewee were set at the industrial level to remain the genericity of the results. Figure 1 illustrates the major steps described below.

Figure 1 Methodology

In step 1, we understood the end-to-end business process of the cotton and yarns lifecycle in the spinning mill operations and identified the key constraints and considerations of the stakeholders in the chain. Interview sessions were conducted with the corresponding department managers and staff to obtain the key decision points and their relevant considerations and constraints. Operational process specific to the company was not in our interest. Six aspects of the process covered in the interviews include: (a) forecast of cotton consumption by the sales and technical department in each spinning mills; (b) the cotton procurement process by the sourcing department; (c) the transportation and warehouse management by the logistics department; (d) the order processing practice in the spinning mill; (e) The cotton mixing techniques and technical design
decisions relevant to the cotton sourcing by the spinning mill technicians; (f) The transportation and delivery practice of cotton and yarn.

In step 2, we obtained the list of costing drivers and their corresponding unit rate at that period. We gathered basic information about the logistics network and facilities such as the storage capacities of warehouses and production capacities of spinning mills, types of cottons and yarn product categories. Current statistics about yarn orders, consumption of cotton, inventory level of cottons and yarn products, operation expenses of logistics facilities and services were obtained as well. Collected data were analyzed to detect abnormalities. Data cleansing was performed and outliers were discarded. All data were formatted into csv format for optimization purpose.

In step 3, we formulated the MILP model based on the business constraints and the logistics network of the spinning industry. We implemented the MILP model with python for Gurobi optimizer. The mixing recipes and yarn product catalogs were re-grouped and consolidated into 17 product items to minimize the problem space. All data were formatted into csv file for execution purpose.

In Step 4, we analyzed the optimization result of the case study by comparing the total logistics cost and inventory levels with the current performance. To understand the impact of cotton prices to the logistics cost, we ran sensitivity analysis with different degree of price increase for the two key cottons, namely ELS and Upland.

In the next session, we provide the detail finding of the business process mapping and data collection and pre-processing.
3.2 Business Process Mapping

The industrial practice of the relevant business processes was described in this session. The decision points described along the process were consolidated from the senior practitioners in this industry.

3.2.1 Consumption Forecasting and Replenishment

Figure 2 Consumption Forecasting and Replenishment Flow

Figure 2 shows the flow of the decision points to be made for cotton replenishment. Consumption Forecasting initiates the whole logistics process. Cotton is a seasonal commodity harvested from August and December every year in Mainland China and other exporting countries such as India and US. Exceptions like Australia starts around May. Before August, companies will start forecasting the cotton consumptions for the upcoming season and plan for the sourcing strategies. The conventional practice in the industry is to base their estimations on the consumption level of last years. Advices from the spinning mills about the upcoming trends in the yarn market and their implication to the cotton demand will be evaluated. A certain percentage increase will be added or subtracted from last year’s consumption as the procurement target. Procurement Planning shall be made to meet the procurement target. Sourcing department will follow the forecasted annual consumption for each grade and type of cottons to conduct purchasing when the cotton becomes available for ordering from the suppliers. In China, the total amount of cottons that can be import from oversea suppliers are subjected to an annual quota granted by the Chinese government every year (Stephen, Gale, & Hansen, 2015). Cotton sourced from domestic suppliers are not in the limitation. Decisions will be made in this period on the amount of different cotton types to be acquired from external or internal sites.
Contracts are established with the suppliers including the transportation to the inbound port. For companies who owned cotton farms such as the sponsor company in this study, a farming plan of the species and quantity of cotton to be seeded will be determined with spinning mills and yarn sales one year ahead when seeds were planted.

The lead time of cotton delivery are around 3 months in usual. For these reason, the spinning mills will set their safety stock level at 3-month upcoming consumptions at least. During the season, any additional needs of cotton will be updated for replenishment. Considerations to the cotton market prices and the quality yield of the season will be a key factor to consider the sourcing strategies.

To achieve their sourcing target with the best quality cotton at a reasonable price, sourcing personnel usually prefer to buy cotton at the early stage based on the annual estimation. Cotton are stored in the warehouse for annual consumptions. Dedicated employee in each spinning mill will review the stock level of cotton every month to ensure safety stock level are met. Replenishment will be made through domestic vendors when stock levels are drop below the reordering level.

3.2.2 Logistics from Supplier to Warehouse, Production and Fabric Mills

Figure 3 shows the decision points for cotton storage and yarn production. Oversea suppliers delivered cotton to the requested inbound port for collection. Domestic suppliers required the company to arrange pick up from the exchange warehouses. Upon receiving the arrival notice, spinning mills will contact the transportation company to arrange the logistics of cotton from the arrival port or the exchange warehouse to their warehouses or to the spinning mills directly. For example, the spinning mills of the sponsor company can hold around 3 weeks of consumptions. Different truck transportation will offer different prices and truckload for the transportations. The price of train transportations is standardized country-wise in China. For cottons to be put in external inventories, a list of handling charge will need to be paid such as train/truck entrance fees,
weigh-in weigh-out fees and stock handling fees. For internal owned warehouses, annual expenses are distributed to the spinning mills based on their average stock level of the corresponding seasons. Cotton bales will be managed by the logistics department after stock-in until they were needed for manufacturing. In the meantime, Warehouse personnel makes periodical stock take to the cotton inventory. The stock level of cottons is recorded and shared with the production planning department in the spinning mill for review. If the stock level drops below the reorder points (i.e. 3-5 months of safety stock level), ordering request will be submitted by the spinning mill to the sourcing department for replenishment.

Upon order arrival, the technical departments will define the cotton mixing plan of the requested product for resource booking. Cotton is collected from the corresponding warehouse to the spinning mill for production based on the material booking and mixing plan for spinning. Finished goods will stock in the yarn warehouse for delivery to fabric mills. In low season, core products will be manufactured and stocked in the warehouse for future demand. The handling charge of yarn in rental warehouses is similar to that of cottons.

The main transportation mode of cotton is train and truck. Often, train would be chosen to transport cotton from the inbound port to the warehouse due to their lower price for high volume transfer. Trucks are the key transportation mode for the transfer of cotton between warehouse and the spinning mills in smaller amounts. For yarn transportation, only trucks will be used to better protect their finished conditions. The transportation and storage of cotton and yarns are managed by a separated logistics and warehouse department usually.
3.2.3 Mixing of Cotton in Yarn Production

Different properties of yarn are spun for different fabrication purpose. For example, yarns for producing woven fabric needs high strength to sustain the weaving process. Also, yarn with a finer touch is used for premium weaving products. These requirements determine that a high proportion of cottons with high strengths and micronairs shall be used. Other requirements such as the color of the fabric will also determine what brightness and yellowness of cotton can be used. Such mixing recipe is a key element allowing us to associate the consumption of cotton types with different yarn products. The list of critical cotton properties contributing to the quality of the yarn is quoted in Table 1 (Sharma, 2014).

