DYNAMIC, SINGLE-STAGE, MULTI-PERIOD, CAPCITATED PRODUCTION SEQUENCING PROBLEM WITH MULTIPLE PARALLEL RESOURCES

by

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ABSTRACT

Valley Metal Container was scheduling its production of 12 ounce aluminum cans using manual methods. Coordinating their supply of cans for three major breweries is very complex and has been improved with techniques from Operations Research utilized by this project. In the packaging of consumer goods, the container industry has many standards for function and geometry. Within the aluminum can industry, the container standard allows suppliers to provide identical containers for various consumer products by simply changing the printed labels on the can so that the consumed product is properly identified. This work demonstrates the use of a Mixed Integer Program to reduce costs associated with changing flexible manufacturing processes from the production of one product label to another. Developing and implementing this program with the scheduling of can manufacturing at Metal Valley Container has provided documented annual savings of $169,230 in labor, scrap and inventory holding costs due to avoided label changeovers. When plans for full can plant utilization are finally realized, this model is expected to save over 1 million dollars annually in opportunity cost of production time.

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CHAPTER ONE

INTRODUCTION

1.1 General Concepts

Many manufacturing systems today are automated, and products are created at amazing rates of speed. This is especially true in the container and packaging industry. Consumer products ranging from dog food to breakfast cereals and from milk to engine oil are brought to fill sites where high speed automated equipment conveys containers into fill positions. The container shapes and functions often generalize from industry to industry. The aluminum can manufacturing industry, for example, has a standard for container specifications that is used to build the same aluminum container anywhere in the world. The specification allows the containers to be filled with any beverage at any customer filling location. Aluminum can suppliers, therefore, are able to diversify their customer base by building can plants that have flexible labeling capabilities. The scheduling of different brand labels so that diverse customer demands are met while minimizing costs associated with label changeovers is the focus of this work.

The beer industry represents a general class of container supply coordination where twelve ounce aluminum cans of the same geometry and function are required for filling a wide variety of brews for consumer demand. As is typical of the packaging industry in general, the only delineating feature of the beverage containers is the decorated labeling printed onto the cans. To illustrate the effort required to support the scheduling of modern high speed filling and packaging operations, this work models the scheduling endeavors of Valley Metal Container as they strive to supply the Coors Brewing Company with aluminum cans.

1.2 Importance to Valley Metal Container

The aluminum can manufacturing process is considered single-stage in that the containers are made on a continuous production line. Coiled aluminum approximating .0100 inches in thickness is uncoiled to initiate can manufacturing. Once the aluminum enters the production line, it does not leave until a container is fully produced and placed on pallets. Any other exit from the line is considered scrap. Cans are conveyed automatically from one subprocess to the next at rates of speeds averaging between 1200 to 1800 cans per minute. A brief outline of the steps in the process follows:

- Aluminum Uncoilers
- Cup Makers
- Can Body Makers
- Washing and Etching
- Label Printing and Overcoating
- Label Inks and Overcoat Curing
- Internal Can Coating
- Internal Coating Curing
- Necking and Flanging
- Light Testing
- Palletizing

The major concern with can production lines is that when any one of the subprocesses stops, all preceding processes have their output blocked and so they must stop. All succeeding processes are starved for input and, therefore, also stop. This is generally true with all continuous operations. If one function in the process stops, the entire line shuts down. Valley Metal Container has six production lines that run in parallel. Each of the lines has at least one printer for labeling cans. When a label change is scheduled, the entire line is down waiting for the printer to be placed back in service. Since all of the containers are the same, the real scheduling effort revolves around deciding which printers should be set up to produce the various demanded beer labels during the shifts of the week. Because the expected label changeover time is one hour, line stoppages associated with scheduled printer setups are very expensive and should be minimized.

I utilized a variation of the lot-sizing problem (Katok, Lewis, and Harrison, 1998) with setup costs, setup times, and multiple resources to formulate an automated weekly scheduling program to minimize costs associated with label changeovers. The lot-sizing problem uses a binary variable as one of the decision variables in a mixed integer program that has a value 1 if a product label is scheduled during a time period and a value 0 if the product label is not scheduled to be produced. This formulation is designed for medium range planning horizons that typically comprise several months of time. Scheduling for the production of cans requires decisions for printer setups to be made every eight hour shift. The time horizon is short term, and the general lot-sizing mixed integer program formulation requires a modification for solving a short term multi-period scheduling problem.

The modification required is really the addition of another binary variable that is linked to the lot-sizing variable. This second binary variable is referred to as the sequencing variable for reasons soon to be explained. The sequencing variable takes the value 1 if a product label is scheduled to be produced in a time period when it was not produced in the previous period. Of course, if the product label had been scheduled in the previous period, the lot-sizing variable would have value 1. Thus, a link or relationship is established between the sequencing variable added to the short term planning horizon and the lot-sizing variable from the medium range planning formulation. In addition, the sequencing variable will have value 0 if the product label is not scheduled for the time period or if it has been scheduled but was also scheduled for the previous time period. In the production sequencing problem, the lot-sizing variable tracks which exact product has been scheduled for printing during any period while the sequencing variable checks the previous period to determine if product labels have changed. In the medium range lot-sizing problem, the lot-sizing decision variable is formulated in the objective function that minimizes costs. In the weekly mixed integer scheduling formulation for this research, the sequencing decision variable is in the objective function.

Inventory management is also very important at Valley Metal Container. The production lines must produce to inventory that is either used for immediate demand or is stored for peak season demand. During peak season, all production is used for immediate demand, and demand in excess of can line capacity is satisfied from long term inventory. For the medium range lot-sizing formulation, inventory costs are minimized in the objective function along with setup costs. In contrast, the sequencing formulation developed and implemented by this research for Valley Metal Container's weekly label schedule utilizes established week starting and week ending inventory levels as constraints. Minimizing inventory holding costs with short term weekly scheduling creates a much larger problem to solve and neglects the larger inventory issues that are associated with annual seasonal demands. Holding costs, therefore, are minimized at an aggregate level in such a way that weekly inventory strategies are made available as constraints for the mixed integer program that solves for minimum label changes. The minimizing of inventory costs is actually solved with another mixed integer program formulated at Valley Metal Container several years ago. Scheduling at the can plant, therefore, first requires that inventory strategies be formulated from aggregate annual demand forecasts. These inventory strategies are then implemented with the scheduling mathematical program represented by this work.

In summary, it is very important for Valley Metal Container to schedule weekly production with a view to satisfying immediate customer demands while implementing seasonal inventory strategies. Our model does this by augmenting current inventory strategies with a mixed integer program that constrains beginning and ending inventory levels to comply with existing inventory plans while minimizing the number of production stoppages required for changing beer labels. This automated scheduling formulation replaces a manual scheduling practice that is slow and vulnerable to the inadequacies of undocumented procedures and to subjective skill levels of individuals who are not educated in operations research and management sciences.

1.3 Importance to Coors Brewing Company

Coors Brewing Company requires the coordination of two major container supply chains at their beer filling and packaging operations. Their containers consist of a two piece aluminum construction: a can body and a can end. The Golden, Colorado brewery has ten beer filling sites. The large consumer demands and the speeds of the conveyors and the filling operations are impressive. At each of the ten filling stations at Golden, can bodies are brought via automated conveyors to a filler, twelve ounces of beer are injected into each can body and a can end is mechanically seamed onto the can body at the rate of thirty filled containers per second. Supply coordination of the brew, can bodies and can ends is critical because, at these rates of speed, every minute of downtime experienced waiting for supplies represents thousands of cans of beer not available for sale. The cost associated with each filler for lost opportunity of beer sales at the Coors Brewing Company is $65 per minute. After the beer has been placed into containers, the cans of beer are conveyed to final packaging lines and prepared for shipment to distribution sites.

1.4 Importance to the Container and Packaging Industry

Nearly all consumable products must be placed in containers and packaged before distribution to retail sales. In most mature container and packaging industries, the package containers have standard design specifications for fit and function. These design standards make it possible for diversifying customer and supplier bases. A manufacturer who makes containers for any particular industry need only understand a customer's requirements for labeling a consumable product to be a viable supplier for this customer's demand for containers. Of course, this implies that their manufacturing lines are flexible enough to accommodate changes for various labeling decorations and descriptive texts.

