A GENERAL DECISION SUPPORT SYSTEM FOR SCHEDULING JOBS ON MULTI-PORT DYEING MACHINES

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ABSTRACT

Much attention is currently being paid in the academic literature to the subject of Decision Support Systems (DSS). Recent studies show that the use of a DSS, coupled with user process knowledge, improves decision results over that which can be attained from the separate use of the process knowledge and the DSS. In addition, the use of the analytical tools in DSS provides a means of improving the effectiveness of decision making in the process of comparing alternatives. In this paper we show how manufacturing processes and information flow can be integrated to provide a framework for the development of a DSS in a specific textile manufacturing environment.

Keywords: Decision support systems, linear programming, operations management

INTRODUCTION

Several factors have contributed to the increased acceptance of DSS for a wide variety of application domains (5). The user-friendliness and ease in which to navigate features of graphical-user-interfaces (GUI) have minimized user anxiety, while the phenomenal strides made in CPU speeds have facilitated the development of model driven DSS. This in turn streamlines the process of comparing and choosing from alternatives. In this paper we discuss the development of a comprehensive DSS for a textile manufacturing environment.

Typically the origins of the problem start at the headquarters where an aggregate capacity planning system prioritizes and groups the incoming customer orders on a weekly basis. These groups of orders known as dye-lots are then scheduled for processing at specific plants with specific due dates mainly based on aggregate plant capacities. At the plant level, operators struggle to maximize the number of dye-lots processed on a daily basis. Industry practices reveal a number of non-standard approaches being used for the scheduling and loading of multi-port dye machines. Also, these practices tend to depend heavily on operators' judgment and manual calculations. A number of firms cite “specific needs” as the principal reason for their individual approaches (4). Some firms restrict their dyeing to a single fabric strand per port thus under utilize their machines, while others load multiple strands to a given port but risk color inconsistencies. Also, the policies for allowable strand length differences, within and across ports, vary from firm to firm. These and other policy differences represent some of the “specific needs” that are most often cited as reasons for the multiple approaches used by piece-dye firms for machine scheduling and loading. An additional reason for multiple approaches is grounded in the fact that many small firms see the computer-based decision support systems as being beyond their level of computing power and sophistication and assume that these systems would add more cost than value to their particular operations. The many different industry practices for dye
machine scheduling and loading point to the need for a common solution approach. The approach must be comprehensive, flexible and user-friendly. The solution needs to be PC-based, requiring little in the way of computer sophistication. Lastly, the solution ought to be adaptable to firms of all sizes and degrees of complexity.

A Brief Overview of Adding Color to Textiles

There are a number of processes to add color to textile fabrics. These fabric dyeing (coloring) processes are technology specific to the production cost and quality requirements of the end products being produced. One group of dyeing process technology is used to dye the textile fabrics that are formed into apparel products for athletic warm-up suits, sweat shirts, jackets, and pants. A widely used technology for dyeing these fabrics is the multiple port, multiple strand pressure-dyeing machine. These machines bathe long lengths of fabric, sewn together to form strands, in a single dye mixture that is specific to a given machine. Each strand length of fabric is passed through the dye mixture by a device that pulls the length through the bath, as a continuous loop on multiple passes, until the correct color has been imparted to the fabric's total length. For any given machine, each different fabric strand (continuous loop) is assigned to a machine port (a machine port is a subdivision of a pressure-dyeing machine that contains the necessary devices to pull long strands through the dye bath.) Each dyeing machine can accommodate single or multiple strands of fabric within the same port. All strands in all machine ports share the same total dye bath liquid and pressure conditions for the given machine. The number of strands a single machine can accommodate is the product of the number of machine ports and the number of strands per port. Many firms maintain machines with varying numbers of machine ports. The same firms maintain small volume machines with minimal numbers of ports to accommodate small lot size requirements and large volume machines with a large number of ports to accommodate large lot size dyeing requirements. Thus a typical firm will schedule a dye machine capacity proportional to the number of machines, the number of machine ports per machine and the number of strands per port.

Generally fabric from the dye-lots will be formed into shirts, jackets and pants where, for example in sweatshirts, the sleeves must have the same color attributes as the body of the shirt. Shirt color attributes must match those of the pants, jacket, etc. Also, the total machine load must contain the correct proportion of different width construction fabrics that will result in the production of some number of complete apparel units with colors that match. This additional restriction often requires strand lengths for a given machine port out of different fabric constructions and widths. For example, in the production of a sweatshirt the fabric for the shirt body requires a different width than the fabric used for the sleeves. The fabric for the collar and waistband is of different width and construction than that used for the body and sleeves, etc. For these cases where a strand of fabric in a given port contains different fabric widths and fabric constructions, since different widths and constructions of fabric have different weights per unit length, it is possible that a standard length strand of fabric in one port could have a significant weight difference from a different strand of a similar length in a different port.