**Table 1 Critical properties of cotton fiber in mixing plan**

<table>
<thead>
<tr>
<th>Critical Properties of Cotton Fiber</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Measured in inch or in mm.</td>
</tr>
<tr>
<td>Fineness</td>
<td>Measured in micronairs. i.e. Weight of fiber in microgram per inch.</td>
</tr>
<tr>
<td>Strength</td>
<td>Force to break the fiber bundle. Measured in Gms per tex.</td>
</tr>
<tr>
<td>Maturity</td>
<td>Measured in maturity coefficient or in maturity ratio. The greater the maturity, the better the absorbency and retention.</td>
</tr>
<tr>
<td>Uniformity</td>
<td>The ratio between the mean length and the upper half mean length of the fibers. Measured in percentage.</td>
</tr>
<tr>
<td>Short Fiber Content</td>
<td>Measured in percentage.</td>
</tr>
<tr>
<td>Trash Content</td>
<td>Measured in percentage.</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Moisture Content</th>
<th>Measured in percentage.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brightness</td>
<td>Represents as Rd value against degree of reflection.</td>
</tr>
<tr>
<td>Yellowness</td>
<td>Represents as +b value.</td>
</tr>
<tr>
<td>Colour Grade</td>
<td>Conjunction of Rd and +b value.</td>
</tr>
</tbody>
</table>

The composition of yarn in the cotton mixing plan can be described with a simplified example in Figure 4. CF50s compact yarn shall comply with 90% cotton in ELS quality and 10% cotton in Upland quality. That 90% ELS quality cotton can use Pima GC2-2 or Xinjiang 137. The other 10% upland cotton can use Xinjiang 3128B or Australia SM. In practice, the ELS quality cotton has superior quality in terms of strength, length and fineness. They could be used to compose the whole yarn when there is a shortage of inventory in upland cotton. However, this results in higher material costs of the final product because ELS usually cost 30% more than upland.

![Figure 4 Cotton composition of a yarn product](image)

### 3.3 Logistics Network

A generic logistic network is built to model the flow of materials across the supply chain of the spinning mill. Figure 5 illustrates the topology of the network. The model has five layers, namely, the supplier layer, the cotton storage layer, the production layer, the yarn storage layer and the customer layer. Supplier layer contains the node at which the ownership of cotton is transferred to the company. The cotton storage layer contains warehouses that store cottons. The production layer
contains spinning mills that transform cotton into yarns. The yarn storage layer contains warehouses that store yarns. The customers layer contains customers where the ownership of the yarns is transferred out from the manufacturing company. The demand of yarns is initiated at the customer layer. Our model starts from the suppliers layer. Overseas cottons arrive at inbound ports. Upon arrival, cottons are either transported directly to the spinning mill or stored in warehouses.

There are two types of warehouses. The rental one charges in terms of storage volume and the owned one constitutes a fixed costed every year unless they are shutdown. Cotton arrived in production plan will be transformed into yarn product and stored in the finished goods warehouses.

Two modes of transportation, train and truck, are considered for cotton transportations. For yarn, only truck transportation is considered to prevent yarns from damage by the train. Customers who placed orders receive the yarn product accordingly.

Each layer may contain multiple facilities at different locations. Subjected to different costs and capacities, both cotton and yarn will be transferred among different warehouses for economic advantages.

Figure 5 Five layers of logistics network in spinning mills
3.4 Assumptions

We present the assumptions we setup in this model to quantify the relevant characteristics of the supply chain at the right level of detail for the optimization purpose. This allows us to abstract the un-necessary detail and noise in actual practice.

- The storage areas of spinning mills and fabric mills are only a staging area for cotton to be consumed in the production line. Such storage area in the spinning mill is not appropriate for long term storage. Their sizes are varying in different spinning mill but in general, a period of consumption shall be allowed.

- No loss of cotton during the transportation. An insignificant amount of cotton might be consumed during the transportation. In this model, we do not take this into account.

- Following the conventional material requirement and warehouse stock taking practice, data points are collected in monthly basis. To align with the granularity of this strategic planning view, we took one month as the appropriate length of a planning period.

- Some of the transportation paths between warehouses are not valid in the conventional practice while it is locally making sense in a cost minimization model. For those non-existing paths, we assume their costs are the same for other factories at the same area.

3.5 Model Formulation

This section presents the MILP of the 5 layers logistic networks we developed in this study for optimization purpose. The key elements in the supply chains are modeled as a set of indexes in the mathematical formations. For example, the list of cotton types we modeled are presented as an integer C. Parameters are input data that describes the configuration of the logistics network. For example, the transportation costs between different places form a matrix of number. Decision
Variables are the values we are looking for in this optimization work. The objective defines the cost function of the whole logistics network to be minimized and finally the constraints are the conditions where the value of the variables in the solution must be satisfied such as the capacity of the warehouses. We explain each of these elements in the following subsections. This formulation is implemented in Python for execution to optimize the logistic networks in our case studies.

### 3.5.1 Sets and indices

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c \in C$</td>
<td>Cotton type such as XJ 137 / Giza 86 / US SJV Acala SM</td>
</tr>
<tr>
<td>$y \in Y$</td>
<td>Yarn product type such as 50-100s N single</td>
</tr>
<tr>
<td>$s \in S$</td>
<td>Cotton supplier such as J. G. Boswell for oversea cotton or AEA&amp;AEC for corporate cotton</td>
</tr>
<tr>
<td>$l \in L$</td>
<td>Inbound port/inland location of the cotton such as Xinjiang port, Wuzhou port, Gao Ming port for oversea cotton</td>
</tr>
<tr>
<td>$m \in M$</td>
<td>Spinning mills</td>
</tr>
<tr>
<td>$a \in A$</td>
<td>Cotton warehouses</td>
</tr>
<tr>
<td>$b \in B$</td>
<td>Yarn warehouses</td>
</tr>
<tr>
<td>$f \in F$</td>
<td>Fabric mills</td>
</tr>
<tr>
<td>$g \in G$</td>
<td>Mode of transportation</td>
</tr>
<tr>
<td>$t \in T$</td>
<td>Period $t$ of the cotton season</td>
</tr>
<tr>
<td>$r \in R$</td>
<td>Required cotton properties in different products. For example, some yarn need Organic Pima cotton. Some yarn needs ELS with a strength above a certain level of a certain maturity level. Different company developed their specific set of requirements for their products based on their experience.</td>
</tr>
</tbody>
</table>
### 3.5.2 Parameters

