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AN ECONOMIC MODEL OF THE MULTIPRODUCT LOT SCHEDULING PROBLEM APPLIED TO REFINED CERAMIC MINERAL PRODUCTS

by

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ABSTRACT

Many manufacturing companies in the minerals industry face the problem of scheduling several similar but distinct products through a parallel process utilizing a common machine that is but one of a series of different machines in the production process. This thesis presents a solution to this lot scheduling problem that is efficient, timely, and cost effective.

This thesis contains a generalized algorithm that can be used to schedule the bottleneck of a n-stage process where there is set-up/tear-down associated with the bottleneck. The objective of the algorithm is to minimize the total set-up/tear-down for a collection of products on the bottleneck machine.

A generalized n-stage scheduling procedure is also written to facilitate the scheduling of an entire n-stage process. The bottleneck is scheduled first, the stages prior to the bottleneck are then scheduled based on the bottleneck schedule and finally the stages after the bottleneck are scheduled also based on the bottleneck schedule.

Following the above definition of an algorithm and scheduling procedure, an application of the above work to a

specific case study is provided. The case study involves scheduling a ceramic material through a common machine, the bottleneck, and then scheduling the stages prior to the bottleneck followed by scheduling the stages after the bottleneck, both schedules being based on the bottleneck schedule. In order to do this, the above work was implemented into a computer in extended BASIC for a DEC PDP-11/34 computer system. This program produces the production schedule for the entire process at the plant used in the case study. The computer implementation of this work was used on a daily basis. Notification was provided by a company representative that estimated cost savings to the company in the utilization of this work by management were in excess of one million dollars in equipment costs.

DEDICATION

To TODD and DARREN

The children of my mind

and

the orphans of my soul

and

To SAM

My friend, my buddy,

and my new meaning in life

and

To T. J., BRIAN, and LORI

The greatest nephews and niece

any uncle could wish to have

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INTRODUCTION

The multiproduct lot scheduling problem is a common problem facing the ceramics industry. A simplified definition is the scheduling of a series of different materials through a set of parallel processes with a common bottleneck. The cost inherent in the reconditioning and/or cleaning of the bottleneck machine is quite large relative to the total cost of a given product (Haessler and Hogue 1976).

Algorithms concerning multiproduct lot scheduling have been evaluated for application to various other industrial materials (e.g., Bomberger 1966). The new algorithm developed here is directly applicable to the ceramic industry but is also usable for the generalized scheduling problem found in other industries. Facilities for the research necessary to this project were provided by the Coors Porcelain Company of Golden, Colorado.

During the summer of 1977, Coors faced a problem in scheduling the production of 32 ceramic products. The difficulty was created by a requirement in the third stage of a four-stage production process, viz., spray dryer cleanup. The scheduling problem was compounded throughout the four-stage process by space and equipment limitations.

This project was undertaken with the following objectives:

1. To determine whether a variant of the lot scheduling algorithm mentioned above or a new algorithm could be made to solve not just this particular scheduling problem but a general class of production scheduling problems in the mineral industries.
2. To determine whether the present method of scheduling was producing optimal results.
3. To assess the possibility of effectively computerizing either the present or an alternative method of scheduling.
4. To develop for consideration alternative scheduling methods.
5. To analyze the existing physical plant, including layout, production routing, equipment type, size and state-of-the-art, for necessary revision, elimination, replacement, or addition of processing units.

This list of objectives had to be accomplished using the following process:

1. Ball mill the raw materials
2. Mix the resulting output in slurry tanks

3. Dry the slurry in a spray dryer
4. Store the completed product

At the time, the facility produced 32 different finished materials using this four-stage job process. Coors calls these finished products "bodies," a term that will be used hereafter. The final products marketed by this company were manufactured from these bodies.

In performing the scheduling function, the variables taken into consideration for each product are as follows:

1. Choice and amount of body to be produced
2. Milling time for each body
3. Mixing time
4. Spray dryer processing and cleanup time
5. Storing of the product in the proper storage facilities

There are also capacity variables associated with scheduling several bodies for processing during a given time period. They are as follows:

1. Ball mill capacity
2. Spray dryer capacity and cleanup time
3. Slurry tank capacity
4. Spray dry storage capacity

The cost variables are loading, emptying, and cleaning the ball mills, slurry tanks, spray dryers, and storage facilities. The most costly variable associated with this four-stage process is cleaning the spray dryer. This cost is sequence-dependent on the order of processing the products. The resemblance of this scheduling problem to the initial statement of the multiproduct lot-sizing problem at the beginning of this thesis is evident.

Of the two available spray dryers, only one presents a scheduling problem since the smaller capacity dryer is used only to dry six regular production bodies. The larger spray dryer is used to dry each of 26 regular production bodies. For purposes of this dissertation, the existence of only one bottleneck is assumed.

In association with this bottleneck, there are seven types of cleanup, so that from a cost basis, the spray drying is the critical phase of the four stages. The specific objective in scheduling is to minimize the total cleanup time (and thus the cost) associated with the dryer for a particular work flow forecast. Given, then, a schedule of bodies for production, the spray dryer is scheduled first, while the remaining three phases of the production process have a schedule based on the sequence of bodies completing the spray dryer phase.

This thesis deals with the techniques involved in scheduling the spray dryer, and thus the other three stages, in an efficient manner. The relevance of this scheduling technique to various other industrial materials with similar processing requirements is apparent.

Based on the literature reviewed in Chapter 1 and the work done on the project, a more general approach to problem definition in ceramic lot sizing is developed. Further, this technique's utility in the Coors facility is analyzed as evidence of feasibility.

In addition to the applicability of this technique to the specific problem treated in this study, the scheduling techique for this four-stage job process has application in other industries, e.g., pharmaceutical manufacturing (Bott 1980) and food manufacturing (Goldman 1980).

CHAPTER 1

LITERATURE REVIEW

The available publications which address the problem of scheduling multiple products on a single machine are Afentakis (1985); Baker (1983); Boctor (1982); Carpaneto, Martello, and Toth (1984); Doll and Whybark (1973); Elmaghraby (1968); Fox (1983); Gavett (1965); Gensch (1978); Glover, Klingman, and Phillips (1985); Goyal (1973; 1975); Graves and Haessler (1978); Haessler (1971; 1979); Hsu (1983); Kurtulus and Davis (1982); Madigan (1968); Newson (1975); Oliff and Burch (1985); Parsons (1966); Rogers (1958); Saipe (1977); Schweitzer and Silver (1983); Silver (1978); Taha and Skeith (1970); Thizy and Van Wassenhove (1985); Vemuganti (1978); Vonderembre and Hasselen (1982); Woolsey (1982); and Williams (1975). These papers make it evident that little has been accomplished regarding the scheduling of multiple products through a four-stage process where one of the machines necessarily dictates the schedule of the remaining three machines.

The machine that controls the scheduling could be any of the four; however, the present investigation deals with the No. 3 machine as being crucial. This situation was chosen as the problem because of a locally available model which could generate the data necessary for the development of an algorithm.

The scheduling method used here is applicable to any position of the critical machine. Comments are made later on the utility of this method as applied to cases other than the one specifically addressed.

A typical problem is the minimization of set-up/tear-down time on one machine (Woolsey and Swanson 1975). Applications of earlier techniques are seen in the food processing industry (Goldman 1980) and the pharmaceutical industry (Bott 1980). Goldman defines, on pages 2 and 3 of his thesis, the classical lot scheduling problem.

Treatment of the problem always assumes that demand for the products has been determined prior to the scheduling of the four-stage process. Demand is based on the forecast for a determined number of future time periods. When this demand has been determined, it must be adjusted to correspond with a lot size that will fit into the four-stage process.

Once the output required is known and the economic batch size for each of the outputs is determined, it is necessary to schedule the one machine that controls the scheduling of the others. This critical machine is the bottleneck. In this project case the bottleneck also happens to be the machine with the greatest operating cost. Although not always the case, the solution reached here is applicable regardless of relative operating costs.

In order to adequately schedule a four-stage process of this nature, it is necessary and sufficient to have deterministic values for the following information:

1. Product type demand
2. Processing time of the various machines
3. Relationships between product type and machine types; e.g., some products can only be processed on certain machines

Earlier authors (Doll and Whybark 1973) assume that for problems of this type, the following characteristics are usually found:

1. Only one product can be produced at a time on a machine.
2. Product production rates are deterministic and constant.
3. Product set-up costs and times are independent of production order.
4. Product demand rates are deterministic and constant.

5. Demand must be met in the periods in which it occurs.
6. Inventory costs are directly proportional to inventory levels.
7. Production capacity is sufficient to meet total demand.