Nearly all container manufacturing is done in sequential and continuous or single-stage fashion. This implies that the entire manufacturing line is down while labels are changed. Because line capacity is lost when labels are changed, the sequencing of labels as a schedule for production should be accomplished with the minimum number of changes. The mixed integer formulation of this research minimizes changeover costs for an industry that experiences dynamic demands that are seasonal. The solution from the program schedules multiple parallel resources that do not assume infinite capacities. The program solves multi-period planning problems.

In summary, because of the similarities shared by the container and packaging industry in general, others may benefit from this work. The benefits of this work are especially important for those who schedule high speed systems with mass quantities being consumed.

CHAPTER TWO
PROBLEM DESCRIPTION

2.1 General Problem Description

Valley Metal Container (VMC) operates in a cooperative partnership with Coors Brewing Company to produce annually 3.2 billion 12 ounce aluminum cans at the largest single site can plant in the world. VMC is located approximately one mile from the Golden, Colorado, brewery. VMC operates six can lines in parallel at the facility. This study describes the development of a model for scheduling can production at VMC. Our model generates a weekly schedule for the production of seven nominal Coors beer labels on the six can lines during a one week or twenty-one shift time period. The major purpose of the model is to minimize costs associated with stopping production to change labels. Our scheduling model has been accepted by senior management and has generated documented savings of $169,230 annually in reduced labor, inventory holding, outside storage, and scrap costs. When plans for full can plant utilization are finally realized, the model is expected to save over one million dollars in opportunity cost of production time due to avoided changeovers.

Beer sales are highly seasonal, and careful inventory management is critical as planners must develop strategies that offset differences in can plant production capacity and peak season demands for beer. Annual forecasts are utilized by aggregate planners to establish weekly inventory levels. On an annual basis the production capacity of the can plant is greater than the demand for beer sales. However, demands during the summer months significantly overrun these capacities. Figure 1 provides a typical graph of this scenario. A production planning tool (PPT) has been implemented at VMC for managing inventories. PPT is actually a mixed integer program that was developed several years ago for minimizing inventory holding costs and also for planning labor requirements.

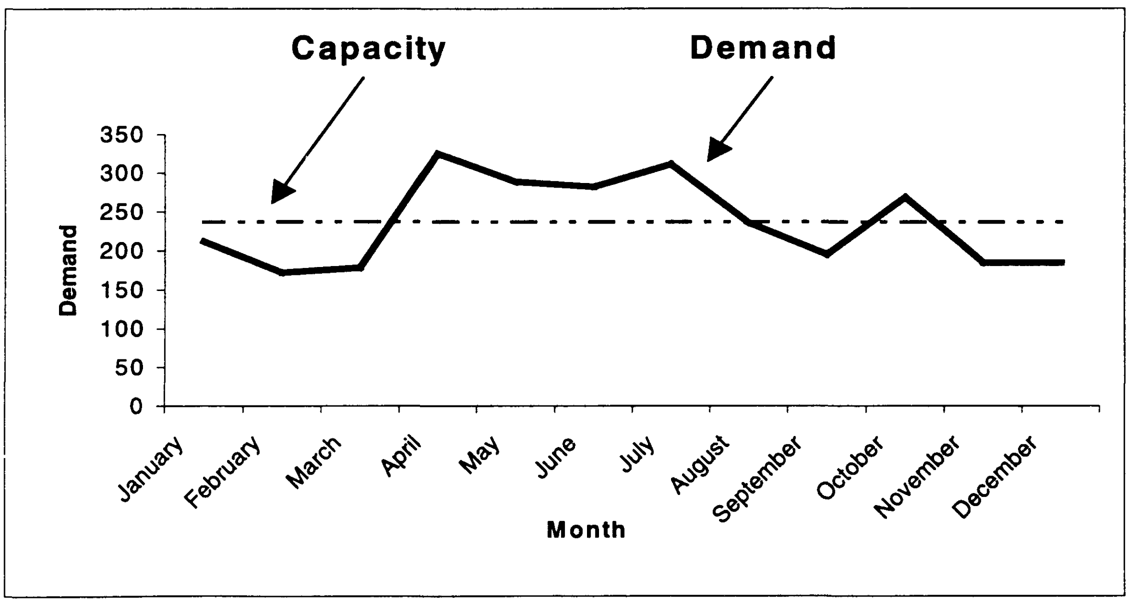

Figure 1 Annual Demand For Beer

The inventory and labor requirements established by PPT become input constraints for the scheduling model developed by this work. Weekly brewery demands are also input as constraints to our weekly scheduling model. Our implemented model is now referred to as the Weekly Scheduling Tool (WST) by can plant personnel. The relationship between PPT and WST is exhibited in Figure 2. WST dictates to operations the label that is to be printed on the cans produced for each line during all twenty-one shifts. All scheduled changeovers are clearly documented with output from WST. Typical changeovers at Valley Metal Container require that the production line be down for one hour, and expected losses are 5,250 cans per printer when bringing a line back up to full production. Costs related to inventory holdings and labor are minimized with PPT. Costs related to changeovers are minimized with WST.

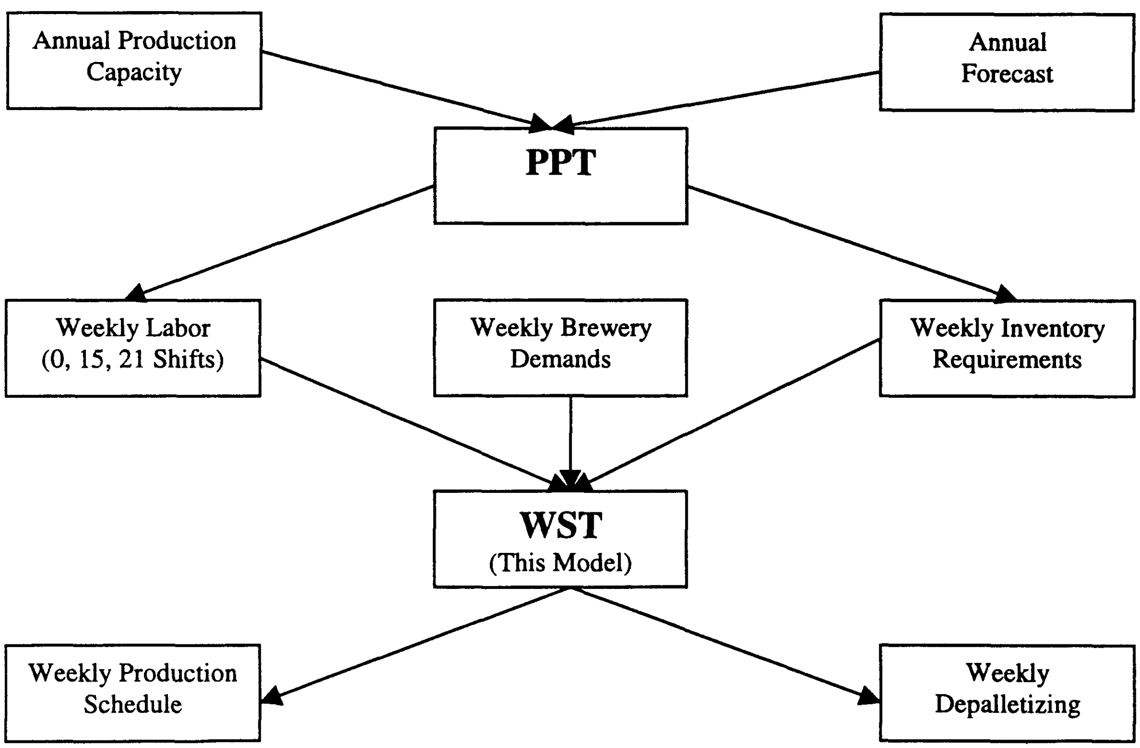

Figure 2 PPT Output Becomes Input to WST

In summary, our scheduling process minimizes labor, changeover, and inventory holding costs while solving seasonal and short-term demand mismatches with resource capacities for building cans. WST is the result of this research. PPT has been used at Valley Metal Container for several years. WST augments the usefulness of PPT by producing a schedule that complies with its inventory strategies.