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$max_{cst}$</td>
<td>The amount of cotton $c$ available for purchases from supplier $s$ at period $t$.</td>
</tr>
<tr>
<td>$d_{dfy}$</td>
<td>The order of yarn $y$ from fabric mill $f$ at period $t$.</td>
</tr>
<tr>
<td>$cd_{myr}$</td>
<td>The mixing ratio of cotton satisfying requirement $r$ in yarn $y$ at period $t$ in spinning mill $m$.</td>
</tr>
<tr>
<td></td>
<td>E.g.</td>
</tr>
<tr>
<td></td>
<td>Yarn 1 (50-100s A1 single twist) requires a distribution of ELS=95%, Upland=5%, Organic_ELS=0%, Organic_Upland=0%</td>
</tr>
<tr>
<td></td>
<td>$cd_{11}=0.95; cd_{12}=0.05; cd_{13}=0.00; cd_{14}=0.00$</td>
</tr>
<tr>
<td>$cca_{mcr}$</td>
<td>The cotton $c$ satisfies the requirement set $r$ at period $t$ in spinning mill $m$. It is a binary variable that if $c$ satisfies $r$, it is 1 or otherwise 0.</td>
</tr>
<tr>
<td>$u_{my}$</td>
<td>Material utilization for producing yarn $y$ at spinning mill $m$ at period $t$.</td>
</tr>
<tr>
<td>$cap_m$</td>
<td>Monthly production capacity of spinning mill $m$.</td>
</tr>
<tr>
<td>$hc_a$</td>
<td>The holding cost of cotton at warehouse $a$.</td>
</tr>
<tr>
<td>$hy_b$</td>
<td>The holding cost for yarn at warehouse $b$.</td>
</tr>
<tr>
<td>$hccap_a$</td>
<td>The holding capacity of cotton warehouse $a$.</td>
</tr>
<tr>
<td>$hycap_b$</td>
<td>The holding capacity of yarn warehouse $b$.</td>
</tr>
<tr>
<td>$hcf_a$</td>
<td>The fix cost of cotton warehouse $a$.</td>
</tr>
<tr>
<td>$hyf_b$</td>
<td>The fix cost of yarn warehouse $b$.</td>
</tr>
<tr>
<td>$p_{cst}$</td>
<td>The purchase cost per tons of cotton $c$ from supplier $s$ at period $t$.</td>
</tr>
<tr>
<td>$tc_{sw_{lga}}$</td>
<td>Transportation cost per ton of cotton from inbound location $l$ to cotton warehouse $a$ in mode $g$ at period $t$.</td>
</tr>
<tr>
<td>Notation</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>$\text{tc}<em>{\text{sm}}</em>{l \rightarrow m}$</td>
<td>Transportation cost per ton of cotton from inbound location $l$ to spinning mill $m$ in mode $g$ at period $t$.</td>
</tr>
<tr>
<td>$\text{tc}<em>{\text{ww}}</em>{a1 \rightarrow a2}$</td>
<td>Transportation cost per ton of cotton from cotton warehouse $a1$ to cotton warehouse $a2$ in mode $g$ at period $t$.</td>
</tr>
<tr>
<td>$\text{tc}<em>{\text{wm}}</em>{a \rightarrow m}$</td>
<td>Transportation cost per ton of cotton from cotton warehouse $a$ to spinning mill $m$ in mode $g$ at period $t$.</td>
</tr>
<tr>
<td>$\text{ty}<em>{\text{mw}}</em>{m \rightarrow b}$</td>
<td>Transportation cost per ton of yarn from spinning mill $m$ to yarn warehouse $b$ in mode $g$ at period $t$.</td>
</tr>
<tr>
<td>$\text{ty}<em>{\text{mf}}</em>{m \rightarrow f}$</td>
<td>Transportation cost per ton of yarn from spinning mill $m$ to fabric mill $f$ in mode $g$ at period $t$.</td>
</tr>
<tr>
<td>$\text{ty}<em>{\text{wf}}</em>{b \rightarrow f}$</td>
<td>Transportation cost per ton of yarn from yarn warehouse $b$ to fabric mill $f$ in mode $g$ at period $t$.</td>
</tr>
</tbody>
</table>
| $\text{oppc}_{a}$ | The opportunity cost for holding 1 ton of cotton in corporate-owned cotton warehouse $a$.  
  i.e. The difference between the amount of money we saved to store 1 ton of cotton ahead for usage and the amount of money we saved from its storage cost plus the amount we can earn by investing that money. |
| $\text{oppy}_{b}$ | The opportunity cost for holding 1 ton of yarn in corporate-owned cotton warehouse $b$.  
  i.e. The difference between the amount of money we saved to store 1 ton of yarn ahead for usage and the amount of money we saved from its storage cost plus the amount we can earn by investing that money. |
| $\text{oc}_{cs}$ | The ordering cost of cotton $c$ from supplier $s$ |
| $q$ | Import quota of oversea cotton |

3.5.3 Decision Variables

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{xe}<em>{\text{mw}}</em>{m \rightarrow b}$</td>
<td>Amount of yarn $y$ (tons) transfer from spinning mill $m$ to yarn warehouse $b$ through transportation mode $g$ at period $t$.</td>
</tr>
</tbody>
</table>
\[ xe_{mf}^{tgymf} \] Amount of yarn \( y \) (tons) transfer from spinning mill \( m \) to fabric mill \( f \) through transportation mode \( g \) at period \( t \).

\[ xe_{wf}^{tgybf} \] Amount of yarn \( y \) (tons) transfer from yarn warehouse \( b \) to fabric mill \( f \) through transportation mode \( g \) at period \( t \).

\[ xc_{sw}^{tgcsfa} \] Amount of cotton \( c \) (tons) transfer from source \( s \) arriving at inbound location \( l \) to cotton warehouse \( a \) through transportation mode \( g \) at period \( t \).

\[ xc_{ww}^{tgcsfa2} \] Amount of cotton \( c \) (tons) transfer from cotton warehouse \( a1 \) to cotton warehouse \( a2 \) through transportation mode \( g \) at period \( t \).

\[ xp_{wm}^{tgrcum} \] Amount of cotton \( c \) (tons) transfer from cotton warehouse \( a \) to spinning mill \( m \) to full-fill the production requirement \( r \) through transportation mode \( g \) at period \( t \).

\[ xp_{sm}^{tgrcslm} \] Amount of cotton \( c \) (tons) transfer from source \( s \) arriving at inbound location \( l \) to spinning mill \( m \) to fulfill the production requirement \( r \) through transportation mode \( g \) at period \( t \).

\[ IC_{atc} \] The amount of cotton \( c \) in cotton warehouse \( a \) at the end of period \( t \).

\[ IY_{bty} \] The amount of yarn \( y \) in yarn warehouse \( b \) at the end of period \( t \).

\[ OF_{tsc} \] The binary variable designating a non-zero ordering of cotton \( c \) from the supplier \( s \) at period \( t \).

\[ OA_{a} \] The binary variable designating the use of cotton warehouse \( a \).

\[ OB_{b} \] The binary variable designating the use of yarn warehouse \( b \).