More recent literature (Hsu 1983, Thizy and Van Wassenhove 1985) validates the above criteria.

This thesis deals with a problem possessing the same characteristics, with the exception of characteristic number 6. In the problem studied, inventory costs were directly proportional to batch sizes.

Numerous attacks have been made on problems of this nature. Apparently, none of the developed methods have actually been used, perhaps due to complexity and perhaps due to corporate reluctance. Doll, Whybark, Haessler, and Goyal were all contacted (Woolsey 1982) and knew of no actual application of these methods. Doll and Whybark (1973) developed a tentative procedure to determine "near optimal" frequencies of production by calculating fundamental cycle times. Later, Haessler and Hogue (1976) extended this procedure to check for solution feasibility and to adjust the fundamental cycle time and production frequency in a systematic manner until a feasible solution was obtained. Additional work on this problem was performed by Elmaghraby (1978), and his work also provided a means for retreating from an impractical and economically unsound solution and determining a procedure for returning to a feasible schedule. Goyal (1973) experimented with an extension of the work performed by Doll and Whybark (1973) by developing an iterative scheme to obtain a more feasible schedule. Kurtulus and Davis (1982) designed a heuristic using two measures: total resource requirements and rate of utilization of each resource type. Mathematical programming was used by Vonderembse and Haessler (1982) to schedule a simple production process in the steel industry. Glover, Klingman, and Phillips (1985) developed a polynomially bounded shortest path algorithm called the PSP algorithm to find the shortest path from one node in a network to all other nodes in the network. At Owens-Corning Fiberglas, Oliff and Branch (1985) used an undefined heuristic to schedule production of glass fiber products. Thizy and Van Wassenhove (1985) introduced a heuristic primal partitioning scheme to schedule the multi-item capacitated lot-sizing problem which also used a Lagrangean relaxation of the capacity constraints. Transforming a lot-sizing problem to an equivalent job-shop scheduling problem by using production costs was designed by Afentakis (1985).

Several heuristic approaches were developed in the earlier years (Madigan 1968), (Stankard and Gupta 1969). Dynamic programming, linear programming, and several tailored algorithms have been used to attack this particular type of problem (Bomberger 1966). Linear programming does not solve scheduling problems well when there are discrete products and machines involved, because it assumes continuous processes. Integer programming has been unsuccessful because the optimization techniques available rarely reach an optimal solution. Dynamic programming is unreasonable because of time constraints and the requirement of an immense amount of high-speed storage. Most analytical techniques propounded have attempted to achieve the optimum solution of an artificial version of the original problem (Elmaghraby 1978). Recently, there has been an introduction of computer software to solve production scheduling problems. The OPT (Optimized Production Technology) package marketed by Creative Output, Inc., for $40,000 contains an undocumented heuristic that claims to schedule the bottleneck of a n-stage process. This package does not claim to produce an optimal solution. Fox (1983) has produced a software package called ISIS, named after the Egyptian goddess, that is designed to schedule a n-stage process, but little emphasis is placed on the scheduling of the bottleneck. It is important to note that previous work has centered on the production of multiple products on the one machine with the restrictive characteristics.

In this four-stage process, it is essential to clean the bottleneck machine after each use unless the next body in the machine is quite closely related to the previous body. The solution process of this thesis consists of heuristic algorithms and optimal algorithms used together to successfully schedule the four-stage process.

The four-stage process that is being used by the Coors Porcelain Company is defined in the next chapter. Each of the four stages is examined in detail so that a complete understanding of the problem is possible.

CHAPTER 2

PROBLEM STATEMENT

The Coors Porcelain Company of Golden, Colorado, produces a multitude of ceramic products for various industries--mining, automotive, electronic, atomic, energy, chemical, petroleum, defense, and other high technology industries. The ceramic products are all manufactured from a base referred to as a "ceramic body." Coors produces 32 ceramic bodies that differ in the kind and amount of raw material that goes into the manufacture of each.

One of the most important differences among ceramic bodies from a scheduling viewpoint is the percentage of alumina (Al_2O_3) in the body. The organizational unit that produces these ceramic bodies is the Ceramic Material Preparation Department or CMP department. The CMP department has a supervisor, three shift foremen, and production workers who load and operate the various machines. The operation of the machines in the CMP department constitutes what the literature calls a four-stage process (Figure 1).

The first stage consists of six ball mills of differing sizes (three that will each handle 6,000 pounds of body; two that will each handle 12,000 pounds of body; and one that

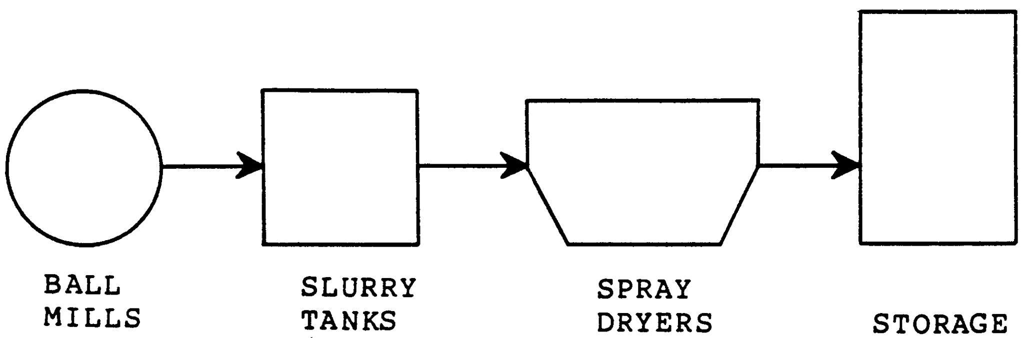

FIGURE 1

FOUR-STAGE PROCESS

will handle 4,000 pounds of body). These six mills are numbered 12 through 17 (Table 1). Ball mills 13 and 16 are belt-driven machines, whereas the other four are direct-drive machines using conventional drive shaft technology. Scheduling is complicated by the fact that only the lighter ceramic bodies can be processed with the belt-driven machines. Located in the plant basement, these mills are loaded from above through trap doors. Each ball mill has its own trap door, and it is necessary for each ball mill to be brought to proper position before loading.

Associated with each ceramic body is a "recipe" that dictates the kind and amount of each raw material that makes up the body. The recipe also dictates how long each body is milled, which can range from one to 20 hours. The purpose of the milling stage is to produce a homogeneous wet mixture of the body. For this stage it is necessary to charge the mill with the additional ingredients required by the particular recipe, mill for the requisite time, empty the ball mill when milling is complete and quality control is satisfied with the mixture, and clean the machine.

Standard times have been determined for loading, charging, emptying, and cleaning of these mills. Water is used in all recipes to create the wet mixture. Ceramic balls are used as the grinding media in the mill.

TABLE 1

BALL MILLS

Number	Capacity
BM-12	6,000 lbs.
BM-13	4,000 lbs.
BM-14	6,000 lbs.
BM-15	6,000 lbs.
BM-16	12,000 lbs.
BM-17	12,000 lbs.

The second stage of the process consists of 18 mixing/storage tanks called "slurry tanks." The purpose of these tanks is to mix the output from several ball mill runs together to produce a homogeneous, consistent mixture of ceramic body for further processing. The ceramic body is stored in these tanks until the entire batch is milled. The slurry tanks are numbered 68 through 89 with the omission of the numbers 71, 82, 85, and 86. The capacity of these slurry tanks ranges from 8,000 pounds to 35,000 pounds (Table 2). When an entire batch of ceramic body is milled, it must all pass through the slurry tanks before transfer to the third stage of the process.

Since there are 18 slurry tanks with various capacities, it is possible to have a maximum of 18 different ceramic bodies stored at one time. Once the entire batch of a particular run is in the slurry tanks, all the tanks containing this particular body are connected in parallel to provide a consistent homogeneous mixture to the third step of the process. After the tanks are emptied, they must be washed to prevent contamination of the next batch.

The third stage of the four-stage process consists of two spray dryers. These spray dryers are connected to the slurry tanks and receive the body in slurry form through a

TABLE 2

SLURRY TANKS

Number	Capacity
ST-68	15,000 lbs.
ST-69	35,000 lbs.
ST-70	35,000 lbs.
ST-72	15,000 lbs.
ST-73	15,000 lbs.
ST-74	15,000 lbs.
ST-75	15,000 lbs.
ST-76	30,000 lbs.
ST-77	15,000 lbs.
ST-78	15,000 lbs.
ST-79	30,000 lbs.
ST-80	8,000 lbs.
ST-81	8,000 lbs.
ST-83	30,000 lbs.
ST-84	30,000 lbs.
ST-87	35,000 lbs.
ST-88	35,000 lbs.
ST-89	35,000 lbs.

series of pipes and hoses. Spray dryer No. 1 is a small dryer with a capacity of 1,000 pounds per hour, and spray dryer No. 2 has a maximum drying capacity of 4,000 pounds per hour (Table 3). For each body, there is a determined pounds-per-hour spray drying rate.