Strands are formed out of fabric width/construction rolls that reside in fabric roll inventory. At any point in time these rolls are of varying sizes (weights) within a given fabric width/construction. Roll size varies in production for a given fabric width/construction and any
given roll may have previously been partially used to produce a previous machine dyeing schedule. In forming a strand of fabric for a given port the firm creates the length weight that is required from several rolls of fabric. When rolls are not completely used in either forming a given port strand, or for some different port strand of the machine load, the remaining length/weight of the roll is returned to inventory.

Global competition coupled with customers' ever increasing demands for improved quality, customization, and shorter delivery lead times require textile firms, like other globally competitive firms, to optimize their operations. Usually this process demands smaller runs with a multitude of dyeing conditions. Short-term profits for the typical piece-dyer are subject to critical limitations of available dye machines, fabrics, technical labor skill, and customer requirements for specific dye-lot mixes of multiple stock-keeping units (SKUs). Hence, firms’ long-term successes largely depend on optimal or near optimal scheduling and processing of customers’ dye orders (for in-depth and non-technical discussions of these issues please refer to (3)). The problems in this domain appear to be perfect candidates for OR techniques. Although the industry has long recognized the need for decision support systems in this domain, specialized and often proprietary nature of these operations together with a multitude of interactive variables have prohibited the development of general-purpose solutions. Recently, the advent of powerful PCs, the availability of rapid application development software together with inexpensive and easy-to-use solvers have brought down the computational and economic barriers of developing DSS.

MATHEMATICAL MODELS FOR THE DSS

The DSS is composed of three phases. At each phase, a model optimizes a specific objective and the results are passed to the next model. Briefly, in the first phase we maximize machine utilization whereas in the second phase we minimize waist, and in the third phase we minimize material handling operations. The following notation is used in the models:

\[ N = \text{Number of (unique) jobs in a given dye order} \]
\[ P = \text{Number of ports} \]
\[ NS = \text{Number of strands per port} \]
\[ WP_{\text{max}} = \text{Maximum weight per port} \]
\[ TP_i = \text{Total pounds of fabric for job } i \]
\[ U_{kj} = \text{Total pounds of SKU}_j \text{ in job } i \]
\[ y_j = \text{Number of yards per pound of SKU}_j \]
\[ SP_{s,p} = \text{Total weight of the fabric strand } s \text{ assigned to port } p \]
\[ SL_{s,p} = \text{Total strand length assigned to strand } s \text{ of port } p \]
\[ w_{s,p,i,j} = \text{Pounds of SKU}_j \text{ from job } i \text{ allocated to strand } s \text{ of port } p \]
\[ m_i = \text{Binary variable, 1 if job } i \text{ is selected, 0 otherwise} \]

Phase I: Machine Utilization

Physical limits, processing norms and trade conditions place restrictions on the loading of a given dye machine. Some of these restrictions include the physical limits of dye machines limit the number of machine ports to P and the number of fabric strands per port to NS, and the
maximum weight limitations per port. Also, for color consistency fabric strand lengths within ports and strand lengths across ports must be of approximately similar lengths. Thus, the length difference between any two fabric strands can not exceed a given maximum number of yards. However, standard processing practices dictate that different job numbers not be allocated to the same fabric strand number. Thus, one fabric strand is associated with one and only one job number. The total pound weigh allocated to the strands of a given port can not exceed some maximum value. An additional fabric handling restriction requires that all strand lengths must be formed from ever increasing or ever decreasing fabric, SKU widths. The above general restrictions are incorporated into the first phase of the DSS as a linear programming (LP) formulation as shown below:

\[
\begin{align*}
\text{Max} & \quad \sum_{s} \sum_{p} \sum_{i} \sum_{j} w_{s,p,i,j} \\
\text{S.T.} & \quad \sum_{s} \sum_{p} \sum_{j} w_{s,p,i,j} = T P_i m_j \quad \forall i \\
& \quad \sum_{i} \sum_{j} \sum_{s} w_{s,p,i,j} \leq WP_{\text{max}} \quad \forall p \\
& \quad \sum_{i} \sum_{j} y_j w_{s,p,i,j} - \sum_{i} \sum_{j} y_j w_{s,p,i,j} \leq d_{\text{max}} \quad \forall s, p \\
& \quad w_{s,p,i,j} \geq 0 \quad \text{and} \quad m_j = 0/1
\end{align*}
\]