### 3.5.4 Objective

\[
\text{Min } Z = \sum_{c \in C, s \in S, t \in T} \sum_{g \in G} \left( \sum_{a \in A, l \in L} xc_{sw}^{tgcsfa} + \sum_{r \in R, m \in M, t \in T} xp_{sm}^{tgrcslm} \right) \times p_{ct} + \sum_{c \in C, s \in S, t \in T} OF_{ts} \times oc_{cs} + \\
\sum_{a \in A, t \in T, c \in C} IC_{atc} \times hc_{a} + \sum_{b \in B, t \in T, y \in Y} IY_{bty} \times hy_{b} + \sum_{a \in A, t \in T, c \in C} IC_{atc} \times oppc_{a} + \sum_{b \in B, t \in T, y \in Y} IY_{bty} \times oppy_{b} + \\
\sum_{a \in A} OA_{a} \times hcf_{a} + \sum_{b \in B} OB_{b} \times hyf_{b} + \sum_{l \in L, m \in M, t \in T, r \in R, c \in C, g \in G} xp_{sm}^{tgrcslm} \times tc_{sm}^{tgfm} +
\]
\[
\sum_{a \in A, m \in M, c \in C, t \in T} x_{p - w_{tgcam}} \times t_{c - w_{nagm}} + \sum_{a \in A, l \in L, c \in C, m \in S} x_{c - s_{lgcma}} \times t_{c - s_{lga}} + \\
\sum_{a, a' \in A, c \in C} x_{c - w_{tgcaf}} \times t_{c - w_{nagal}} + \\
\sum_{m \in M, b \in B, y \in Y} x_{e - m_{gymb}} \times t_{y - m_{gbmf}} + \sum_{m \in M, f \in F, y \in Y} x_{e - m_{gymf}} \times t_{y - m_{nfgf}} + \\
\sum_{b \in B, f \in F, y \in Y} x_{e - m_{gbf}} \times t_{y - w_{bgf}} \quad (1)
\]

The objective functions define the total relevant cost of the logistics network to be minimized. It contains: (i) the total cost of cotton purchased from different suppliers (ii) the ordering cost in each purchase (iii) the holding cost of all cottons and yarns during (iv) the opportunity cost of occupying the warehouses for storing cotton and yarns (v) the total cost of transportation for cotton and yarn and (vi) the fixed cost of operating the cotton and yarn warehouses.

The total cost of cotton is equal to the spot market price of the cotton multiply by total amount ordered. The holding cost of cotton and yarn is equal to the holding cost of cotton per tons multiply by the total number of tons stored in the warehouses in each period. The opportunity cost is equal to the rental rate of the warehouse multiply by the tons of cotton and yarns we stored. In other words, it represents how much the company is losing if the storage spaces are rent out for incomes. The total cost of transportation are the expenses in transporting cottons and yarns between different places in the logistic networks. The fixed cost of warehouses are the depreciations and other fixed expenses to support the operation of the warehouses in every period. The company will not be charged on the fixed cost if no storage is assigned for the whole year.
3.5.5 Constraints

- Demand Constraint: Each customer has a demand on yarn products to be delivered for its needs. This constraint ensures that the logistics network transport enough amount of yarn either from the spinning mills or from the yarn warehouses to satisfy its demand in all periods.

\[
\sum_{g \in G, m \in M} xe_{- mf_{gymf}} + \sum_{g \in G, be \in B} xe_{- wf_{gymbf}} \geq d_{gy} \quad \forall y \in Y, t \in T, f \in F \quad (2)
\]

- Supply Constraint: Some of the suppliers such as the farmer owned by the corporate have a limitation on the amount of cotton that it can yield in each year. This constraint ensures that the company cannot buy more than the supplier can be yielded in all periods.

\[
\sum_{g \in G, re \in A, le \in L} xc_{- sw_{gcsle}} + \sum_{g \in G, re \in R, me \in M, le \in L} xp_{- sm_{tgrcslm}} \leq maxc_{ext} \quad \forall s \in S, c \in C, t \in T \quad (3)
\]

- Supply Constraint: There is an annual quota on the amount of cottons that the spinning mill can be imported from overseas. This constraint ensures that the company did not buy more that it is allowed by the annual quota.

\[
\sum_{g \in G, re \in A, re \in T, re \in C, se \in S, le \in L} xc_{- sw_{gcsle}} + \sum_{g \in G, re \in R, re \in T, me \in M, re \in C, se \in S, le \in L} xp_{- sm_{tgrcslm}} \leq q \quad (4)
\]

- Manufacturing Capacity Constraint: Each spinning mill plant has a certain production capacity. This constraint ensures that the spinning mill \( m \) produce within its monthly production capacity

\[
\sum_{g \in G, ye \in Y, be \in B} xe_{- mw_{gymb}} + \sum_{g \in G, ye \in Y, f \in F} xe_{- mf_{gymf}} \leq cap_{m} \quad \forall i \in M, t \in T \quad (5)
\]
- Storage Capacity Constraint: Cotton warehouse has a maximum capacity of cotton it can stored in any given period. This constraint ensures that the logistics network does not transport cotton into the warehouse that is more than it can hold for all periods.

\[
\sum_{c \in C} IC_{wc} \leq hccap_a \forall a \in A, t \in T \quad (6)
\]

- Storage Capacity Constraint: Yarn warehouse has a maximum capacity of yarn it can stored in any given period. This constraint ensures that the logistics network does not transport yarn into the warehouse that is more than it can hold for all periods.

\[
\sum_{y \in Y} IY_{wc} \leq hycap_b \forall b \in B, t \in T \quad (7)
\]

- Blending Constraint: Each yarn product has a recipe defining what properties of cotton and their proportion is needed in the spinning process. This constraint ensures that the amount of cotton consumed for producing the yarn products are in the proper proportion as required for the spinning process:

\[
\sum_{g \in G, c \in C, a \in A} xp_{-wm} + \sum_{g \in G, c \in C, s \in S, l \in L} xp_{-sm}\n_{gr\text{csl}m} = \sum_{g \in G, f \in F, y \in Y} (xe_{-mf_{tgym} \times cd_{myr} \times u_y}) + \sum_{g \in G, b \in B, y \in Y} (xe_{-mw_{tgym} \times cd_{myr} \times u_y})
\forall m \in M, r \in R, t \in T \quad (8)
\]

- Blending Constraint: Several types of cotton may also carry the required properties for spinning purpose. This constraint ensures that cottons without the required properties cannot be used in the spinning process.

\[
\sum_{g \in G, c \in C, a \in A} xp_{-wm} + \sum_{g \in G, c \in C, a \in A} xp_{-sm} \leq cca_{mr} \times \text{BigNum}
\forall c \in C, r \in R, m \in M, t \in T \quad (9)
\]
• Stock Flow Constraint: The total amount of cotton stock in and stored in cotton warehouse shall not be more than the amount it can stock out in all period. This constraint ensures that the amount of cotton left at the end of last period and the cotton stock in this period equals to the amount of cotton left at the end of this period and the amount of cotton stock out in this period.