The spray dryers represent the bottleneck of the four-stage process. Cleaning of the dryers is the most time consuming and costly step of the four-stage process, and it is therefore imperative to schedule the bodies through the dryers in a sequence that will minimize total cleanup time for a scheduling period consisting of seven days. After a particular body is spray dried, spray dryer No. 1 must undergo one of two types of cleaning, one that takes almost zero hours, i.e., essentially no cleanup, and one that takes 20 hours.

There are seven different types of cleanup associated with spray dryer No. 2 and the time inherent in these is 0 hours, 4 hours, 5 hours, 9.7 hours, 11.2 hours, 16.9 hours, and 20 hours. The type of cleaning is determined by the next body to be spray dried.

The fourth stage of the four-stage process consists of several different types of spray-dry storage facilities. Third stage output is stored in the type of spray dry storage facility that is sufficient for that particular

TABLE 3

SPRAY DRYERS

Number	Capacity
SD-1	1,000 lbs/hour
SD-2	4,000 lbs/hour

body. For this stage, there exist four 100,000 lb. capacity silos, five 15,000 lb. capacity zipper tanks, nine 28,000 lb. capacity standardizers, and one 24,000 lb. capacity standardizer. There are also miscellaneous storage devices called tote tanks (3,000 pound capacity), bags (2,000 pound capacity), and barrels (500 pound capacity). Storage facilities and capacities are listed in Table 4.

Throughout the four-stage process, it is necessary to maintain batch integrity. For this to be accomplished, the spray dry storage facility must be completely empty and cleaned before another batch is stored. Contamination of a ceramic body cannot be tolerated, since marketability of the finished ceramic product is heavily dependent upon the purity of the product.

It is noted that the peculiarities of the Coors situation do not affect the generalization of the algorithm, which was developed with a view toward the solution of any multi-stage lot scheduling problem; however, as with any general tool, a specific edge must be honed to do a specific job, and modification of the algorithm for a particular use will obviously be necessary in any given application.

TABLE 4

STORAGE

STANDARDIZERS

Number	Capacity
S-30	28,000 lbs.
S-31	28,000 lbs.
S-32	24,000 lbs.
S-33	28,000 lbs.
S-35	28,000 lbs.
S-36	28,000 lbs.
S-37	28,000 lbs.
S-38	28,000 lbs.
S-39	28,000 lbs.

ZIPPER TANKS

Number	Capacity
ZT-40	15,000 lbs.
ZT-41	15,000 lbs.
ZT-42	15,000 lbs.
ZT-43	15,000 lbs.
ZT-44	15,000 lbs.

(Continued)

TABLE 4 (Continued)

STORAGE

SILOS

Number	Capacity
S-1	100,000 lbs.
S-2	100,000 lbs.
S-3	100,000 lbs.
S-4	100,000 lbs.

MISCELLANEOUS

Type	Capacity
Tank	3,000 lbs.
Barrel	500 lbs.
Bag	2,000 lbs.

CHAPTER 3

THEORETICAL DEVELOPMENT

There are two general problems addressed by this thesis. One is the development of a generalized algorithm to schedule the bottleneck of a n-stage process, and the other is the development of a generalized n-stage scheduling procedure to schedule a n-stage process.

It is appropriate, at this point, to present a generalized scheduling algorithm that can be used for a variety of production problems. This algorithm should have a name that is suitable for any of these production scheduling situations.

Bottleneck Scheduling Algorithm

Conditions. A collection of products, each requiring a certain amount of processing time, needs to be processed through a machine that is the bottleneck in a n-stage process. Preparation (set-up/tear-down) time must be applied before the machine can process the next product. Preparation (set-up/tear-down) time is substantial and costly, and the total preparation time for a collection of products is a function of the sequence of the products.

A single product quality variable determines the preparation (set-up/tear-down) time. The last product processed in the previous production schedule through this bottleneck is known.

Objective. Schedule the bottleneck to minimize the total amount of preparation (set-up/tear-down) time for a collection of products.

1. Determine the products to be processed.
2. Identify the product quality variable influencing preparation (set-up/tear-down) time.
3. Select a unit of measure for this product quality variable and assign a numerical value to each of the products in step 1 according to this product quality variable.
4. Arrange the products from step 1 in either descending value order or ascending value order as determined in step 3 depending on whether a lower bound on product quality is desired or an upper bound on product quality is desired. Assign product numbers from 1 to n according to this numerical sequence.
5. Start the schedule with the same product that was last processed in the previous schedule if that product is demanded. If this product is not

demanded, start the schedule with the next demanded product, after the product last processed, in the numerical sequence from step 4. When the end of the numerical sequence from step 4 is reached, the next product processed will be no. 1 and continue the schedule following the numerical sequence until the demanded collection has been scheduled.

6. Determine the preparation (set-up/tear-down) time necessary for each pair of consecutive products in the step 5 sequence.
7 For the sequence of products and preparation (set-up/tear-down) times from steps 5 and 6, calculate the starting and finishing times for processing each of the products and the starting and finishing times for each of the preparations.
8. Schedule the bottleneck using the results of step 7.

To schedule all n stages of the process, the following generalized n-stage scheduling procedure was developed. The m^{th} stage of the procedure is the bottleneck.

Generalized N-stage Scheduling Procedure

1. Determine the demand for each of the products for time period 1 through time period n.
2. Reduce the demand in time period 1 through time period n for each of the products to reflect the finished inventory of each of the products and also to reflect the in-process inventory of each of the products.
3. Assign group numbers to each of the products:

   Group 1 - products with demand in time period 1.

   Group 2 - products with demand in time period 2 and demand in time period 1 is 0.

   .

   .

   .

   Group n - products with demand in time period n and demand in time periods 1 through n-1 is 0.
4. Add demands for time period 1, time period 2, ... , time period k for each of the group 1 products.

   Add demands for time period 2, time period 3, ... , time period k for each of the group 2 products.

.

.

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The demand for each of the group n products is simply the demand for time period n.

Note: k represents number of time periods to be reflected in the production schedule.

5. Determine the schedule for the bottleneck, the m^{th} stage of the process, by using the Bottleneck Scheduling Algorithm. Group 1 products are scheduled first, group 2 products are scheduled second, ..., group n products are scheduled last.
6. Schedule the m-1 stages before the bottleneck by using the schedule generated in step 5 for the bottleneck. Schedule in the order--stage 1 through stage m-1.
7. Schedule the n-m stages after the bottleneck using the schedule generated in step 5 for the bottleneck. Schedule in the order--stage m+1 through stage n.

Analysis of the scheduling of the bottleneck resulted in the discovery of three sufficient conditions for an optimal solution to the scheduling of the bottleneck.

Optimality is defined in the sense of minimizing the total amount of preparation (set-up/tear-down) time.

Suppose n products exist that can be processed using a given machine and they are designated as P-I where I ranges from 1 to n. The n products are in descending or ascending order of some defined measure of product quality. Assume the following n x n matrix of preparation times exists such that C_{ij} represents the hours of preparation that are necessary between the end of the processing of product P-I and the beginning of the processing of product P-J.

	P-01	P-02	P-03	P-04	...	P-(n-1)	P-n
P-01	$C_{1,1}$	$C_{1,2}$	$C_{1,3}$	$C_{1,4}$	...	$C_{1,n-1}$	$C_{1,n}$
P-02	$C_{2,1}$	$C_{2,2}$	$C_{2,3}$	$C_{2,4}$	...	$C_{2,n-1}$	$C_{2,n}$
P-03	$C_{3,1}$	$C_{3,2}$	$C_{3,3}$	$C_{3,4}$	...	$C_{3,n-1}$	$C_{3,n}$
P-04	$C_{4,1}$	$C_{4,2}$	$C_{4,3}$	$C_{4,4}$	...	$C_{4,n-1}$	$C_{4,n}$
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
P-(n-1)	$C_{n-1,1}$	$C_{n-1,2}$	$C_{n-1,3}$	$C_{n-1,4}$	...	$C_{n-1,n-1}$	$C_{n-1,n}$
P-n	$C_{n,1}$	$C_{n,2}$	$C_{n,3}$	$C_{n,4}$	...	$C_{n,n-1}$	$C_{n,n}$

<u>Pence's Theorem.</u> Given the above n x n matrix, the three sufficient conditions for which the sequence P-01, P-02, P-03, ..., P-(n-1), P-n is optimal in terms of minimizing the total amount of preparation time are as follows:

1. $C_{ij} >= C_{ji}$ for $1<=j<i<=n$.
2. For each row i = 1 to n, the C_{ij}'s in row i are monotonically nondecreasing for $i<=j<=n$.
3. For each column j = 1 to n, the C_{ij}'s in column j are monotonically nonincreasing for $1<=i<=j$.