2.2 Specifics

Valley Metal Container is charged with the responsibility of supplying 12-ounce cans to each of three breweries owned and operated by Coors Brewing Company. The Shenandoah, Virginia, and Memphis, Tennessee, breweries receive Coors Light cans only, and all deliveries are made on 19 layer pallets (7,984 cans per pallet) the week before filling. Deliveries to the Golden, Colorado, brewery are much more complicated. Demand is satisfied to each of ten fill lines from either 17 layer pallets (7,140 cans per pallet) or cell bin trailers (100,000 cans per trailer). Fill Line # 5 must receive cans only on pallets. Fill Line # 3 may receive cans from either cell bins or pallets. All remaining eight fill lines must receive cans from cell bins only. In addition, the Golden brewery may change demand for any of seven beer labels during any hour of operation. Production from each of six can lines may go directly into cell bin trailers or onto either 17 or 19 layer pallets. Once on pallets, cans may be shipped directly to any of the proper brewery demand sites, or they may be depalletized into cell bins using C22 depalletizer. There are 54 cell bin trailers and an unlimited supply of pallet making materials. The relationship between can line capacities and brewery demands with long and short-term inventories is exhibited in Figure 3.

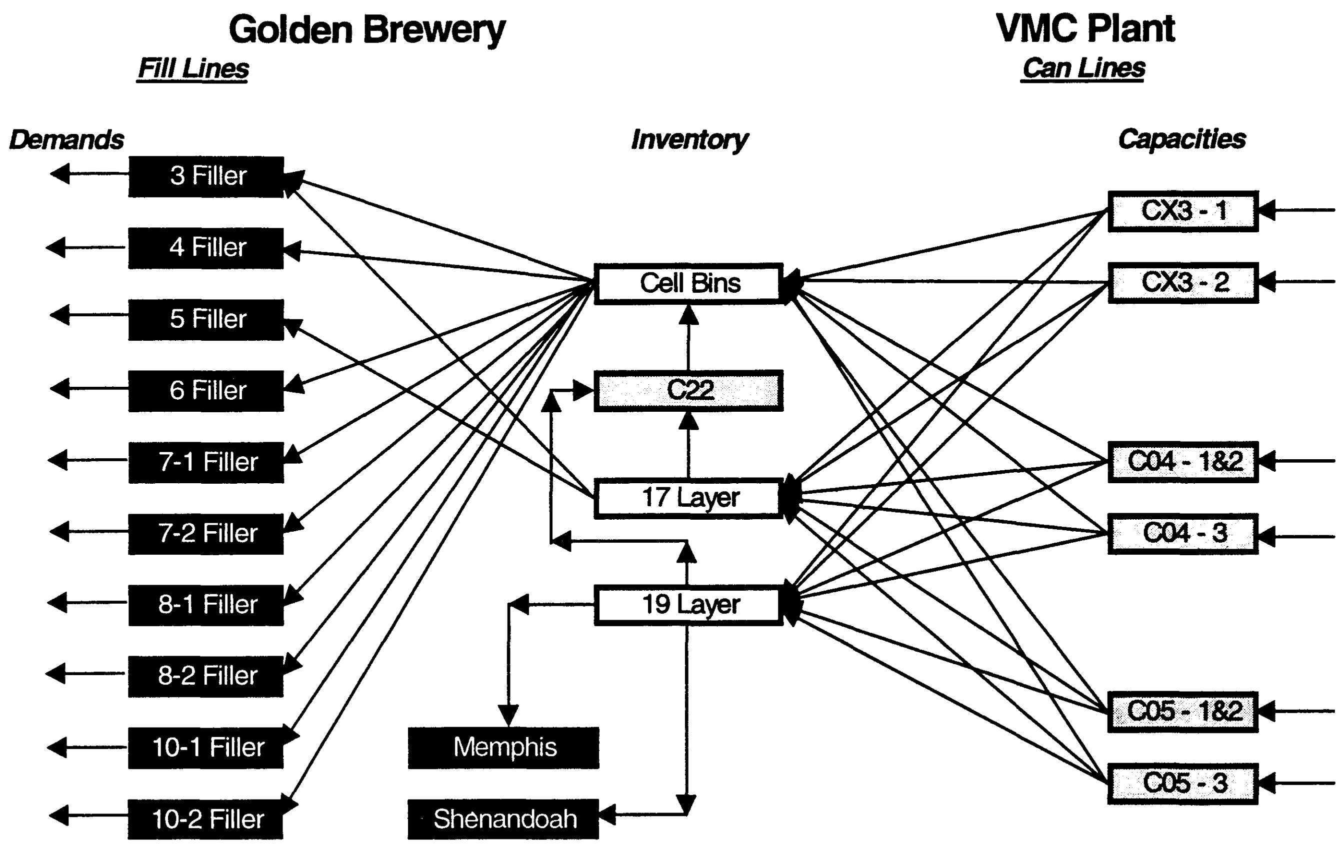

Figure 3 Relationships – Demands, Inventories, and Capacities

VMC has six production lines and eight printers. The production lines designated CX3/1, CX3/2, C04/3, and C05/3 each have one printer for decorating can labels.

Production lines C04/1&2 and C05/1&2 each have two printers. Each line has different crewing requirements and output rates. Table 1 exhibits line capacities and labor costs. Changeover costs represented in this table include labor and scrap. Issues with lost capacity associated with printer changeovers are explained in Chapter 4. The costs incurred by lost changeover capacity are documented in the business case (Section 4.2).

Table 1 Line Capacities, Changeover and Manufacturing Costs (Week 27)

	CX3-1	CX3-2	C04-1&2	C04-3	C05-1&2	C05-3
Cans per Shift	532,000	532,000	885,000	442,667	960,000	480,000
Changeover Costs	$272.03	$272.03	$486.17	$243.08	$516.18	$258.09
Cost per 1000 cans	$1.959	$1.959	$1.831	$1.831	$1.939	$1.939

Seven beer labels are demanded by the Golden brewery. They include Coors Original (C), Coors Light (L), Keystone Light (Q), Extra Gold (E), Keystone Premium (Y), Keystone Dry (P), and Keystone Ice (G). The brand labels are scheduled using the abbreviation in parenthesis. There are several printer constraints at VMC. Since CX3-1 has the only five color printer (all others are four color), the Extra Gold label may only be produced on this line. C05-1&2 and C05-3 may only print either Coors Light label or Keystone Light label. C04-1&2 and C04-3 may print any label except Extra Gold; but, if either Coors Light or Keystone Light is scheduled on one line, then only Keystone Light or Coors Light may be scheduled on the other. If any other label is scheduled on either

C04 line, then all labels except Coors Light, Keystone Light, or Extra Gold may be scheduled on the other C04 line.

C22 depalletizer may be scheduled to move 17 and 19 layer inventory into cell bins. C22 has the capacity to depalletize 105,000 cans per hour at a cost of $49 per hour. Since the objective function of our model minimizes costs, C22 is utilized when it is available as a means for eliminating expensive printer changeovers.

2.3 Solution Methodology

It is the responsibility of PPT to manage all long term inventory requirements in such a way that holding costs are minimized and all seasonal demands are met. Inventory holding cost has been determined to be $250 per million cans per week. The VMC warehouse holds 150 million cans, and this space is considered to be free even though there is labor associated with the warehousing function. When inventory levels are greater than 150 million cans, commercial warehouses are engaged. Outside warehouse rental fees are equated to a one time per pallet charge of $3.50. This is $490 per million cans. A minimum inventory buffer equivalent to three days demand is maintained. This is not safety stock per se, but is used to allow reduced lost production time due to label changes for products that are packaged in small batches at the brewery.

Storage and holding costs make inventory expensive, but too little inventory is even more critical. Maximum weekly demand is approximately 45% greater than VMC output. Anytime VMC can not meet brewery demand for lack of inventory, beer not packaged waiting for containers is considered lost sales volume. The loss rate is calculated at $65 for every minute a fill site is down waiting for can delivery. In its calculations for determining weekly inventory levels for all brand labels, the priority for PPT is assuring inventories are never empty.