\[
\sum_{g \in G, m \in S, le \in L} xc - sw_{gca} + \sum_{g \in G, a \in A} xc - w_{gca} + IC_{t+ac} \\
= \sum_{g \in G, r \in R, m \in M} xp - w_{gca} + \sum_{g \in G, a \in A} xc - w_{gca} + IC_{tac} \\
\forall a \in A, c \in C, t \in T \quad (10)
\]

• Stock Flow Constraint: The total amount of yarn stock in and stored in yarn warehouse shall not be more than the amount it can stock out in all period. This constraint ensures that the amount of yarn left at the end of last period and the yarn stock in this period equals to the amount of yarn left at the end of this period and the amount of yarn stock out in this period.

\[
\sum_{g \in G, m \in M} xe - mw_{gb} + \sum_{g \in G, b \in B} xe - w_{gb} + IY_{t,by} = \sum_{g \in G, f \in F} xe - w_{gb} + \sum_{g \in G, b \in B} xe - w_{gb} + IY_{t,by} \\
\forall b \in B, y \in Y, t \in T \quad (11)
\]

• Linking constraint: This constraint ensures that OF is cannot be zero when an order is made to a cotton supplier in any period. When it is one, ordering cost shall be charged in the objective function.

\[
\sum_{g \in G, a \in A, le \in L} xc - sw_{gca} + \sum_{g \in G, m \in M, re \in R, le \in L} xp - sm_{gca} \leq OF_{tac} \times \text{BigNum} \\
\forall c \in C, s \in S, t \in T \quad (12)
\]
• Linking constraint: This constraint ensures that OA is cannot be zero if it stored cotton in any period. When it is one, fixed cost of the cotton warehouse shall be charged in the objective function.

\[ \sum_{c \in C, t \in T} IC_{atc} \leq OA_a \times \text{BigNum} \quad \forall a \in A \ (13) \]

• Linking constraint: This constraint ensures that OB is cannot be zero if it stored yarn in any period. When it is one, fixed cost of the yarn warehouse shall be charged in the objective function.

\[ \sum_{y \in Y, t \in T} IY_{byt} \leq OB_b \times \text{BigNum} \quad \forall b \in B \ (14) \]

• Variables are non-negative numbers

\[
\begin{align*}
xe_{\_mw} & \geq 0 \\
xe_{\_mf} & \geq 0 \\
xw_{\_tgbf} & \geq 0 \\
xw_{\_tgbh2} & \geq 0 \\
xc_{\_sw} & \geq 0 \\
xc_{\_swtgb2} & \geq 0 \\
xw_{\_tgca1} & \geq 0 \\
xp_{\_wm} & \geq 0 \\
xp_{\_sm} & \geq 0 \\
IC_{atc}, IY_{byt} & \geq 0 \\
OF_{tsc}, OA_a, OB_b & \in \{0,1\}
\end{align*}
\]
4. Case Studies

4.1 Company Background

The sponsor company in this case study have five cotton yarn spinning mills in 3 major cities in China. Figure 6 shows the annual procurement of cotton from season 02/03 to 16/17. In the season 16/17, over 28.4k tons of cotton yarn is produced for 384 customers including its woven and knit fabric mills in Guangdong area. The annual procurement of cotton has been increased from 15k tons to over 31.6k tons.

Being one of the top men’s woven and knit shirt exporter in China, the company consumes over 8k tons of ELS cotton annually for yarn production. The projected cotton consumption is expected around 20-30% for the launch of two new spinning mills by the end of 2019. Catering the seasonality of cottons, the conventional strategy of cotton replenishment is to build up the inventory early in the first half of the season to support the annual consumptions. In season 16/17, the maximum inventory level of cotton is at 30k tons (Figure 7) and 1.4k tons for yarn (Figure 8).
Maintaining such level of inventory costing the company for a total of RMB$16.9 MM. According to the finance department, the growth of warehouse costing was at 4-6% in the last 3 seasons. Experienced the stagnated growth of the apparel business in recent years, the company launched several initiatives to revisit and redesign the current way of operations to strengthen the profitability and effectiveness of production planning and supply chain design. The objective in this case study was to find out how the replenishment policy and the storage location of cotton and yarn could be optimized to reduce the total logistics cost under the current infrastructure setup and business constraints.

The MILP model developed in Chapter 3 was adopted to the logistics network of the company for the optimization. The logistics network of the company was illustrating in Figure 9 with a summary in Table 2. Cottons were purchased from domestic suppliers, corporate farmers. Overseas cotton was received from three inbound ports. Cottons were stored in seven cotton warehouses in which five of them were corporate owned while two were rented. Received cotton were transported either by truck or train depending on the distance and cost provided by the logistics service provider. Five spinning mills owned by the company are in three major cities of China. The yarn products were either stored in the yarn warehouses or delivered to the customers directly. Only truck was taken for the transportation of yarn to protect its quality. Setting the season 16/17 as the benchmark for this study, all 7,820 orders received in the season is obtained for optimization.
Cottons and yarns are regrouped into five types and seventeen types respectively to reduce the problem spaces without affecting the total consumption of cotton required. For the consolidated seventeen types of yarn products, eight class of properties requirement in cotton was defined. The five-month safety stock requirements setup by the company is adopted. In the season 16/17, the company had been granted 4,426 tons of import quota.

Figure 9 Logistics network of the case study company

Table 2 Detail information about the logistics network of the company

<table>
<thead>
<tr>
<th>Network Configurations</th>
<th>Planning Configurations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inbound locations: 5</td>
<td>Planning period: 12 months (Season 16/17)</td>
</tr>
<tr>
<td>Cotton suppliers: 7</td>
<td>Types of cotton: 5</td>
</tr>
<tr>
<td>Cotton warehouses: 6</td>
<td>Types of yarn: 17</td>
</tr>
<tr>
<td>Spinning mills: 5</td>
<td>Properties required in mixing plan: 8</td>
</tr>
<tr>
<td>Yarn warehouses: 7</td>
<td>Number of orders: 7820</td>
</tr>
<tr>
<td>Customers/Fabric mills: 6</td>
<td>Cotton import quota (Season 16/17): 4426 tons</td>
</tr>
<tr>
<td>Mode of transportation: 2 (train/truck)</td>
<td>Safety stock level: 5 months</td>
</tr>
</tbody>
</table>
4.2 Server Configuration

The optimization model is implemented with Python v3.6.3 with gurobipy modules. The model is solved by the Gurobi Optimizer under educational license obtained directly from its corporate website: http://www.gurobi.com/downloads/download-center. The model is run on a Lenovo computer equipped with Intel CORE i7 vPro processor and 8GB of physical memory with Windows 10.

4.3 Data Collection & Pre-Processing

Current data from the latest complete season of 16/17 starting from August 2016 to July 2017 is collected for the study. These data include: (i) relevant costs in transportation and storage from logistics department, (ii) the consumption of different types of cotton in different products from the consumption records in spinning mills (iii) the manufacturing capacities of different spinning mills from the production planning department and (iv) the storage capacities of different warehouses from the logistics department.