<u>Proof.</u> (by mathematical induction)

1. Prove the theorem is true for the first nontrivial case where n = 3 products. Proof consists of examining the 3! or 6 different sequences that can be produced from the three products to determine if the sequence P-01 P-02 P-03 is optimal.

	TO	P-01	P-02	P-03	Product Quality
	P-01	C_{11}	C_{12}	C_{13}	99.0
FROM	P-02	C_{21}	C_{22}	C_{23}	98.0
	P-03	C_{31}	C_{32}	C_{33}	96.0

Sequence	Hours of preparation
P-01 P-02 P-03	$C_{12} + C_{23} = Z$
P-01 P-03 P-02	$C_{13} + C_{32} >= Z$

since $C_{13} >= C_{12}$ by 2 and $C_{32} >= C_{23}$ by 1.

P-02 P-01 P-03	$C_{21} + C_{13} >= Z$

since $C_{21} >= C_{12}$ by 1 and $C_{13} >= C_{23}$ by 3.

P-02 P-03 P-01	$C_{23} + C_{31} >= Z$

since $C_{23} = C_{23}$ and $C_{31} >= C_{13} >= C_{12}$ by 1 and 2.

P-03 P-01 P-02	$C_{31} + C_{12} >= Z$

since $C_{31} >= C_{13} = C_{12}$ by 1 and 2 and $C_{12} = C_{12}$.

P-03 P-02 P-01	$C_{32} + C_{21} >= Z$

since $C_{32} >= C_{23}$ by 1 and $C_{21} >= C_{12}$ by 1.

2. Assume theorem is true for n-1 products, i.e., for any n-1 products that satisfy the conditions of the theorem, the sequence P-01 P-02 ... P-(n-1) is optimal.

3. Prove theorem is true for n products. Assume P is an operator that represents a permutation of the products P-01, ..., P-n, e.g., P = P(P-01, ..., P-n) represents any permutation of the n products P-01, ..., P-n. Let C be an operator that represents the total amount of preparation time for a permutation of the products P-01, ..., P-n, e.g.,

C = C(P-01 ... P-n) represents the total preparation time for the sequence of n products P-01 ... P-n. The conjectured optimal sequence is represented by $P_0 = P_0$(P-01, ..., P-n) = P-01 ... P-n. C(P_0) is the total preparation time for the conjectured optimal sequence.

Case I.

P-n stays in position n and there is a random permutation of P-01, ..., P-(n-1). So P = P(P-01, ..., P-n) = P(P-01, ..., P-(n-1))P-n.

C(P) = C(P(P-01, ..., P-(n-1))) + $C_{r,n}$
where r is any one of the products
P-01, ..., P-(n-1).

C(P) >= C(P_0(P-01, ..., P-(n-1))) + $C_{r,n}$
since C(P(P-01, ..., P-(n-1)))
>= C(P_0(P-01, ..., P-(n-1))) by the assumption that the theorem is true for n-1 products.

C(P) >= C(P_0(P-01, ..., P-(n-1))) + $C_{n-1,n}$ = C(P_0)
since $C_{r,n}$ >= $C_{n-1,n}$ where r <= n-1 by condition 3 of the theorem.
Therefore, C(P) >= C(P_0).

Case II.

There is a random permutation of P-01, ..., P-(n-1) and P-n is placed in position 1.

So P = P(P-01, ..., P-n) = P-nP(P-01, ..., P-(n-1)).

$C(P) = C_{n,k} + C(P(P\text{-}01, \ldots, P\text{-}(n-1)))$
where k is any one of the products P-01, ..., P-(n-1).

$C(P) >= C_{n,k} + C(P_0(P\text{-}01, \ldots, P\text{-}(n-1)))$
since $C(P(P\text{-}01, \ldots, P\text{-}(n-1)))$
$>= C(P_0(P\text{-}01, \ldots, P\text{-}(n-1)))$ by the assumption that the theorem is true for n-1 products.

$C(P) >= C_{n-1,n} + C(P_0(P\text{-}01, \ldots, P\text{-}(n-1)))$
$= C(P_0)$
since $C_{n,k} >= C_{k,n} >= C_{n-1,n}$ by conditions 1 and 3 of the theorem.

Therefore, $C(P) >= C(P_0)$.

Case III.

There is a random permutation of P-01, ..., P-n and P-n ends up between P-k and P-r where P-k and P-r are any two of the products P-01, ..., P-(n-1).

So P = ... P-k P-n P-r P-s ....

For r > k

$$C(P) = C(\ldots P\text{-}k) + C_{k,n} + C_{n,r} + C_{r,s} + C(P\text{-}s \ldots)$$
$$>= C(\ldots P\text{-}k) + C_{k,r} + C_{n,r} + C_{r,s} + C(P\text{-}s \ldots)$$
$$= C(P(P\text{-}01, \ldots, P\text{-}(n-1))) + C_{n,r}$$

since $C_{k,n} >= C_{k,r}$ for r > k by condition 2 of the theorem.

$$C(P) >= C(P_0(P\text{-}01, \ldots, P\text{-}n) + C_{n,r}$$

since C(P(P-01, ..., P-(n-1)))

$>= C(P_0(P\text{-}01, \ldots, P\text{-}(n-1)))$ by the assumption that the theorem is true for n-1 products.

$$C(P) >= C(P_0(P\text{-}01, \ldots, P\text{-}(n-1))) + C_{n-1,n} = C(P_0)$$

since $C_{n,r} >= C_{r,n} >= C_{n-1,n}$ by conditions 1 and 3 of the theorem.

Therefore, $C(P) >= C(P_0)$.

For k > r

$$C(P) = C(\ldots P\text{-}k) + C_{k,n} + C_{n,r} + C_{r,s} + C(P\text{-}s \ldots)$$
$$>= C(\ldots P\text{-}k) + C_{k,n} + C_{k,r} + C_{r,s} + C(P\text{-}s \ldots)$$

$= C(P(P\text{-}01, \ldots, P\text{-}(n-1))) + C_{k,n}$

since $C_{n,r} >= C_{k,r}$ for $k > r$ by conditions 1 and 3 of the theorem.

$C(P) >= C(P_0(P\text{-}01, \ldots, P\text{-}(n-1))) + C_{k,n}$

since $C(P(P\text{-}01, \ldots, P\text{-}(n-1)))$

$>= C(P_0(P\text{-}01, \ldots, P\text{-}(n-1)))$ by the assumption that the theorem is true for n-1 products.

$C(P) >= C(P_0(P\text{-}01, \ldots, P\text{-}(n-1))) + C_{n-1,n} = C(P_0)$

since $C_{k,n} >= C_{n-1,n}$ by condition 3 of the theorem.

Therefore, $C(P) >= C(P_0)$.

This theorem does not address the role of the restart, i.e., theorem only deals with the three sufficient conditions for an optimal sequence of the products P-01, ..., P-n. The role of the restart is handled by the Bottleneck Scheduling Algorithm.

Further investigation shows that not one of these three conditions is necessary for an optimal solution. This is illustrated by the following example. The example is constructed so that none of the three conditions is satisfied for a given optimal sequence.

		TO	P-01	P-02	P-03	P-04	Product Quality
	P-01		0	1	3	1	90.0
FROM	P-02		3	0	1	3	98.0
	P-03		2	0	0	1	96.0
	P-04		4	2	3	0	95.0

CODE	PREPARATION TIME
0	0 HOURS
1	1 HOURS
2	2 HOURS
3	3 HOURS

Sequence	Hours of preparation
P-01 P-02 P-03 P-04	3
P-01 P-02 P-04 P-03	7
P-01 P-03 P-02 P-04	6
P-01 P-03 P-04 P-02	6
P-01 P-04 P-02 P-03	5
P-01 P-04 P-03 P-02	4
P-02 P-01 P-03 P-04	7
P-02 P-01 P-04 P-03	7
P-02 P-03 P-01 P-04	4
P-02 P-03 P-04 P-01	6
P-02 P-04 P-01 P-03	10

P-02 P-04 P-03 P-01	8
P-03 P-01 P-02 P-04	6
P-03 P-01 P-04 P-02	5
P-03 P-02 P-01 P-04	4
P-03 P-02 P-04 P-01	7
P-03 P-04 P-01 P-02	6
P-03 P-04 P-02 P-01	6
P-04 P-01 P-02 P-03	6
P-04 P-01 P-03 P-02	7
P-04 P-02 P-01 P-03	8
P-04 P-02 P-03 P-01	5
P-04 P-03 P-01 P-02	6
P-04 P-03 P-02 P-01	6

Inspection of these 24 sequences shows that there is only 1 optimal solution. It is critical to note that this optimal sequence, P-01 P-02 P-03 P-04, corresponds to the sequence of the bodies in the row (column). This example satisfies none of the three requirements for the unique optimal solution.