An optimal solution to the above linear programming formulation is one that maximizes dye machine utilization. The optimal solution maximizes the dye order pounds loaded on any given dye machine. The above LP formulation guarantees an optimal solution as long as there is enough total fabric material per SKU to satisfy the demand per dye order. If it is given that sufficient material exists, then the output of the LP solution is a machine load profile which returns output values for the decision variable \( w_{s,p,i,j} \) in units of pounds of SKU \( j \), on job \( i \), assigned to fabric strand \( s \), in machine port \( p \). Output is converted to yards by the conversion factor \( y_j \), yards per pound for the \( j^{th} \) SKU.

**Phase II: Material Usage**

Material to meet the specified machine-load profile exists in the form of fabric roll inventory. These rolls of fabric may be of various sizes, measured in pounds, for a given SKU. Thus, a dye machine load may be composed of multiple rolls of fabric of different weights per SKU where the sum of the weights of the individual rolls must be equal to or greater than the total job requirements for the given SKU. For example, if \( R_{r,j} \) is the weight in pounds of the \( r^{th} \) selected fabric roll of the \( j^{th} \) SKU for the \( i^{th} \) job then \( \sum_{r} R_{r,j} \geq U_{i,j} \) for all \( i, j \) where the sum of the individual selected roll weights for the \( j^{th} \) SKU satisfies the SKU weight requirements for the \( i^{th} \) job. The fabric roll selection process may vary from application to application. Firms with automated inventory retrieval systems may, for example, opt to choose rolls using a "picking strategy" that minimizes fabric roll retrieval delays. Other firms may opt to use a linear programming approach that minimizes excess fabric roll poundage sent to the plant floor via the following. Let \( R_{r,j} \) be the roll weight for roll \( r \) of SKU \( j \) and \( u_{i,j} \) is a binary variable to determine which rolls to pick in order to minimize the excess weight (EW) per SKU. Then,
\[
\begin{align*}
\text{Min} & \quad \sum_{i} \sum_{j} EW_{i,j} \\
\text{S.T.} & \quad \sum_{r} R_{r,j} q_{i,j} - U_{i,j} = EW_{i,j} \quad \forall i, j \\
& \quad q_{ij} = 0/1
\end{align*}
\] (6) (7) (8)

Whatever the strategy for fabric roll selection, Phase II for dye machine scheduling and loading is the process of determining fabric roll availability to support a given job and the selection of rolls to complete that job with minimum excess weight.

**Phase III: Strand Forming for Machine Port Loading**

Given the machine load profile from the Phase I linear programming solution, and the fabric rolls selected from inventory in Phase II, strand forming for machine port loading becomes the final critical step in the dye machine scheduling and loading process. For this last phase of the machine scheduling and loading process, Phase III, the goal is to develop a solution for the proper sequencing of the fabric rolls as fabric strands for each of the machine ports. The solution should minimize manual operations on the plant floor and the solution output should provide operators with "user-friendly" instructions as how to carry out the strand forming for each machine port on the plant floor. "User-friendly" instructions are those which tell operators at the turn-poles the number of pounds to extract from each selected roll and the order of sewing these roll extracts, to form a given strand for a given machine port. Here, the input for each strand-port has been predetermined in Phase II for each job SKU. Instructions that provide for the turn-pole operators the fraction of each fabric roll allocated to each strand-port, coupled with the restrictions that strands must be sewn across SKUs in increasing or decreasing widths, meet the Phase III requirements for machine port loading. The LP formulation for this phase is:

\[
\begin{align*}
\text{Min} & \quad \sum_{r} \sum_{j} E_{r,j} \\
\sum_{r} \sum_{j} R_{r,j} x_{r,j,s,p} = w_{s,p,i,j} & \quad \forall i, j, s, p \\
R_{r,j} - \sum_{s} \sum_{p} R_{r,j} x_{r,j,s,p} = E_{r,j} & \quad \forall r, j \\
x_{r,j,s,p} & \geq 0
\end{align*}
\] (9) (10) (11) (12)

where:

- \( E_{r,j} \) = roll pounds not allocated to any strand and port,
- \( R_{r,j} \) = weight in pounds of the \( r \)th selected fabric roll of the \( i \)th SKU for the \( j \)th job,
- \( x_{r,j,s,p} \) = fraction of roll \( R_{r,j} \) allocated to the \( s \)th strand of the \( p \)th machine port.