Transactional data including the product demand, the cotton consumptions per yarn product and Current inventory level are extracted from the application database of the ERP systems. Because the recipe for cotton mixing in different yarn products is highly confidential to the business, in this study we obtained the estimation by averaging the Current consumption of cotton for each yarn product recorded in system database.

Relevant costs in transportation are consolidated by the logistics department based on the actual price list from the service provider in season 16/17. Some of the transportation path is absent in today's operations. To retain the optimization possibilities, the logistic cost of some absent but logical transportation paths were estimated based on the existing path with close proximity in both starts and destinations.
Manufacturing capacities are collected from the production planning managers at each spinning mill. Technically, each type of products consumes different loadings. To keep the problem space manageable, the standard loading consumption commonly shared across spinning mills for building master production planning is employed.

4.4 Result

The data file (in csv format) of parameters was prepared as described in section 4.3 and loaded into the python environment for execution. The optimization result is obtained with an objective bound within 0.02%.

![Inventory Level of Cotton in Season 16/17](image)

**Figure 10 Optimized inventory level of cotton**

Figure 10 shows the comparison of the inventory level of cotton along the season before and after optimization. Table 3 provided the summary of the optimization result. Comparing with the current cost in season 16/17, the optimized solution saves RMB $8.16m (23%) of the total logistics cost. By relocating the yarn products in other warehouses, two yarn warehouses at city area are suggested to close: TPE_Yarn_W, TongTian_Yarn_W. Looking into the costing factors, the optimized solution has a higher ordering cost and transportation cost but with a much lower inventory level for both
cotton and yarn. The higher ordering cost in the optimized solution suggests that cottons are ordered in smaller chunks and more frequent than the current practice.

Table 3 Current logistics cost vs. optimized logistics cost

<table>
<thead>
<tr>
<th>Season 16/17</th>
<th>Current Cost (RMB$,000)</th>
<th>Optimized Cost (RMB$,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordering Cost</td>
<td>1.9</td>
<td>2.9</td>
</tr>
<tr>
<td>Holding Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Cotton</td>
<td>16,947</td>
<td>4,000</td>
</tr>
<tr>
<td>- Yarn</td>
<td></td>
<td>1,080</td>
</tr>
<tr>
<td>Transportation Cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Cotton</td>
<td>18,000</td>
<td>7,400</td>
</tr>
<tr>
<td>- Yarn</td>
<td></td>
<td>14,306</td>
</tr>
<tr>
<td>Total Logistics Cost</td>
<td>34,948.9</td>
<td>26,788.9</td>
</tr>
</tbody>
</table>

Figure 11 and 12 show the comparison of total annual cost of inventory, transportation and purchased cotton before and after optimization. We see that the optimized solution expense higher in transportation cost but has much saving in inventory and cotton purchase. Less cotton is purchased in the optimized model shows that the historic inventory level is more than it needs. Notes that both the historic practice and optimization model also carries 5-months safety stocks to ensure the sourcing department has plenty of time for cotton replenishment in case a certain cotton type is fall under the re-order point. Normal lead-time to order cotton is 3 months.
Review the volume comparison in Figure 13, we can find the average stock level of both cotton and yarn has been decreased by 40-50% in the optimized solution. In terms of transportation, the optimized solution cost RMB$2.7m more than the Current expenses. The higher transportation cost is expected to cover the extra distances needed for closing warehouses in the optimized solution. In the next section, we examine the distribution of these cost in detail and analyze how cost are saved.
4.5 Cost Distribution in the Optimized Solution

Table 4 shows the cost breakdown of the logistic network. In the RMB$4.9m storage costs, RMB$3.99 m (80.47%) is expended in storing cotton while yarn accounts for the other RMB$0.97 m (19.53%). Comparing the expenses distribution for cotton and yarn warehouses, Cotton storage in city area contributes only 55.15% of expenses while yarn storages in city area made 88.63% of the storage expenses. This aligns with the business needs where yarn products shall be located at the South China region that closer to the fabric mills and external customers. For the 5-month safety stocks, it would be wiser to store in rural area distribute it when they are needed.

Table 4 Cost breakdown of cotton warehouse in optimized solution

<table>
<thead>
<tr>
<th>Cotton Warehouse (Optimized)</th>
<th>Subtotal (RMB$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rural Area</strong></td>
<td></td>
</tr>
<tr>
<td>CJIE_Cotton_W</td>
<td>927,670</td>
</tr>
<tr>
<td>XJE_Cotton_W</td>
<td>473,128</td>
</tr>
<tr>
<td>TPE_Cotton_W</td>
<td>393,103</td>
</tr>
<tr>
<td><strong>City Area</strong></td>
<td></td>
</tr>
<tr>
<td>CNRCC_Cotton_W</td>
<td>874,359</td>
</tr>
<tr>
<td>GLS_Cotton_W</td>
<td>35,478</td>
</tr>
<tr>
<td>TongTian_Cotton_W</td>
<td>1,295,920</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3,999,659</td>
</tr>
</tbody>
</table>
In terms of cotton storage, TongTian_Cotton_W accounts for 32.4% of the total cotton inventory cost. This warehouse is rented in the city area with unit storage cost 70% higher than that of the CNCRC_Cotton_W. The sponsor company is investigating the possibility to consolidate the rented warehouses to a centralized self-owned one with other business units of the same company.

Table 5 Cost breakdown of yarn warehouses in optimized solution

<table>
<thead>
<tr>
<th>Yarn Warehouse (Optimized)</th>
<th>Subtotal (RMB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rural Area</strong></td>
<td></td>
</tr>
<tr>
<td>CJE_Yarn_W</td>
<td>59,885</td>
</tr>
<tr>
<td>TPE_Yarn_W</td>
<td>-</td>
</tr>
<tr>
<td>XJE_Yarn_W</td>
<td>50,477</td>
</tr>
<tr>
<td><strong>City Area</strong></td>
<td></td>
</tr>
<tr>
<td>TongTian_Yarn_W</td>
<td>-</td>
</tr>
<tr>
<td>XiAn_Yarn_W</td>
<td>160,256</td>
</tr>
<tr>
<td>GLS_Yarn_W</td>
<td>73,783</td>
</tr>
<tr>
<td>GES_Yarn_W</td>
<td>736,021</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,080,424</td>
</tr>
</tbody>
</table>

For the breakdown of yarn storage given in Table 5, GES_Yarn_W accounts for 68.12% of the yarn inventory cost. Comparing with other spinning mill, GES produce over 90% of specialty yarn products. Higher inventory level is required to support its wide product catalog while its production capacity is only 20% of the total capacities. In next section, we will explore further about the source of savings.
4.6 Inventory Management in Optimized Model

The key cost saving in the optimized model are contributed from effectively lowering the stock level of both cotton and yarn. As a result, two warehouses can be closed. In this section, we explain the replenishment pattern of the optimized model. Figure 14 below provides the current inventory level of cotton warehouses in season 16/17.