CHAPTER 4

PROBLEM SOLUTION

During the summer of 1977, the management of Coors Porcelain was asked by the CMP (Ceramic Material Preparation) department to increase the production capacity of all four stages of the CMP department. Management was naturally reluctant to spend capital to improve a department that they did not know how to schedule or control. It was the contention of the CMP department that they did not have enough capacity to produce the body demanded by the production departments. Management realized that the output of the CMP department could be increased if the department was not presently being scheduled optimally. No one really knew if the department was being scheduled in the best possible manner; neither did anyone in management or industrial engineering really understand how to schedule production through the four stages.

The overall problem was to design a procedure for the scheduling of these four stages. The objective was to design a scheduling procedure that would make the best use of the equipment and could be understood by all the parties involved. After this investigator extensively interviewed the people in the CMP department and the Quality Control department, it was determined that the critical stage of this four-stage process was the third stage called spray drying. A very large amount of time was spent cleaning the spray dryer before a new body could be dried. During cleaning, all production was stopped, creating a relatively large amount of idle time. The cleaning was necessary to prevent contamination of the next body.

This scheduling problem can be formulated as a costed-network problem and as a 0-1 integer programming problem.

(A) Formulation as a Costed-Network Problem.

Consider, for example, the 3 x 3 problem with the cost matrix shown below where C_{ij} represents the cleaning, in hours, it takes to go from body i to body j.

		TO BODY		
		1	2	3
	1	C_{11}	C_{12}	C_{13}
FROM BODY	2	C_{21}	C_{22}	C_{23}
	3	C_{31}	C_{32}	C_{33}

This problem may be formulated as a costed-network as seen in Figure 2 where the definition in the arcs is (cost from node i to node j, upper bound in flow, lower bound in flow). Note that this problem may be collapsed into the network illustrated in Figure 3.

The return arc with a large negative cost is really equivalent to a profit, thus driving the out-of-kilter or appropriate lot minimizing algorithm to completion. Further, the upper and lower bound on the return arc of 1 requires that a flow of 1 unit through the network will define the appropriate minimum path. The 3 x 3 problem generates 4 nodes and 5 arcs. For a 4 x 4 problem the collapsed network definition would be as shown in Figure 4. The above 4 x 4 problem generates 11 nodes and 16 arcs.

For a n x n problem,

$$\text{the number of arcs} = 1 + \sum_{j=1}^{n-1} \prod_{k=1}^{j} (n-k).$$

For the problem associated with this dissertation,

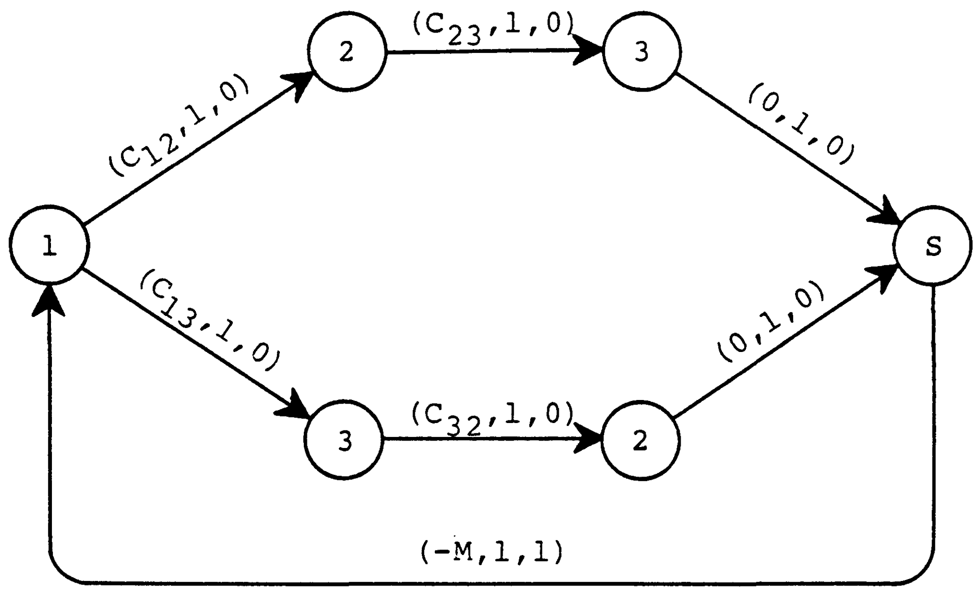

FIGURE 2

3 X 3 COSTED-NETWORK MODEL

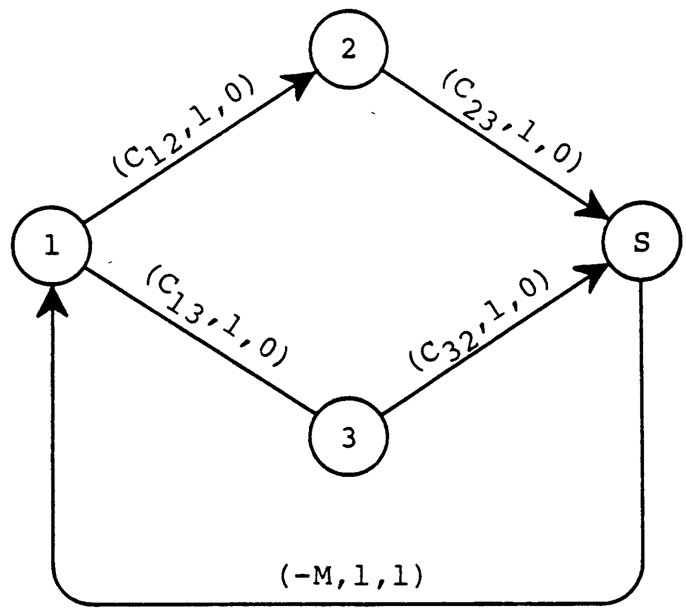

FIGURE 3

COLLAPSED 3 X 3 COSTED-NETWORK MODEL

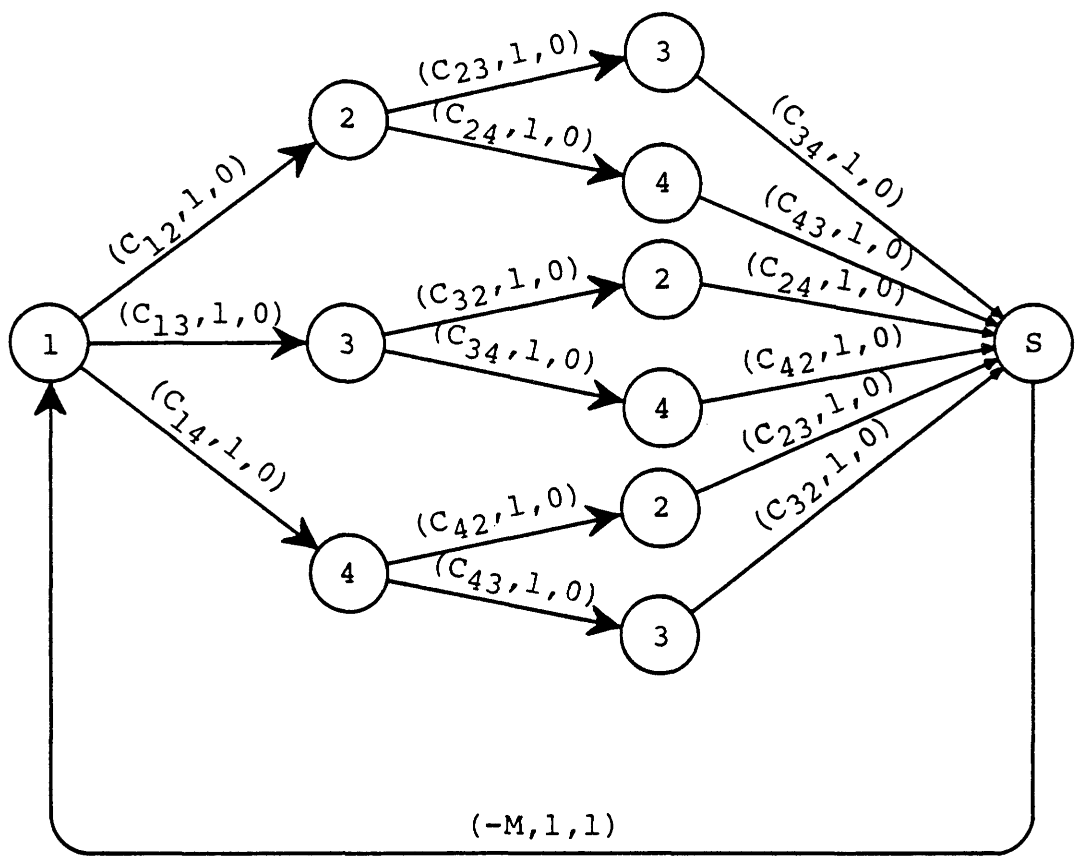

FIGURE 4

COLLAPSED 4 X 4 COSTED-NETWORK MODEL

$$\text{the number of arcs} = 1 + \sum_{j=1}^{26} \prod_{k=1}^{j} (27-k).$$

The number of nodes generated would be of the same magnitude. It would be impossible to build an actual network model of this size for 27 bodies.