PPT is also responsible for minimizing labor costs. Can making is best accomplished without ever stopping. Scrap rates are greatly increased when cold equipment is restarted. Ideally, lines are run 24 hours per day, seven days a week. However, if lines must be stopped to adjust for excess capacity, PPT must calculate the optimum among no production during a week or either a five or seven day work week for crewing. PPT determines the weeks of the year that each line will be down, run five days or run seven days with allowances for periodic maintenance and construction projects.

PPT has been successfully formulated and implemented as a mixed integer program by Mr. Bob Sadler, an industrial engineer at Coors Brewing Company. Mr. Sadler coded a C program to provide a matrix of variable and constraint coefficients for his Cplex solver. His formulations are documented in the Coors Engineering Center. His mathematical program provides the required hours of operation by line and by week necessary to build inventories during the off season and to augment production capacities during peak season.

With weekly line capacities and inventory levels optimized to minimize inventory holding and labor costs, WST is responsible to combine weekly brewery demands with

PPT output to schedule can line production with minimized changeover costs. The beginning and ending inventory positions and line capacities are actually constraints for WST. The changeover decision variable is in the objective function for minimizing costs. Table 2 illustrates an example partial schedule for week 10 can production provided by WST.

Table 2 Sample Weekly Schedule From WST

Shift	CX3-1	CX3-2	C04-1&2	C04-3	C05-1&2	C05-3
Mon - G	G	No Label	L	Q	L	L
Mon - D	G	No Label	L	Q	L	L
Mon - S	C	No Label	L	Q	L	L
Tue - G	C	No Label	L	Q	L	L
Tue - D	C	No Label	L	Q	L	L
Tue - S	C	No Label	L	Q	L	L
Wed -G	C	No Label	L	Q	L	L
Wed - D	C	No Label	L	Q	L	L
Wed - S	C	No Label	L	Q	L	L
Thr - G	E	No Label	L	Q	L	L
Thr - Sat	Continue	Continue	Continue	Continue	Continue	Continue
Sun - G	No Label	No Label	Y	G	L	L
Sun - D	No Label	No Label	Y	G	L	L
Sun - S	No Label	No Label	Y	G	L	L

Also required of WST is a summary of the can quantities produced in each time period. Table 3 illustrates a sample partial summary of cans produced for each line during week 10. A similar table of can quantities summarizing the exact amount of each brand label that is moved from 17 and 19 layer pallets into cell bins is also produced. WST is often able to avoid expensive label changeovers by utilizing C22.

Table 3 Sample Quantities Summary From WST

Shift	CX3-1	CX3-2	C04-1&2	C04-3	C05-1&2	C05-3
Mon - G	531,915	0	885,347	442,723	426,984	442,723
Mon - D	531,915	0	885,347	442,723	885,347	442,723
Mon - S	465,426	0	885,347	442,723	885,347	442,723
Tue - G	531,915	0	885,347	442,723	885,347	442,723
Tue - D	531,915	0	885,347	442,723	885,347	442,723
Tue - S	531,915	0	885,347	442,723	885,347	442,723
Wed -G	531,915	0	885,347	442,723	885,347	442,723
Wed - D	531,915	0	885,347	442,723	885,347	442,723
Wed - S	531,915	0	885,347	442,723	885,347	442,723
Thr - G	465,426	0	885,347	442,723	885,347	442,723
Thr - Sat	Continue	Continue	Continue	Continue	Continue	Continue
Sun - G	0	0	885,347	442,723	885,347	442,723
Sun - D	0	0	885,347	442,723	885,347	442,723
Sun - S	0	0	885,347	442,723	885,347	442,723

2.4 Final Considerations

We implemented WST in GAMS (General Algebraic Modeling System) and solved the problem using OSL (Optimization Subroutine Library) solver. The software is executed with a 400 MHz Pentium processor operating with Windows NT. An advantage of using an algebraic modeling language such as GAMS is that it is designed to grow or become smaller with changes in can manufacturing configurations or practices. For example, can lines may be added or removed from the model with simple changes to the index set governing the resources. The same is true for adding, removing, or changing the types of brand labels. This scaling feature of GAMS is one of its strongest assets and will prove invaluable for weekly operations scheduling of resources that must be flexible.

The following list of data must be made available as input to the GAMS formulation of WST:

- Can Line Labor Requirements (from PPT).
- Beginning and ending total inventories for all brand labels (from PPT).
- Beginning and ending cell bin inventories (from warehouse information).
- Beginning and ending 19 layer inventories (from warehouse information).
- Can line capacities (from production for all six lines).
- Demand for 17 layer pallets to Golden brewery (from the brewery).
- Demand for cans in cell bins for Golden brewery (from the brewery).
- Demand for 19 layer pallets to Memphis and Shenandoah (from Memphis and Shenandoah Breweries).
- The processing time required to make 1000 cans (from production for all six lines).
- The variable cost of producing 1000 cans (from production for all six lines).
- The changeover times required for each of the brand labels (from production for all six lines).
- The changeover costs for each brand on each line (from production for all six lines).

WST uses SSLINK (Rutherford, 1998), an Excel Spreadsheet Interface that allows nontechnical scheduling personnel to access all of the above documented data inputs for their weekly scheduling activities using Windows and Excel. These software packages are familiar to Valley Metal Container employees; and, therefore, facilitates implementation of WST with little training.

Because solutions are achieved real time (seconds), scheduling scenarios can be run with a variety of inputs to examine total manufacturing costs associated with each configuration. For example, Golden Filler # 3 is able to receive cans on either 17 layer pallets or in cell bins. The brewery prefers deliveries be made in cell bins. However, if printer changeovers can be avoided by scheduling the # 3 depalletizer, WST can provide justifications in terms of less costs for superseding the brewery's unquantified preference for cell bin deliveries to # 3 Filler. Without the optimization of costs provided by WST, schedulers at VMC were often asked to provide cell bin deliveries to Filler #3 when deliveries on pallets would save can line downtimes by avoiding label changes. WST allows schedulers to push back requests from customers that make can production more expensive.

It is anticipated that WST may be used for other resource planning projects. For example, recall the constraint on C04 that requires either Coors Light or Keystone Light be produced on C04-3 if either Coors Light or Keystone Light is scheduled to be produced on C04-1&2. This really is a limitation of the washer package being used on C04 to clean and etch the aluminum cans before printing a label. Proposals have been made to change washer packages so that both legs of C04 can run completely label independent. The change is expensive, and it is hoped that WST can be used to model savings in reduced label changeover costs with the existing washer package restrictions removed.

Another expensive capital spending effort could receive help from WST modeling. For years it has been the desire of VMC and CBC logistics personnel to acquire depalletizers for more Golden brewery fillers so that these fill lines would have the capability to receive cans on pallets. Over the years, aluminum has been taken out of cans to save millions of dollars in aluminum costs. To achieve this down gauging of aluminum, container sidewalls are made thinner. For every .0002 inches of thickness taken from the starting gauge of aluminum coils, VMC saves approximately 3 million dollars annually in aluminum costs. Handling of the down gauged aluminum cans has become more critical because the thinner can walls crease and dent more easily. So, while aluminum savings for cans have spiraled upward, quality issues for dents with cell bin handling have also grown. The solution offered by engineering is to move away from cell bin deliveries to pallets. It is hoped that removing the cell bin constraint from WST modeling will produce changeover savings and help justify fill line depalletizers.

As a final highlight for the implementation of WST at VMC are year 2000 issues. While most of the scheduling at VMC is done manually, the management of cell bin inventories has been automated to assist schedulers from running out of empty trailers required for hourly Golden brewery demand. Schedulers often anticipate demand by filling empty trailers several hours or shifts early. Without the aid of their automated cell bin configurator, it is likely that some trailers would be filled too soon and held awaiting a fill line while another fill line waits for empty cell bin trailers to arrive to be filled by either C22 or one of the can lines. Keep in mind that each brewery fill line is operating at speeds of approximately 1800 filled cans per minute, and some VMC can lines produce nearly 2000 cans per minute. At these rates, cell bin management is critical. WST replaces the need for their antiquated cell bin software at a time when year 2000 issues were requiring a total reevaluation and rewrite of its programming. Estimated savings due to WST implementation are approximately $80,000. This represents a one time saving in addition to the documented annual savings of $169,230 provided by WST as part of the business case of Section 4.2.