ELS cottons are the main material stored in the warehouses. In the current inventory level of cotton as illustrated in Figure 14, XJ ELS starts to rise from October 16 to Mar 17 from 4,876.5 tons to 16,652.8 tons. Similarly, the purchase of XJ Upland also takes a similar approach. The inventory of XJ Upland starts to rise from 3,957.3 tons to 9,596 tons between October 16 to Feb 17.

Figure 14 Current cotton inventory level - Season 16/17
Figure 15 illustrated the optimized cotton inventory. In contrast, the optimized model takes a more mild approach in cotton replenishment. Comparing with the current ELS inventory level, we can see that the optimized model do not ramp up ELS cotton for off-season usage until Jan 2017. That is three months before the high quality ELS cotton becomes rare in the market but also 3 months after they became available in this season.

The replenishment of upland (Figure 16) also shows an interesting pattern in the optimized model. Current inventory level of XJ Upland shows that replenishment starts at Oct 2016 all the way until Feb 2017. Comparatively, the optimized model (Figure 17) does not replenish XJ Upland as long as the inventory has more than 5 months of safety stock levels for forecast consumption until Nov 2016. Considering the fact that the availability of the upland cotton covered almost the full year, the inventory level are controlled under 5,000 tons while the current inventory goes up to 9,000 tons at Feb 2017. Figure 16 shows a clearer picture on the replenishment of cottons along the season. We see that no all types of cotton are replenished due to the reason that there are only small amount of them is replenished or there are enough of those replenished in last year which can fulfill the needs in this season.
Regarding the inventory level of yarn product, if we compare the envelop of the current inventory level (Figure 18) with that of the order fulfillment pattern (Figure 19), we can see that the conventional approach attempts to maintain a certain level of yarn stocks to align with the demand pattern of the products. In the contrary, the optimized model (Figure 20) focus in minimizing the stocking of two main products CF501 and CF802. Their productions are shift towards the Just-in-time approach where they are produced according to the demand and shipped without leaving inventory. This reduces a large amount of inventory required for finished. Two yarn warehouses, namely TongTian_Yarn_W and TPE_Yarn_W can be closed.
Figure 18 Current yarn inventory in season 16/17

Figure 19 Order fulfillment of products in season 16/17

Figure 20 Optimized yarn inventory in season 16/17
5. Sensitivity Analysis

In this section, sensitivity analysis is conducted to see how inventory cost response to the spot market price of cotton and the charging of warehouses in different areas.

5.1 The Price of the Cotton

The price of cotton in spot market is one of the key factors affecting the replenishment decision of manufacturing materials. When managers expect a rise in material prices, they place orders as early as possible to secure the production needs. However, this comes into a huge economic consequence in inventory management. According to the statistics quoted by the company (Figure 21), the price of ELS cotton has been topped at RMB 35,000/tons at Jan 2014 while the US Pima has been to RMB 31,739/tons at November 2014. The lowest price was reached around the end of Aug 2016 at RMB 23,912/tons (diff. 32.7%) and RMB 21,000/tons (diff. 66.6%) for US Pima and China ELS respectively.

![Figure 21 ELS price trend since Jan 2014 to Sep 2017](image)

At about the same period, the price of upland cotton (Figure 22) has also been topped at RMB 15230/tons for import from overseas and topped at RMB 20,204/tons for import from domestic
suppliers. Comparing with the lowest price in Mar 2016 at RMB 10234/tons and RMB 12271/tons, there are 48.8% and 64.6% difference.

Based on the current trend of spot market price of ELS and Upland cottons in both domestic and foreign markets, we setup the sensitivity analysis with both ELS (XJ ELS, US Pima) and Upland (XJ upland, US Upland) by linearly increasing and decreasing their price towards the end of the the season ranging between -60% and 60%.

### 5.2 ELS Cotton Price

Figure 23 illustrated the sensitivity of the inventory cost to the price of ELS cottons including XJ ELS, US Pima and Giza 86 from -60% to 60% towards the end of the season. As the price of cotton rises in a larger extent, the optimized model purchase ELS earlier to minimize the impact of price increase despite the increase in total inventory cost. In particular, the cost of cotton inventory is increased by RMB$257,000 (5.0%) and the cost of yarn inventory is increased by RMB$261,000 (27.4%) contributing to an overall increase of 8.6% in total cost when the spot price increases 10% towards the end of the season. To the other end, when the spot price of the cotton drops 10%, the cost of cotton inventory is decreased by RMB$593,000 (9.8%) and the cost of yarn inventory is decreased by RMB$7,000 (0.7%).
Comparing the inventory level of cotton with (Figure 24) and without (Figure 15) the increase of spot price, it is more economical to build up cotton inventory as early as Nov 2016 if the spot price of cotton rises above 10%. This case applies to all ELS cottons which has limited availability for its high quality.

However, the increase in inventory cost becomes much less after 10%. The earliest period that we can receive ELS cotton for production is at Nov 2017 and we cannot further push the procurement
of ELS cotton to an earlier period to off-set the change in cotton price. Therefore, we do not see further trade-off can be done at the inventory cost to gain further advantages in compensating the price increase.

Observation has been made to the operation of the warehouses as well. Table 6 shows the warehouses that can become idle in the scenarios. The cotton warehouse 2 (GLS_Cotton_W) can be closed in most of the circumstances. Yarn warehouse 3 (Tongtian_Yarn_W) gives a better economic value to be closed when inventory level can be decreased while warehouse 4 (TPE_Yarn_W) is the second warehouse to be closed. This is a sensible choice because location of the Tongtian Yarn inventory is closed to the city center and that the XiAn warehouse is located close enough to absorb its storage capacity. In the other way, when the price of the ELS cotton went down, it becomes more economical to stock cotton later for saving the total inventory cost.

Table 6 Cotton and Yarn warehouses usage in sensitivity analysis

<table>
<thead>
<tr>
<th>Types</th>
<th>Increase</th>
<th>Cotton WH Closed</th>
<th>Yarn WH Closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELS</td>
<td>-60%</td>
<td></td>
<td>3,4</td>
</tr>
<tr>
<td>ELS</td>
<td>-40%</td>
<td>2</td>
<td>3,4</td>
</tr>
<tr>
<td>ELS</td>
<td>-20%</td>
<td></td>
<td>3,4</td>
</tr>
<tr>
<td>ELS</td>
<td>-10%</td>
<td>2</td>
<td>3,4</td>
</tr>
<tr>
<td>ELS</td>
<td>0%</td>
<td>2</td>
<td>3,4</td>
</tr>
<tr>
<td>ELS</td>
<td>10%</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>ELS</td>
<td>20%</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>ELS</td>
<td>40%</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>ELS</td>
<td>60%</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Upland</td>
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<td>2</td>
<td>3,4</td>
</tr>
<tr>
<td>Upland</td>
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<td>2</td>
<td>3,4</td>
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<td>Upland</td>
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<td>3</td>
</tr>
<tr>
<td>Upland</td>
<td>60%</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>
5.3 Upland Cotton Price

The change of spot price in upland cotton contributes a similar effect to the upland inventory cost. As seen in the cotton inventory diagram in Figure 25, when the spot price of the upland cotton rises by 10%, it is more economic to build up cotton inventory as early as in July 2016 to absorb the increase in price.