(B) Formulation as a 0-1 Integer Programming Problem. The variables for this model are defined as follows:

X_{ij} = 1 if body type j <u>immediately</u> follows body type i in the sequence of bodies to be spray dried.

X_{ij} = 0 if body type j <u>does</u> <u>not</u> <u>immediately</u> follow body type i in the sequence of bodies to be spray dried.

C_{ij} = amount of cleaning in hours that takes place between body i and body j.

Objective function for this model:

Min Z (total hours of cleanup)

$$= \sum_{i=1}^{27} \sum_{j=1}^{27} C_{ij} X_{ij}.$$

The constraints for this model take the following form:

$$\sum_{j=1}^{27} X_{ij} = 1 \text{ for every } i = 1 \text{ to } 27.$$

These constraints require that each body be followed by another body in the sequence of bodies to be spray dried.

$$\sum_{i=1}^{27} X_{ij} = 1 \text{ for every } j = 1 \text{ to } 27.$$

These constraints require that each body be preceded by another body in the sequence of bodies to be spray dried.

It is also necessary to introduce constraints that will prevent loops within the sequence of bodies to be spray dried. These constraints take the following form:

$$U_i - U_j + 27X_{ij} <= 26 \qquad \text{for } 1<=i,j<=27$$

where U_i, U_j are arbitrary real numbers.

This would result in an additional 27 x 27 or 729 constraints.

These constraints are also be defined as follows by McMillan (1970):

Let $(i_1\ i_2\ \ldots\ i_{27})$ be a permutation of the integers 1 through 27. The constraints would be defined as follows:

$$X_{i_1,i_2} + X_{i_2,i_3} + \ldots + X_{i_{r-1},i_r} + X_{i_r,i_1} <= r-1 \text{ where } r = 2 \text{ to } 13.$$

r value	number of constraints
2	2! = 2
3	3! = 6
4	4! = 24
5	5! = 120
6	6! = 720
7	7! = 5,040
8	8! = 40,320
9	9! = 362,880
10	10! = 3,628,800
11	11! = 39,916,800
12	12! = 479,001,600
13	13! = 6,227,020,800

The point is that the formulation of this scheduling problem as a 0-1 Integer Programming problem results in a model that is economically unrealistic to solve using state-of-the-art techniques for integer programming. It would be necessary to construct an integer program that could handle (for 27 bodies) 27! different sequences. The reason for the discussion above is to demonstrate that classical formulation methods of operations research, at this time, are absolutely unsuitable. Thus, a new method and approach is necessary.

It was determined that the principal characteristic of a body is its alumina content. The alumina content of a particular body could be slightly increased without violating specifications, but could not be decreased. Drying a 98% body after a 99% body had been dried required essentially no cleaning of the dryer because the presence of the 99% body would do nothing more than increase the alumina content of the 98% body; however, drying a 99% body after a 98% body had been dried would decrease the alumina content of the 99% body. The lowering of the alumina content could not be tolerated for quality control reasons; therefore, in this case, the careful cleaning of the dryer was essential.

Let A_i be the alumina content of the i^{th} body. An initially perceived solution would be to begin by ordering the jobs so that $A_1 > A_2 > ... > A_n$. This ordering in decreasing order of alumina content was suggested as a logical arrangement that had not been tried. All parties involved agreed that this should improve the productivity.

Further investigation and experimentation revealed, though, that another variable was involved. This variable was the closeness of alumina content of succeeding bodies. Let A_{oi} be $|A_i - A_{i+1}|$. Then if $A_{oi} < A_{ok}$, less cleaning would be required between bodies i and i+1 than between bodies k and k+1.

Additional analysis resulted in the identification of different types of cleaning that had to occur from any one body to each of the other bodies. By monitoring spray dryer cleaning reports, it was noted that cleanup times appeared to have no predictable pattern. Coordination between the CMP department, QC department and this investigator resulted in the discovery of a pattern of cleaning times that was related directly to A_i, A_{i+1} and A_{oi}. Careful study of the data showed that there were seven different cleaning times. Codes were assigned to these cleaning times to simplify the construction of the matrix.

Code	Cleanup Time
0	0 Hours
1	4 Hours
2	5 Hours
3	9.7 Hours
4	11.2 Hours
5	16.9 Hours
6	20 Hours

The end result was a matrix of cleanup codes (Table 6) that was used not only in scheduling the dryer but also in ensuring that the appropriate cleanup was performed between any two bodies. This matrix of cleanup codes was actually used to ensure that the correct cleanup was performed. The rest of this chapter will address the scheduling of the dryer.

After a particular ceramic body is spray dried, it is necessary to clean the dryer in preparation for the next body to be dried. The cleaning process is time consuming and labor intensive; ergo, it is costly.

The objective function for this problem takes the following form, where Z represents total cleanup time:

Minimize Z (total cleanup time)

$$= C_{i_1,i_2} + C_{i_2,i_3} + C_{i_3,i_4} + \ldots + C_{i_{n-1},i_n}$$

where $C_{i_j,i_{j+1}}$ represents the number of hours of cleanup elapsed between the spray drying of body number i_j and the starting of spray drying body number i_{j+1}.

<u>Binary Case (Spray Dryer No. 1)</u>. A special case exists in the situation in which either no cleaning takes place or complete cleaning takes place. A binary (0 or 1) case exists not only theoretically but also in the situation

investigated for spray dryer No. 1.

Any time one of the six types of bodies always assigned to spray dryer No. 1 is spray dried, it is necessary to completely clean this dryer before a different body can be dried. This cleaning takes 20 hours and can only be performed by a certain number of workers, so it is not possible to reduce the cleaning time by introducing more workers. If the next body brought to spray dryer No. 1 is the same as the previous body, cleaning is not necessary. With this in mind, it makes sense to spray dry one ceramic body before introducing a different ceramic body.

Ceramic bodies are designated by CB-nn where nn ranges from 01 to 32. A 6 x 6 matrix of cleanup codes is presented to illustrate the binary case (Table 5). In this matrix there are only two codes, 0 and 6. Code of 0 corresponds to no cleaning and code of 6 corresponds to a complete cleaning.

The objective in scheduling dryer No. 1 is to minimize the total cleanup time associated with a particular collection of bodies. A collection of bodies will number from one to six so that the number of ways the bodies can be processed through the dryer ranges from 1! (or 1) to 6! (720).

TABLE 5

SPRAY DRYER NO. 1 CLEANUP CODES

FROM \ TO	CB-01	CB-02	CB-03	CB-04	CB-05	CB-06
CB-01	0	6	6	6	6	6
CB-02	6	0	6	6	6	6
CB-03	6	6	0	6	6	6
CB-04	6	6	6	0	6	6
CB-05	6	6	6	6	0	6
CB-06	6	6	6	6	6	0

CODE	CLEANUP TIME
0	0 HOURS
6	20 HOURS

Since C_{ij} is constant in this case the total cleanup time is merely

$$Z = T \times C_{ij},$$

where T represents the number of different types of bodies in the batch and C_{ij} is a constant.

The total cleanup time, Z, is also a constant for any given number of body types; hence, the sequence of bodies is immaterial since Z is not a function of sequence. Thus all spray drying sequences for spray dryer No. 1 will produce the same total amount of cleanup.