CHAPTER THREE

PROBLEM FORMULATION

3.1 Model Concepts and Objectives

The objective of our model is to minimize total production costs associated with printer changeovers for the week being scheduled. Because C22 depalletizer may be used to transfer 17 and 19 layer inventory into cell bin inventory, expensive label changes may be avoided by depalletizing. However, the costs associated with depalletizing must be less than or equal to the cost for changing a printer setup. Therefore, the objective function for the mixed integer formulation of our weekly scheduling model minimizes the sum of all setup costs and depalletizing.

Our mixed integer program has three major areas of formulation. They include index sets, data, and an objective function with decision variables and constraints. The sets of entities being modeled are seven nominal beer labels, six can lines, and twenty-one time periods. These entities become products (P), resources (R), and shifts of eight hour periods (T) respectively in the index sets. The index sets, data, and variable definitions are documented in the next sections. The mathematical representations of the objective function and the model constraints follow the definitions. Constraint details are provided last.

3.2 Index Sets:

P – Products $P = \{ p \mid p = Coors\ Original, Coors\ Light, Keystone\ Light, Extra\ Gold, Keystone\ \text{Pr}emium, Keystone\ Dry, Keystone\ Ice \}$

R – Resources $R = \{ r \mid r = CX3-1, CX3-2, C04-1\,\&\,2, C04-3, C05-1\,\&\,2, C05-3 \}$

T – Time Periods $T = \{ t \mid t = t0, Mon-G, Mon-D, Mon-S, Tue-G, Tue-D, Tue-S, Wed-G, \cdots, Sun-G, Sun-D, Sun-S, t22 \}$

3.3 Objective Function Decision Variables:

x_{prt} – production of product p on resource r during period t $\forall (p \in P, r \in R, t \in T)$

$smdepal_{pt}$ – can depalletizing of product p during period t from 19 layer inventory $\forall (p \in P, t \in T)$

$depal_{pt}$ – can depalletizing of product p during period t from 17 layer inventory $\forall (p \in P, t \in T)$

z_{prt} – 1 if product p has been changed to another label during period t on resource r; 0 otherwise $\forall (p \in P, r \in R, t \in T)$

3.4 Other Decision Variables:

$cellbin_{pt}$ – amount of product p put into cell bin inventory during period t $\forall (p \in P, t \in T)$

$cellinv_{pt}$ – amount of product p in cell bins for period t $\forall (p \in P, t \in T)$

$decell_{pt}$ – amount of product p consumed from cell bins during period t $\forall(p \in P, t \in T)$

$inv19_{pt}$ – amount of product p on 19 layer pallets for period t $\forall(p \in P, t \in T)$

$layer19_{pt}$ – amount of product p put into 19 layer inventory during period t $\forall(p \in P, t \in T)$

$line5_{pt}$ – amount of product p consumed from 17 layer pallets during period t $\forall(p \in P, t \in T)$

$palinv_{pt}$ – amount of product p on 17 layer pallets for period t $\forall(p \in P, t \in T)$

$pallet_{pt}$ – amount of product p put into 17 layer pallet inventory during period t $\forall(p \in P, t \in T)$

y_{prt} – 1 if $x_{prt} > 0$; 0 otherwise $\forall(p \in P, r \in R, t \in T)$

3.5 Data:

$beg19_p$ – beginning 19 layer inventory of product p $\forall(p \in P)$

$begcell_p$ – beginning cell bin inventory of product p $\forall(p \in P)$

cap_{rt} – amount of resource r available in time period t $\forall(r \in R, t \in T)$

$dcost_p$ – depalletizer cost for product p $\forall(p \in P)$

$demand_{pt}$ – demand for cell bins from the Brewery for product p in period t $\forall(p \in P, t \in T)$

$demand5_{pt}$ – demand for 17 layer pallets of product p in time period t $\forall(p \in P, t \in T)$

$end19_p$ – ending 19 layer inventory of product p $\forall(p \in P)$

$endcell_p$ – ending cell bin inventory of product p $\forall (p \in P)$

$finalinv_p$ – total ending 17 layer inventory of product p $\forall (p \in P)$

$invflex_p$ – percentage product p may vary from ending inventory constraint $\forall (p \in P)$

M_{prt} – minimum of demand or capacity for product p on resource r for time period t; used in changeover decisions (a large number) $\forall (p \in P, r \in R, t \in T)$

$pcost_{pr}$ – cost to produce 1000 units of product p on resource r $\forall (p \in P, r \in R)$

$ptime_{pr}$ – consumption of resource r in hours to produce 1000 units of product p $\forall (p \in P, r \in R)$

$scost_{pr}$ – cost incurred when resource r is changed over to product p $\forall (p \in P, r \in R)$

$startinv_p$ – total starting 17 layer inventory of product p $\forall (p \in P)$

$stime_{pr}$ – fixed consumption of resource r when changed over to product p $\forall (p \in P, r \in R)$

3.6 Objective Function:

$$Min \quad Z = \sum_{p \in P}\sum_{r \in R}\sum_{t \in T}(pcost_{pr}x_{prt} + scost_{pr}z_{prt}) + dcost\sum_{p \in P}\sum_{t \in T}(depal_{pt} + smdepal_{pt})$$

subject to:

Inventory Flow:

1) $inv19_{\text{"Light"},t-1} + layer19_{\text{"Light"},t} - smdepal_{\text{"Light"},t} - inv19_{\text{"Light"},t} = 0 \quad \forall\ (t \in T, t \neq t0)$

2) $cellinv_{p,t-1} + cellbin_{p,t} + depal_{p,t} - decell_{p,t} - cellinv_{p,t} = 0 \quad \forall\ (p \in P, t \in T, t \neq t0)$

3) $palinv_{p,t-1} + pallet_{p,t} - depal_{p,t} - line5_{p,t} - palinv_{p,t} = 0 \quad \forall\ (p \in P, t \in T, t \neq t0)$

4) $palinv_{p,\text{"t22"}} \leq finalI_p invflex_p \quad \forall\ (p \in P)$

5) $palinv_{p,\text{"t22"}} \geq finalI_p / invflex_p \quad \forall\ (p \in P)$

6) $\sum_{p \in P} palinv_{p,\text{"t22"}} \geq \sum_{p \in P} finalI_p$

7) $\sum_{r \in R} x_{p,r,t} - cellbin_{p,t} - pallet_{p,t} - layer19_{p,t} = 0 \quad \forall\ (p \in P, t \in T)$

Defining Changeovers:

8) $x_{p,r,t} \leq M_{p,r,t} y_{p,r,t} \quad \forall\ (p \in P, r \in R, t \in T, t \neq t0)$

9) $z_{p,r,t} \geq y_{p,r,t} - y_{p,r,t-1} \quad \forall\ (p \in P, r \in R, t \in T, t \neq t0)$

10) $\sum_{p \in P} y_{p,r,t} \leq 1 \quad \forall\ (r \in R, t \in T)$

Capacity:

11) $\sum_{p \in P} ptime_{p,r} x_{p,r,t} + \sum_{p \in P} stime_{p,r} z_{p,r,t} \leq cap_{r,t} \quad \forall\ (r \in R, t \in T)$

12) $\sum_{p \in P} cellinv_{p,t} + decell_{p,t} \leq 5000000 \quad \forall\ (t \in T)$

13) $\sum_{p \in P} (depal_{p,t} + smdepal_{p,t}) \leq 840000 \quad \forall\ (t \in T)$

Demand:

14) $decell_{p,t} \geq demand_{p,t} \quad \forall\ (p \in P, t \in T)$

15) $line5_{p,t} \geq demand5_{p,t} \quad \forall\ (p \in P, t \in T)$

16) $inv19_{\text{"Light"},\text{"t22"}} - end19_{\text{"Light"}} = smdemand$

Side Constraints:

17) $y_{\text{"Light","c043"},t} + y_{\text{"Key Light","c043"},t} - y_{\text{"Light","c041-2"},t} - y_{\text{"Key Light","c041-2"},t} = 0 \qquad \forall\,(t \in T)$

18) $x_{\text{"ExtraGold"},r,t} = 0 \qquad \forall\,(r \in CX3-2, C04-1\,\&\,2, C04-3, C05-1\,\&\,2, C05-3)$

19) $y_{p,r,t} \in \{0,1\} \qquad \forall\,(p \in P, r \in R, t \in T)$

20) $All\ other\ decision\ \text{var}iables \geq 0$

3.7 Objective Function and Constraint Details

The flow of cans through cell bin, 17 layer and 19 layer inventories is constrained by equations 1 through 7. Equation 1 controls 19 layer inventory. The first subscript on all of the variables is "Light" because only Coors Light label can be put on 19 layer pallets. Equation 1 says that the number of cans on 19 layer pallets during any shift is equal to the number of cans produced during the shift added to the number of cans in inventory from the previous shift while the number of cans being depalletized into cell bins on C22 are subtracted from this total.