With the output from the above Phase III LP formulation all information is now available to provide instructions to the strand forming, turn-pole operators and complete the machine port loading part of the process. The number of pounds taken from the \( r \)th roll of SKU \( j \) and allocated to the \( s \)th strand in the \( p \)th port is defined as: \( R_{r,j} x_{r,j,s,p} \) for all \( r, j, s, \) and \( p \).
Thus, in the strand forming process \( R_{r,j} \times_{r,1,p} \) pounds are extracted from roll \( r \) of SKU \( j \), as part of the material used in developing strand \( s \) in port \( p \). Any remaining pounds on the \( r \)th roll are "set aside" to be used in developing other strands for other ports within the Phase II machine loading solution. These totals are given to the turn-pole operators and are sequenced from broad to narrow width SKUs or from narrow to broad width SKUs.

**SYSTEM CHARACTERISTICS**

A typical three-phase system of the type outlined in this paper contains a user-friendly interface between the operator and the scheduling and loading system. The process of scheduling a dye order begins with an operator choosing a dye order number from a list of open dye orders via the user interface on a PC screen. Once the dye order number is entered the Phase I processor uses the associated dye order requirements data for its fabric roll selection process. The Phase I processor receives the dye order requirements and fabric roll data from the roll inventory database as inputs to the Phase I system. This input data feeds a roll selection algorithm, such as the LP formulation for roll selection described earlier in this paper. This algorithm is contained within the Phase I system as a software component of the system. The output from the algorithm returns a list of reserved fabric rolls that will be used in the processing of the confirmed dye order number. If adequate fabric rolls are available to process the entered dye order, the operator then confirms or cancels the dye order number’s processing. Confirmation of the dye order processing generates a “picking” order for the selected rolls. A cancellation of the dye order number’s processing takes the rolls off reserve and makes them available to other dye order scheduling. Once a dye order is confirmed the Phase II processor generates a machine load for that order. Inputs for Phase II include the processing and fabric parameter data associated with the given dye order number and any processing restrictions associated with the order. Here, depending on the system design, the operator may be allowed to input processing restrictions (maximum strand weights, maximum strand yard differences, etc.) via the user interface, or these restrictions may be hard-coded and not accessible to the volition of the operator. All input data, is fed into the Phase II algorithm, such as the LP formulation for port loading described earlier in this paper, and the output from the algorithm is the machine load profile, used for machine scheduling and loading. Once the machine load profile has been developed in Phase II, this profile and the selected fabric rolls from Phase I are used as data inputs to the Phase III processor. The Phase III processor takes these inputs and generates the fabric strands for each machine port, using an algorithm such as the strand forming LP formulation described in this paper.

The system architecture required to implement the above three-phase system is lacking in complexity and may be designed around a variety of client/server assumptions. A standard database management system that provides input to any of a number of linear and integer programming software packages are minimal systems requirements for implementation of the scheduling and loading applications. The system can easily be built to respond to all but very rare data errors which are discovered on the shop floor, corrected and handled either by substitution on the shop floor or by rerunning the scheduling system with corrected data.
SUMMARY AND CONCLUSIONS

The multiple approaches used by firms to solve scheduling and loading problems for multi-port, pressure-beck dyeing, points to the need for a comprehensive, general-purpose approach to these problems. A fully integrated dye order processing system that meets the general-purpose needs of a wide range of piece dyeing firms is needed.

The decision support system outlined in this paper meets the requirements as a general-purpose solution process for the scheduling and loading of multi-port, pressure beck, dyeing operations. It is comprehensive, yet flexible enough to meet the needs of a wide range of firm operational complexity. The major contribution of this DSS is the elimination of spot decisions by turn-pole operators concerning how fabric rolls should be sewn together to build the fabric strands for each dye machine port load. The greater precision of strand forming and machine loading generated from the DSS leads to significant processing and cost improvements. These include; lead time reductions, repeatability of the dyeing process, improvements in labor and dye machine productivity, and reductions in materials and handling costs.

The DSS offers a user-friendly, flexible, approach to the scheduling and machine-loading problem. The approach allows the piece dyer the options of running the system as a totally automated scheduling and loading system, or running the system as a "what if ?" decision aid tool, under the total control of a manual decision-maker. Because the approach is PC-based, it requires little in the way of computer sophistication and is easily adaptable to firms of all sizes and degrees of complexity.

REFERENCES