Generalized Case (Spray Dryer No. 2). A similar but more complicated situation occurs with dryer No. 2. There are 27 ceramic bodies processed through this dryer, and this dryer has seven different cleaning processes ranging from zero hours (essentially no cleaning) to 20 hours (complete cleaning). As has been previously described, the hours of cleaning that must be performed is a function of the alumina content of the succeeding bodies and how closely the two sequential bodies are related in terms of alumina content. Table 6 presents a 27 x 27 matrix of cleanup codes showing the hours of cleaning required as different bodies are passed through dryer No. 2.

The bodies represented in Table 6 are arranged in descending alumina content order, i.e., the body with the highest alumina content is at the top of the list and the body with the lowest alumina content is at the bottom of the list. The conjecture is that sequencing the bodies in this manner results in an optimal sequence if

1) for i,j $1<=j<i<=27$ it is true that $C_{ij} >= C_{ji}$ and for i,j $1<=i<j<=27$ it is true that $C_{ij} <= C_{ji}$ where C_{ij} represents the cleanup time going from body i to body j, and C_{ji} represents the cleanup time going from body j to body i
2) for each row i=1, ..., 27 the numbers in row i are monotonically nondecreasing after the element C_{ii}
3) for each column j=1, ..., 27 the numbers in column j are monotonically nonincreasing before the element C_{jj}

It is conjectured that these requirements will probably generate several optimal sequences. It is further conjectured that if $C_{ij} > C_{ji}$ for $1<=j<i<=27$, if $C_{ij} <= C_{ji}$ for $1<=i<j<=27$, and the numbers in each row (column) are strictly increasing (decreasing) after (before) the corresponding diagonal element, then there is only one optimal sequence. This will be investigated later in this chapter. For the matrix of cleanup codes in Table 6, these three requirements are not exactly satisfied. Bodies CB-15

TABLE 6

SPRAY DRYER NO. 2 CLEANUP CODES

FROM \ TO	CB-07	CB-08	CB-09	CB-10	CB-11	CB-12	CB-13	CB-14	CB-15	CB-16	CB-17	CB-18	CB-19	CB-20	CB-21	CB-22	CB-23	CB-24	CB-25	CB-26	CB-27	CB-28	CB-29	CB-30	CB-31	CB-32	CB-01
CB-07	0	0	0	4	4	4	4	4	4	4	4	2	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3
CB-08	1	0	0	4	4	4	4	4	4	4	4	2	2	2	4	4	3	3	3	3	3	3	3	3	3	3	3
CB-09	1	0	0	4	4	4	4	4	4	4	4	2	2	2	4	4	3	3	3	3	3	3	3	3	3	3	3
CB-10	5	5	5	0	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3
CB-11	5	5	5	4	0	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3
CB-12	5	5	5	4	4	0	4	4	4	4	4	4	4	2	4	4	3	3	3	3	3	3	3	3	3	3	3
CB-13	5	5	5	4	4	4	0	0	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3
CB-14	5	5	5	4	4	4	4	0	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3
CB-15	6	6	6	6	6	6	6	6	0	2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
CB-16	6	6	6	6	6	6	6	6	6	0	2	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
CB-17	5	5	5	4	4	4	4	4	4	4	0	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3
CB-18	5	5	5	4	4	4	4	4	4	4	4	0	0	0	4	4	3	3	3	3	3	3	3	3	3	3	3
CB-19	5	5	5	4	4	4	4	4	4	4	4	2	0	0	4	4	0	0	0	0	3	3	3	3	3	3	3
CB-20	5	5	5	4	4	4	4	4	4	4	4	2	0	0	4	4	3	3	3	3	3	3	3	3	3	3	3
CB-21	5	5	5	4	4	4	4	4	4	4	4	4	4	4	0	4	3	3	3	3	3	3	3	3	3	3	3
CB-22	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	0	3	3	3	3	3	3	3	3	3	3	3
CB-23	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	0	0	2	2	2	2	2	2	0	0	0
CB-24	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	0	0	2	2	2	2	2	2	0	0	0
CB-25	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	0	0	0	0	0	0	0	0	0
CB-26	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	1	0	0	0	0	0	0	0	0
CB-27	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	1	0	0	0	0	0	0	0	0
CB-28	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	1	0	0	0	0	0	0	0	0
CB-29	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	0	0	0	0	0	0	0	0
CB-30	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	0	0	0	0	0	0	0	0
CB-31	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	0	0	0	0	0	0	0	0	0
CB-32	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	0	0	0	0	0	0	0	0	0
CB-01	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	0

CODE	CLEANUP TIME
0	0 HOURS
1	4 HOURS
2	5 HOURS
3	9.7 HOURS
4	11.2 HOURS
5	16.9 HOURS
6	20 HOURS

and CB-16 do not satisfy requirement 1 for a special reason. These bodies have a special binding material that the other bodies do not have. Also requirements 2 and 3 are not always satisfied by the rows and columns. This is also due to special ingredients that are contained in some bodies but not in others. Thus by sequencing these bodies in descending alumina content order, an optimal sequence is not obtained if the conjecture is true.

The objective in the scheduling of the No. 2 dryer is the same as the objective for the No. 1 dryer--to minimize the total cleanup hours for a particular batch of bodies. This scheduling is complicated because there are seven different cleanup codes associated with the No. 2 dryer. The number of bodies in a dryer No. 2 batch can range from one to 27 so that the number of different ways to schedule spray dryer No. 2 ranges from 1! (1) to 27! (10,888,869,450,418,352,160,768,000,000). If there are n different bodies in a sequence of dryer No. 2 bodies, then there are n factorial different sequences possible. The number of bodies to be spray dried through dryer No. 2 usually does not exceed 15, which greatly reduces the number of sequences to a mere 15! (1,307,674,368,000) possibilities. The "troublesome" bodies mentioned in the previous paragraph may or may not appear in this sequence.

For the matrix of cleanup codes and sequence of bodies shown in Table 6, the total of hours of cleanup is equal to the sum of the hours of cleanup on the "slant" of the matrix (Flood 1955). The "slant," as defined by Flood, consists of all the elements immediately above the diagonal, together with the element in the lower left-hand corner of the matrix. This sequence of bodies has a total cleanup time of 8(11.2) + 1(9.7) + 3(5) + 1(16.9) = 131.2 hours. Given that all 27 bodies are spray dried and that the spray drying sequence is determined by descending alumina content, then the total hours of cleanup is 131.2.

For the purpose of investigation, consider the following situation and four hypothetical examples. Suppose that on a given day the following bodies need to be dried: CB-01, CB-02, CB-03, and CB-04. The hypothetical cleanup codes for this collection of bodies are shown in the matrix below. To simplify the examples, it is appropriate to assume that the cleanup codes correspond to the actual number of hours of cleaning. It is freely admitted that a problem of this limited size is highly unlikely; however, a small problem serves as a good illustration. Obviously, there are 4! (24) different sequences associated with these 4 bodies.

Example 1

		TO CB-01	TO CB-02	TO CB-03	TO CB-04	% Alumina
	CB-01	0	1	2	3	99.8
FROM	CB-02	2	0	1	2	98.0
	CB-03	3	2	0	1	96.0
	CB-04	4	3	2	0	95.0

CODE	CLEANUP TIME
0	0 HOURS
1	1 HOURS
2	2 HOURS
3	3 HOURS
4	4 HOURS

Sequence	Hours of cleanup
CB-01 CB-02 CB-03 CB-04	3
CB-01 CB-02 CB-04 CB-03	5
CB-01 CB-03 CB-02 CB-04	6
CB-01 CB-03 CB-04 CB-02	6
CB-01 CB-04 CB-02 CB-03	7
CB-01 CB-04 CB-03 CB-02	7

CB-02 CB-01 CB-03 CB-04	5
CB-02 CB-01 CB-04 CB-03	7
CB-02 CB-03 CB-01 CB-04	7
CB-02 CB-03 CB-04 CB-01	6
CB-02 CB-04 CB-01 CB-03	8
CB-02 CB-04 CB-03 CB-01	7
CB-03 CB-01 CB-02 CB-04	6
CB-03 CB-01 CB-04 CB-02	9
CB-03 CB-02 CB-01 CB-04	7
CB-03 CB-02 CB-04 CB-01	8
CB-03 CB-04 CB-01 CB-02	6
CB-03 CB-04 CB-02 CB-01	6
CB-04 CB-01 CB-02 CB-03	6
CB-04 CB-01 CB-03 CB-02	8
CB-04 CB-02 CB-01 CB-03	7
CB-04 CB-02 CB-03 CB-01	7
CB-04 CB-03 CB-01 CB-02	6
CB-04 CB-03 CB-02 CB-01	6

Inspection of these 24 sequences shows that there is only 1 optimal solution. It is critical to note that this optimal sequence, CB-01 CB-02 CB-03 CB-04, corresponds to the sequence of the bodies in the row (column). This example satisfies all 3 of the requirements for the conjectured unique optimal solution.