Equations 2 and 3 are similar to equation 1. Equation 2 says that the amount of cans in cell bin inventory during any shift is the sum of the amount of cans from the previous shift with cans produced into cell bins and with depalletized cans from 17 and 19 layer inventory while the number of cans used for demand is subtracted from that total. Equation 3 says that the number of cans on 17 layer pallet inventory during any shift is the sum of the number of cans in inventory from the previous shift with number of cans produced during the shift while the number of cans depalletized and the number of cans satisfying demand to #5 Filler are subtracted from this total.

Equations 4 through 7 link the final inventory count specified by PPT with the schedule of WST. Equations 4 and 5 say that the final inventory of cans at the end of the week's production must be equal to the inventory specified by PPT plus or minus a variation that may be specified by the scheduler. The amount of this variation is controlled by the *invflex* parameter in the formulation. Equation 6 says the variation allowed for each product label less than the PPT inventory level must be equal to the variation greater than PPT inventory levels for the other labels. Equation 7 says that everything produced must go onto either 17 or 19 layer pallets or into cell bin trailers.

The focus of this formulation is the changeover constraints which are equation numbers 8, 9 and 10. Equation 10 says that for any can line during any particular shift of the week there can be one and only one beer label scheduled for manufacturing. The variable y is binary. It must be declared as a binary variable to the mixed integer program solver, and it is the only binary variable in the formulation. The rest of the formulation is linear. The variable y is the binary variable used in the medium range lot-sizing problem formulation referenced in Section 1.2. Y has the value 1 if a label is scheduled to be produced, and it has a value of 0 if it not scheduled.

Equation 9 says that no changeover has occurred if the product scheduled for any time period is the same as the product scheduled for the previous time period. In this case, the decision variable z is assigned the value 0 and no changeover costs are added to the objective function. Of course, z will also have the value 0 if the product is not scheduled.

If, however, the product scheduled for any time period is different than the previous time period, then z is assigned the value 1 and changeover costs for that product and can line are added to production costs being minimized by the objective function. It should be noted that although z will only have values of zero or 1, this is a function of the formulation. The variable z is the short term sequencing modification added to the medium term lot-sizing problem also referenced in Section 1.2. Hence, z is part of the objective function formulation while y is not.

Equation 8 provides a link between the production variable x and the binary variable y. It succinctly says that the amount of any particular beer label produced on a can line during some shift of the week must be zero if it is not scheduled. Recall that equation 10 sets y to be zero if the label is not to be scheduled for a line during any particular shift. The M (a big number) in this formulation is the smaller of either the total demand for a product for the week or the capacity of a can line during the shift. Equation 8 ensures that the amount produced of any label on a can line during the shift of work will be zero if it is not scheduled and will be less than or equal to M if it is scheduled.

Capacity is constrained with equations 11 through 13. Equation 11 says that the capacity for a can line during any shift must be greater than or equal to the sum of the capacity consumed making cans and any capacity consumed by printer changeovers. Equation 12 says that the cell bin capacity is less than or equal to 5 million cans. Recall that each trailer holds 100,000 cans, and there are 54 trailers in total. Four trailers are not counted as they are held in reserve for emergencies. Equation 13 says that the capacity for C22 to depalletize cans from pallets into cell bins is 840,000 per shift.

The next three equations constrain demand. Equation 14 says that the amount of cans consumed from cell bins must be greater than or equal to the demand for cans from cell bins. Equation 15 says the same for 17 layer pallets. Equation 16 says that the inventory of 19 layer pallets for the last shift of production is equal to the weekly demand for the Shenandoah and Memphis breweries added to the ending 19 layer inventory constrained by the model.

The C04 side constraint is formulated as equation 17. Recall that the binary variable *y* is 1 if a label is scheduled for a line and shift, and it is zero if it is not. Notice if Coors Light is scheduled for C04-3, then the only other labels that can be scheduled for C04-1&2 while satisfying the constraint are either Coors Light or Keystone Light. The equations become $1+0-1-0=0$ *or* $1+0-0-1=0$ respectively. The reader should convince himself that only combinations of Coors Light and Keystone Light beers will satisfy this equation once either brand has been scheduled for either leg of C04.

Equation 18 says that the Extra Gold label may only be printed on production line CX3-1. Equation 19 says that *y* is a binary variable (i.e. it may only have values of either 1 or 0). Equation 20 says that all of the decision variables must be positive.

This mixed integer formulation has a total of 4,509 decision variables and 3,023 constraints when it is implemented with seven nominal beer labels, six production lines and twenty-one shifts of eight hours each. Using the GAMS software and OSL solver on a 400 MHz Pentium processor and Windows NT, this formulation solves in 58 seconds. For reference, mixed integer programs are known to be NP-hard (Billington, McClain, and Thomas, 1983).

CHAPTER FOUR

RESULTS AND SOLUTION IMPACT

4.1 Data Collection and Solution Feasibility

To demonstrate feasibility and an understanding of what might be achieved with this research, in April of 1998, we decided that our mathematical program should be used to schedule a week of production from the recent past. Week 10 (Coors Calendar for the first week in March) was selected. Many hours of data collection preceded the use of WST for scheduling Week 10. I set up and conducted interviews to obtain processing times, processing costs, setup times, setup costs, and capacities for each of the production lines. I validated these operating parameters with finance and management, and I verified them by observing the operations. The demand structure for week 10 required reconstruction since demand is transmitted to schedulers with an archaic manual paper system that is retrievable with some effort. In all, I spent over fifty hours out on the lines verifying and validating the data.

After acquiring the model data, WST went through an iterative cycle of enhancements as the user became more involved. As the model and the data matured with real world refinements requested by the schedulers, another twenty hours of work were logged. The final WST schedule used for comparison against the actual schedule for week 10 demonstrated that demand and inventory constraints could be met with eight fewer label changes and $1,830 in cost avoidance utilizing C22 depalletizer. With this encouragement, we decided that beginning Week 18, we would use WST to schedule the next five weeks of production. We also reconstructed the demand structure for Weeks 14 through 17 so that these weeks could also be scheduled by WST for evaluation. In this way, ten weeks of comparisons would be available for evaluation. All of the WST scheduling was done independent of standard scheduling practice. Quality and Industrial Engineering worked with WST while scheduling personnel continued their work unbiased by this effort. The results of our work are summarized in Tables 4 through 8.