![Figure 25 Optimized cotton inventory when spot price increase by 10%](image)

Price change of upland cotton has a less impact to the inventory cost than that of ELS cotton. Illustrated in Figure 26, when the price of upland cotton rises by 10%, the cost of cotton inventory increased by RMB$395,000 (7.8%) and the yarn inventory is increased by RMB$100,000 (10.5%). It results in an overall increase of 8.2% in total inventory cost in order to hold the cotton purchased at lower prices. Such increase in inventory cost becomes less after 10% because the increase of inventory cost by purchasing more cotton at earlier time cannot be compensated by the saved cost in purchasing cheaper cotton. To the other end, when the spot price of the cotton drops 10%, the cost of cotton inventory is decreased by RMB$971,000 (19.2%) and the cost of yarn inventory is increased by RMB$55,000 (5.8%).
5.4 Discussion

Table 7 summarizes the impact of spot price on the total inventory cost of cotton. When the spot price of cotton is expected to increase, it is economically more reasonable to replenish the cotton at an earlier time even though it results in a higher cost of inventory. The increase in inventory cost is compensated by the gain of buying cotton at a lower price at an earlier time. However, there is a large quantity of cotton purchased for the consumption in the second half of the season for ELS cotton. Such quantity has a larger impact on the overall increase in the inventory cost. This impact becomes greater when higher demand is needed at the later time of the season. Therefore, the optimal time of replenishment shall be determined by both the speculative increase of spot price as well as the projected demand pattern of cotton in the season. Making the cotton replenishment of the annual demand at the beginning of the season is not always economically justifiable.

Table 7 Change of total inventory cost when spot price of cotton change

<table>
<thead>
<tr>
<th>Change in Spot Price</th>
<th>Total inventory cost (Price change in ELS)</th>
<th>Total inventory cost (Price change in Upland)</th>
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<td></td>
<td></td>
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</tbody>
</table>
Comparing the degree of increase between ELS and Upland cotton in Table 7, we observe that the cost of inventory is more sensitive to the price increase of ELS cotton than that of upland cotton. In particular, the inventory cost is increased by 8.6% for 10% increase of ELS cotton while the increase in inventory cost is only by 8.2% for 10% increase of upland cotton. Such a difference is caused by the seasonality and the price difference between ELS and Upland cotton. ELS is in general more suitable for many kinds of yarn due to its better properties in length, fineness and strength. As a result, it can be used in producing more types of yarn than upland cotton. Its price in spot market is in general higher most of the time. Secondly, ELS has a higher seasonality over the upland cotton. The availability of high quality ELS usually ends around March. Therefore, most of the demand in the second half needs to be sourced in the first half and put into stock while upland cotton is available for the whole season. Therefore, the demand of upland cotton in the second half can gain more in minimizing the inventory cost when they are purchased in the second half of the season. As a result, we observe a less change in inventory cost when the spot price of upland cotton is increased.

The optimization model developed in Chapter 4 can provide a vigorous and quantitative view for the company to determine the optimal point of replenishment of different types of cotton given the current spot price, the speculative price increase/decrease and the forecast demand of yarn products or cotton consumption throughout the season. In addition, the sensitivity test showed that the current logistics network has its limitation in absorbing all economic impact to the total cost
when the price changes beyond a certain limit. The company can make use of the quantified result to justify more proactive action to increase the robustness of their logistics network when a more drastic fluctuation in price is projected. These actions can include: (i) readjusting the committed volume of rental spaces for cotton storage based on the speculative price forecasted at the beginning of the season, (ii) strengthening the long-term relationship with the supplier to improve the real-time information transparency on the availability and selling status of the cotton types which is highly seasonal in the market and (iii) leveraging financial tools and futures to offset the impact of price increase that cannot be absorbed by early storage. Increasing the committed volume of the rental spaces provides an extra buffer in the logistics network to offset the price fluctuations. Understanding the latest selling status from the supplier about the highly seasonal cotton allows the sourcing personnel to react to actual availability of the cotton rather than making decisions on emotional judgement by general comments from the market. The company can be more innovative in taking proactive measures to increase the robustness of their supply chain against the drastic change in the supplier market.
6. Conclusion

In this project, we developed an integrated MILP model for the logistics network among a group of spinning mills. The main contribution of this work is to fill the gaps between the prior optimization research in logistics and the spinning industry in China by formulating the industry-specific policies and business considerations in practice to make the optimization result more valuable for business decision making. These gaps include the spot prices of cotton, the import quota of the Chinese government, the rules of cotton mixing in spinning process and the opportunity costs of cotton inventory. Industry-specific constraints including the international import quota of cotton, yarn production capacities, cotton mixing strategies and seasonality of cotton supplies are introduced to adopt the real business situations in the China spinning industry. The optimization framework can be used as a tool to guide the replenishment decision of the cotton sourcing personnel in practice. The model was applied to the sponsor company to find how the replenishment time of cotton can be fine-tuned based on the seasonality of different types of cotton to optimize the total logistics cost for the spinning mills. We demonstrated that a company can obtain 23% logistics cost saving every year by different replenishment strategies. The conventional practice in the industry attempted to source cotton at the beginning of the season for the whole year consumptions. While the current practice provides extra amount of time for sourcing personnel to purchase high quality cotton, in this quantitative study, we reviewed the economic implications of this practice and showed that different replenishment options can be taken according to the scarcity of the cotton types. For high quality ELS cotton, its availability in the market is limited and replenishment can be made with 2-3 months before it ran out in the first half of the season. For upland cotton which is available throughout the year, maintaining a 5-month safety stock of the forecast demand would be enough to ensure the manufacturing needs. In this case study, we show that adopting this demand driven approach allows us to reduce the average inventory level of cotton by 40.9% and the same of yarn
inventory by 48.2%. Two warehouses for storing yarn products have opportunities to be consolidated with other warehouses at a close region. Further discussion and study shall be made with the logistics department to explore the implementation details in practice.

The methodology and the optimization model can be extended in the future work to study the logistics cost impact on (i) the future government policy in national cotton supply such as cost subsidies in sourcing domestic cotton from Xinjiang; (ii) the latest transportation policy which limits the maximum lot size of truckload transportations; (iii) the cost consideration of different master production plans implied by the optimized result and (iv) the distribution of safety risk when cottons of the same type are stored in the same warehouses. Since the spot price of the cotton is one of the key factors in the optimization consideration, future study can explore enhancing the model to adopt the stochastic nature of the price to reflect the probabilistic nature of price forecasting to improve the robustness of the optimization result.
References