Table 4 Printer Change and C22 Depall Comparisons

Week # 10		
Printer	Actual	WST - MIP
CX3 Concord	1	2
CX3 Vulcan	0	0
C04 / 1	2	1
C04 / 2	2	1
C04 / 3	2	1
C05 / 1	2	0
C05 / 2	2	0
C05 / 3	2	0
Total:	13	5
C22 Costs:	$5,096	$3,266
8 Printer Changes Avoided		
$1,830 Less Depall Costs		

Week # 14		
Printer	Actual	WST - MIP
CX3 Concord	3	2
CX3 Vulcan	3	3
C04 / 1	3	0
C04 / 2	3	0
C04 / 3	0	1
C05 / 1	0	0
C05 / 2	0	0
C05 / 3	0	1
Total:	12	7
C22 Costs:	$4,312	$3,352
5 Printer Changes Avoided		
$960 Less Depall Costs		

Table 5 Printer Change and C22 Depall Comparisons

Week # 15		
Printer	Actual	WST - MIP
CX3 Concord	1	0
CX3 Vulcan	0	0
C04 / 1	2	1
C04 / 2	2	1
C04 / 3	2	1
C05 / 1	0	0
C05 / 2	0	0
C05 / 3	0	0
Total:	7	3
C22 Costs:	$2,744	$2,249
4 Printer Changes Avoided		
$495 Less Depall Costs		

Week # 16		
Printer	Actual	WST - MIP
CX3 Concord	2	1
CX3 Vulcan	0	1
C04 / 1	4	1
C04 / 2	4	1
C04 / 3	2	1
C05 / 1	0	0
C05 / 2	0	0
C05 / 3	0	0
Total:	12	5
C22 Costs:	$3,136	$4,953
7 Printer Changes Avoided		
$1,817 More Depall Costs		

Table 6 Printer Change and C22 Depall Comparisons

Week # 17		
Printer	Actual	WST - MIP
CX3 Concord	0	0
CX3 Vulcan	1	0
C04 / 1	1	0
C04 / 2	1	0
C04 / 3	1	0
C05 / 1	0	0
C05 / 2	0	0
C05 / 3	0	0
Total:	4	0
C22 Costs:	$782	$2,155
4 Printer Changes Avoided		
$1,373 More Depall Costs		

Week # 18		
Printer	Actual	WST - MIP
CX3 Concord	2	3
CX3 Vulcan	2	2
C04 / 1	3	0
C04 / 2	3	0
C04 / 3	3	0
C05 / 1	2	0
C05 / 2	2	0
C05 / 3	0	0
Total:	17	5
C22 Costs:	$4,312	$3,364
12 Printer Changes Avoided		
$948 Less Depall Costs		

Table 7 Printer Change and C22 Depall Comparisons

Week # 19		
Printer	Actual	WST - MIP
CX3 Concord	0	2
CX3 Vulcan	0	0
C04 / 1	1	0
C04 / 2	1	0
C04 / 3	2	0
C05 / 1	0	0
C05 / 2	0	0
C05 / 3	0	0
Total:	4	2
C22 Costs:	$1,176	$1,819
2 Printer Changes Avoided		
$643 More Depall Costs		

Week # 20		
Printer	Actual	WST - MIP
CX3 Concord	2	1
CX3 Vulcan	1	2
C04 / 1	1	0
C04 / 2	1	0
C04 / 3	1	0
C05 / 1	0	0
C05 / 2	0	0
C05 / 3	0	0
Total:	6	3
C22 Costs:	$4,312	$2,734
3 Printer Changes Avoided		
$1,578 Less Depall Costs		

Table 8 Printer Change and C22 Depall Comparisons

Week # 21		
Printer	Actual	WST - MIP
CX3 Concord	0	0
CX3 Vulcan	0	0
C04 / 1	0	0
C04 / 2	0	0
C04 / 3	0	0
C05 / 1	2	0
C05 / 2	2	0
C05 / 3	1	0
Total:	5	0
C22 Costs:	$2,744	$2,040
5 Printer Changes Avoided		
$704 Less Depall Costs		

Week # 22		
Printer	Actual	WST - MIP
CX3 Concord	4	1
CX3 Vulcan	0	3
C04 / 1	2	0
C04 / 2	2	0
C04 / 3	0	2
C05 / 1	0	0
C05 / 2	0	0
C05 / 3	0	1
Total:	8	7
C22 Costs:	$2,744	$1,860
1 Printer Change Avoided		
$884 Less Depall Costs		

The final numbers for the parallel efforts revealed that WST met all necessary criteria while providing schedules that required 5.1 less label changes and $356.60 less in depalletizing costs on average per week when compared to schedules generated in the normal manner. Three weeks later, our efforts for developing WST gained formal recognition from senior management at Valley Metal Container. We implemented an interim form of WST beginning Week 25. All of the development work for WST had been formulated and tested using GAMS software licensed by the Colorado School of Mines. The computing devices utilized were slow. Most of the work was accomplished with a Pentium 166 megahertz computer configured with 32 megabytes of RAM. While most demand and inventory data solved in 5 to 15 minutes, some of the tougher scenarios took several hours to complete. We decided that a business case should be developed to provide a GAMS license for Coors. We also decided that the scheduling staff should be provided with faster workstations so that their work could proceed unimpeded by slow computing technology. The labor of scheduling personnel is very expensive and should be minimized as well.

4.2 Business Case

Coors Industrial Engineering (Bob Sadler) collaborated with Quality Engineering (Dennis Ott) to provide a business case for the capital procurement of GAMS and two Pentium 400 megahertz computers equipped with 384 megabytes of RAM. The computing machines were configured with high speed HP laser printers for fast and professional report generation by the scheduling staff. The nominal equipment cost was estimated to be $20,000.

To be conservative, an average of four less label changes per week for 50 weeks in a year was modeled for this business case. The expected loss of cans to scrap for each label changeover is 5,250. The Finance Department at VMC places the value of a can at $.027. Therefore, the total value of scrap generated during a label change is $142. A reduction of four label changeovers per week gives annual savings of $28,400. Also saved are $356.60 every week in C22 depalletizer crewing. This provides another $17,830 of annual savings. Total annual savings in scrap and depalletizer labor are $46,230.

The decrease in label changeovers yields an increase of four hours available for production each week. Because VMC meets annual customer demand, we made no claim with the business case for the retail value of the additional cans made during these four hours (opportunity costs). Savings come from higher effective line rates which allow lower non-peak inventory levels and reduced holding and storage costs. Table 9 shows the current planning rates for each can line. If a single change is eliminated on CX3 and C04, and two from C05, higher rates may be calculated. The lines do not actually run faster. They simply run an additional hour per week for each label change eliminated. Table 10 shows the direct labor costs for each line for five and seven day schedules.

Premium pay practices force continuous schedules to be greater than the ratio of seven to five the cost of a five day work week.

Table 9 Increase in Effective Line Rates With Fewer Label Changes

Line	Current Rate Cans / Hour	Changes Eliminated	Improved Rate Cans / Hour
C05	180,000	2	181,000
C04	166,000	1	166,460
CX3	133,300	1	133,800

Table 10 Direct Labor for 5 and 7 Day Schedules

Line	5 Day Schedule	7 Day Schedule
C05	$36,480	$58,640
C04	$31,920	$51,070
CX3	$27,360	$43,780

Inventory holding cost is based upon the transfer price of cans held in storage and an interest rate of .491 percent per week. This is equivalent to the annual rate of 29 percent calculated by the Coors Brewing Company. The calculation includes the cost of capital, taxes, warehousing, damage, and obsolescence. Outside storage costs are incurred when contract warehouse space is used to hold inventory. When inventory levels exceed 150 million cans, any cans added to inventory are subjected to a $.50 per thousand or $3.50 per pallet charge.

We developed a spreadsheet to determine the value of these increased effective line rates. Table 11 at the end of this chapter exhibits the final evaluation of the spreadsheet. The right side of the evaluation is made using currently established line rates. The left side uses line rates that are effectively improved by returning four hours of capacity not used by label changeovers for every week of production. The "total" row at the bottom of the spreadsheet shows that CX3 is scheduled 48 hours more with WST, but both the larger capacity lines are scheduled less. C04 is scheduled 48 hours less, and C05 is scheduled 96 hours less. The evaluation shows that WST savings are $123,000 annually. With the scrap and depalletizer labor savings reported before, the total annual savings provided by WST for the business case was $169,230.

After many meetings with users, operations managers, senior managers and financial personnel, the business case was accepted. It is estimated that another 50 hours of work went into the effort of justifying the software and hardware required to give the scheduling group ownership of WST. New capital expenditures are very difficult to have approved in the middle of a financial cycle. This type of expense is more readily accepted during budget planning periods which precede each fiscal year.

A final undocumented cost avoidance is also noted. As reported by the scheduling manager (Susan Schulze), a weekly schedule consumes approximately 3 to 4 staff hours per week to assemble. The focus of their scheduling effort is cell bin management. The strategic import from PPT is often neglected in lieu of tactics to manage cell bins. This practice tends to promote increased printer changeovers as a current week's scheduling effort compensates for poor strategic schedules produced earlier. WST not only produces a weekly schedule in minutes, but it does so with both the short term concerns of cell bin management and with the long term view provided by PPT.

Table 11 Evaluation of Improved Scheduling - $123,000 Cost Savings

Improved Rates

CX3	133800
CO4	166480
CO5	181000
Total Cost ($MM)	$7,637

wk	CX3	C04	C05	Prod	SALES	INV
						183.5
1	120	120	0	36.0	25.0	194.5
2	120	120	30	41.5	70.9	165.0
3	120	120	60	46.9	62.6	149.3
4	120	108	90	50.3	56.2	143.5
5	120	120	120	57.8	51.2	150.1
6	120	120	120	57.8	57.6	150.2
7	120	120	108	55.6	55.0	150.8
8	120	120	120	57.8	55.0	153.5
9	120	120	120	57.8	55.0	156.3
10	120	120	120	57.8	60.6	153.5
11	120	120	72	49.1	60.6	142.0
12	120	24	120	41.8	60.6	123.2
13	120	120	120	57.8	64.2	116.7
14	120	120	120	57.8	76.4	98.1
15	168	120	120	64.2	76.4	85.9
16	168	168	168	80.9	76.4	90.3
17	168	112	156	69.4	76.4	83.3
18	168	112	168	71.5	72.3	82.5
19	168	112	168	71.5	82.9	71.1
20	168	168	168	80.9	82.9	69.1
21	168	168	168	80.9	82.9	67.1
22	168	168	144	76.5	81.3	62.3
23	168	168	168	80.9	82.2	61.0
24	168	156	168	78.9	82.2	57.6
25	156	168	168	79.2	82.2	54.7
26	168	168	168	80.9	82.1	53.5
27	168	168	168	80.9	76.7	57.6
28	168	168	156	78.7	76.7	59.5
29	168	168	168	80.9	76.7	63.6
30	168	156	168	78.9	76.7	65.7
31	168	168	168	80.9	75.7	70.8
32	168	168	168	80.9	73.4	78.3
33	120	168	168	74.4	73.4	79.4
34	168	168	156	78.7	73.4	84.7
35	168	168	168	80.9	71.8	93.7
36	168	156	168	78.9	66.0	106.5
37	144	144	144	69.3	66.0	109.8
38	168	168	168	80.9	66.0	124.6
39	156	168	120	70.6	70.7	124.5
40	168	168	168	80.9	60.0	145.4
41	168	168	168	80.9	60.0	166.3
42	168	0	168	52.9	60.0	159.2
43	168	0	168	52.9	60.0	152.1
44	168	0	168	52.9	58.7	146.3
45	120	0	156	44.3	60.4	130.2
46	168	0	168	52.9	60.4	122.7
47	168	0	168	52.9	60.4	115.2
48	120	25	120	41.9	62.6	94.5
49	168	42	168	59.9	60.8	93.6
50	168	60	120	54.2	60.8	86.9
51	168	143	164	76.0	60.8	102.0
52	120	120	120	57.8	60.8	98.9
total	7824	6222	7364	3415.4	3500.0	

	$7,760,000
-	$7,637,000
	$123,000

Current Rates

CX3	133300
CO4	166000
CO5	180000
Total Cost ($MM)	$7,760

wk	CX3	C04	C05	Prod	SALES	INV
						183.5
1	120	120	0	35.9	25.0	194.4
2	120	120	30	41.3	70.9	164.8
3	120	120	60	46.7	62.6	148.9
4	120	108	90	50.1	56.2	142.9
5	120	120	120	57.5	51.2	149.2
6	120	120	120	57.5	57.6	149.1
7	120	120	108	55.4	55.0	149.5
8	120	120	120	57.5	55.0	152.0
9	120	120	120	57.5	55.0	154.5
10	120	120	120	57.5	60.6	151.4
11	120	120	72	48.9	60.6	139.8
12	120	24	120	41.6	60.6	120.8
13	120	120	120	57.5	64.2	114.1
14	120	120	168	66.2	76.4	103.8
15	120	168	168	74.1	76.4	101.6
16	168	168	168	80.5	76.4	105.7
17	168	112	156	69.1	76.4	98.3
18	168	112	168	71.2	72.3	97.3
19	168	112	168	71.2	82.9	85.6
20	168	168	168	80.5	82.9	83.3
21	168	168	168	80.5	82.9	81.0
22	168	168	144	76.2	81.3	75.8
23	168	168	168	80.5	82.2	74.2
24	168	156	168	78.5	82.2	70.5
25	156	168	168	78.9	82.2	67.3
26	168	168	168	80.5	82.1	65.7
27	168	168	168	80.5	76.7	69.5
28	168	168	156	78.4	76.7	71.1
29	168	168	168	80.5	76.7	74.9
30	168	156	168	78.5	76.7	76.7
31	168	168	168	80.5	75.7	81.4
32	168	168	168	80.5	73.4	88.6
33	120	168	168	74.1	73.4	89.3
34	168	168	156	78.4	73.4	94.3
35	168	168	168	80.5	71.8	103.0
36	168	156	168	78.5	66.0	115.5
37	144	144	144	69.0	66.0	118.5
38	168	168	168	80.5	66.0	133.0
39	156	168	120	70.3	70.7	132.6
40	168	168	168	80.5	60.0	153.1
41	168	168	168	80.5	60.0	173.7
42	168	0	168	52.6	60.0	166.4
43	168	0	168	52.6	60.0	159.0
44	168	0	168	52.6	58.7	153.0
45	120	0	156	44.1	60.4	136.7
46	168	0	168	52.6	60.4	128.9
47	168	0	168	52.6	60.4	121.2
48	120	25	120	41.7	62.6	100.3
49	168	42	168	59.6	60.8	99.1
50	168	60	120	54.0	60.8	92.2
51	168	143	164	75.7	60.8	107.0
52	120	120	120	57.5	60.8	103.7
total	7776	6270	7460	3420.2	3500.0	

CHAPTER FIVE

CONCLUSIONS AND AREAS FOR FURTHER RESEARCH

5.1 Conclusions

This research extols the benefits of mathematical programming for scheduling high speed container and packaging systems which produce goods consumed in mass quantities. Diverse container manufacturers manage flexible production systems that enable them to supply their containers to a variety of customers simply by changing the labeling applied to the containers. Under this umbrella of factors, scheduling container operations becomes an issue of producing to inventory by sequencing product labels during short planning horizons.

With this work, we developed and implemented a mixed integer program for the sequencing of label changes as an aid to scheduling within the aluminum container industry. Because this industry depends on processes that run at formidable speeds, management of inventories for meeting both daily and seasonal demand is critical. We have shown that the solution to minimizing productions costs associated with label changeover downtimes may be implemented with our mixed integer program using inventory strategies as constraints to the model. At Valley Metal Container, this model replaced a manual scheduling system that enables weekly scheduling personnel to contribute $169,230 annually in cost avoidance to their manufacturing operations.

5.2 Areas for Further Research

In addition to supplying aluminum can bodies to the Coors Brewing Company, Valley Metal Container also supplies aluminum can ends and glass bottles. The glass operations are especially interesting for further research because their production operations are fully capacitated. This means that all production lost to changing labels represents lost opportunity for sales of glass bottles. I have not studied the economic situation for our glass operations. However, as part of the work accomplished with the can container research, we determined that opportunity costs of can body production are approximately $5,000 per hour. If we multiply $5,000 by the four label changes now avoided with our new scheduling abilities for the fifty weeks of production scheduled per year, we recover 1 million dollars annually in sales. We cannot claim these costs savings until our can operations are fully capacitated.

Because the glass operations at Valley Metal Container is fully capacitated, this model offers a larger dimension in savings at their facility. Any capacity added to the glass operations due to less setups from improved scheduling represents more than cost avoidance such as experienced with this research at the can plant. The glass operations would be able to sell all products manufactured with the increased capacity. The opportunity for increased sales is much more attractive than mere cost avoidance. This research should be extended to the other operations at Valley Metal Container, but it is especially important to improve scheduling where opportunity costs can be saved.

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