Example 2

		TO CB-01	TO CB-02	TO CB-03	TO CB-04	% Alumina
	CB-01	0	1	1	2	99.8
FROM	CB-02	1	0	1	2	98.0
	CB-03	2	2	0	1	96.0
	CB-04	3	3	2	0	95.0

CODE	CLEANUP TIME
0	0 HOURS
1	1 HOURS
2	2 HOURS
3	3 HOURS
4	4 HOURS

Sequence	Hours of cleanup
CB-01 CB-02 CB-03 CB-04	3
CB-01 CB-02 CB-04 CB-03	5
CB-01 CB-03 CB-02 CB-04	5

CB-01 CB-03 CB-04 CB-02	5
CB-01 CB-04 CB-02 CB-03	6
CB-01 CB-04 CB-03 CB-02	6
CB-02 CB-01 CB-03 CB-04	3
CB-02 CB-01 CB-04 CB-03	5
CB-02 CB-03 CB-01 CB-04	5
CB-02 CB-03 CB-04 CB-01	5
CB-02 CB-04 CB-01 CB-03	6
CB-02 CB-04 CB-03 CB-01	6
CB-03 CB-01 CB-02 CB-04	5
CB-03 CB-01 CB-04 CB-02	7
CB-03 CB-02 CB-01 CB-04	5
CB-03 CB-02 CB-04 CB-01	7
CB-03 CB-04 CB-01 CB-02	5
CB-03 CB-04 CB-02 CB-01	5
CB-04 CB-01 CB-02 CB-03	5
CB-04 CB-01 CB-03 CB-02	6
CB-04 CB-02 CB-01 CB-03	5
CB-04 CB-02 CB-03 CB-01	6
CB-04 CB-03 CB-01 CB-02	5
CB-04 CB-03 CB-02 CB-01	5

Inspection of these 24 sequences shows that there are 2 optimal solutions. For this example, both CB-01 CB-02 CB-03 CB-04 and CB-02 CB-01 CB-03 CB-04 are optimal sequences. It is critical to note that 1 of the 2 optimal sequences corresponds to the sequence of the bodies in the row (column). This example satisfies all 3 of the requirements for the conjectured more than 1 optimal solution.

Example 3

	TO	CB-04	CB-03	CB-02	CB-01	% Alumina
	CB-04	0	2	3	4	95.0
FROM	CB-03	1	0	2	3	96.0
	CB-02	2	1	0	2	98.0
	CB-01	3	2	1	0	99.8

CODE	CLEANUP TIME
0	0 HOURS
1	1 HOURS
2	2 HOURS
3	3 HOURS
4	4 HOURS

Sequence	Hours of cleanup
CB-01 CB-02 CB-03 CB-04	3
CB-01 CB-02 CB-04 CB-03	5
CB-01 CB-03 CB-02 CB-04	6
CB-01 CB-03 CB-04 CB-02	6
CB-01 CB-04 CB-02 CB-03	7
CB-01 CB-04 CB-03 CB-02	7
CB-02 CB-01 CB-03 CB-04	5
CB-02 CB-01 CB-04 CB-03	7
CB-02 CB-03 CB-01 CB-04	7
CB-02 CB-03 CB-04 CB-01	6
CB-02 CB-04 CB-01 CB-03	8
CB-02 CB-04 CB-03 CB-01	7
CB-03 CB-01 CB-02 CB-04	6
CB-03 CB-01 CB-04 CB-02	9
CB-03 CB-02 CB-01 CB-04	7
CB-03 CB-02 CB-04 CB-01	8
CB-03 CB-04 CB-01 CB-02	6
CB-03 CB-04 CB-02 CB-01	6

CB-04 CB-01 CB-02 CB-03	6
CB-04 CB-01 CB-03 CB-02	8
CB-04 CB-02 CB-01 CB-03	7
CB-04 CB-02 CB-03 CB-01	7
CB-04 CB-03 CB-01 CB-02	6
CB-04 CB-03 CB-02 CB-01	6

Inspection of these 24 sequences shows that there is only 1 optimal solution. It is critical to note that this optimal sequence, CB-01 CB-02 CB-03 CB-04, <u>does</u> <u>not</u> correspond to the sequence of the bodies in the row (column). Notice also that this example does not satisfy requirement 1 of the 3 requirements for the conjectured unique optimal solution.

<u>Example 4</u>

	TO	CB-01	CB-02	CB-03	CB-04	% Alumina
	CB-01	0	2	2	1	99.8
FROM	CB-02	2	0	1	2	98.0
	CB-03	3	2	0	2	96.0
	CB-04	1	3	2	0	95.0

CODE	CLEANUP TIME
0	0 HOURS
1	1 HOURS
2	2 HOURS
3	3 HOURS
4	4 HOURS

Sequence	Hours of cleanup
CB-01 CB-02 CB-03 CB-04	5
CB-01 CB-02 CB-04 CB-03	6
CB-01 CB-03 CB-02 CB-04	6
CB-01 CB-03 CB-04 CB-02	7
CB-01 CB-04 CB-02 CB-03	5
CB-01 CB-04 CB-03 CB-02	5
CB-02 CB-01 CB-03 CB-04	6
CB-02 CB-01 CB-04 CB-03	5
CB-02 CB-03 CB-01 CB-04	5
CB-02 CB-03 CB-04 CB-01	4
CB-02 CB-04 CB-01 CB-03	5
CB-02 CB-04 CB-03 CB-01	7
CB-03 CB-01 CB-02 CB-04	7
CB-03 CB-01 CB-04 CB-02	7
CB-03 CB-02 CB-01 CB-04	5
CB-03 CB-02 CB-04 CB-01	5
CB-03 CB-04 CB-01 CB-02	5

CB-03 CB-04 CB-02 CB-01	7
CB-04 CB-01 CB-02 CB-03	4
CB-04 CB-01 CB-03 CB-02	5
CB-04 CB-02 CB-01 CB-03	7
CB-04 CB-02 CB-03 CB-01	7
CB-04 CB-03 CB-01 CB-02	7
CB-04 CB-03 CB-02 CB-01	6

Inspection of these 24 sequences shows that there are 2 optimal solutions. It is critical to note that the optimal sequences, CB-02 CB-03 CB-04 CB-01 and CB-04 CB-01 CB-02 CB-03 do not correspond to the sequence of the bodies in the row (column). This example satisfies only 1 of the 3 requirements that correspond to the conjectured more than 1 optimal solution. Requirements 2 and 3 are not satisfied by this example.

The primary purpose is to develop an algorithm so this chapter concludes with an algorithm that is used to schedule the bodies to be dried using spray dryer No. 2.

Spray Dryer No. 2 Scheduling Algorithm

1. Determine the bodies that have a nonzero demand and need to be dried.
2. Arrange the bodies from step 1 in descending alumina content order.
3. Using the matrix of cleanup codes (Table 6), determine the cleaning that is necessary after each of the bodies.
4. For the sequence of bodies and cleanups in step 3, calculate the starting and finishing times for each of the bodies and each of the cleanups.
5. Schedule spray dryer no. 2 using the results of step 4.

An example demonstrating this algorithm is presented in Chapter 5.

For this specific case study, the Spray Dryer No. 2 Scheduling Algorithm schedules the third stage of this four-stage process. The four-stage process is scheduled by using the Four-Stage Scheduling Procedure contained in appendix D. This four-stage scheduling procedure uses the Spray Dryer No. 2 Scheduling Algorithm to schedule the third stage of this four-stage process.

CHAPTER 5

COMPUTER PROGRAM

Any new development or extension such as the one developed in this work must be tested through implementation to become integrated into the economic system. To accomplish this, a complete system was designed, developed, and implemented for the four-stage-with-bottleneck solution found in Chapter 3. Because of (1) volume of data, (2) time sensitivity of scheduling, and (3) complexity of the algorithm, the system was computerized. State-of-the-art systems development and design techniques were used. The result was not only a highly efficient manner of scheduling, but also a reporting system that management could use for information and control.

The scheduling system which resulted was designed, coded, tested, and debugged for the Coors Porcelain Company in-house DEC PDP 11/34 computer system. The system named "CMPSCH" was written in extended BASIC and consists of four programs. CMPSCH was designed to handle the scheduling of all of the machines in each of the four stages. The linkage between these machines is illustrated in Figure 5. There are three input files, three input-output files, and four output files associated with CMPSCH. A hierarchy chart

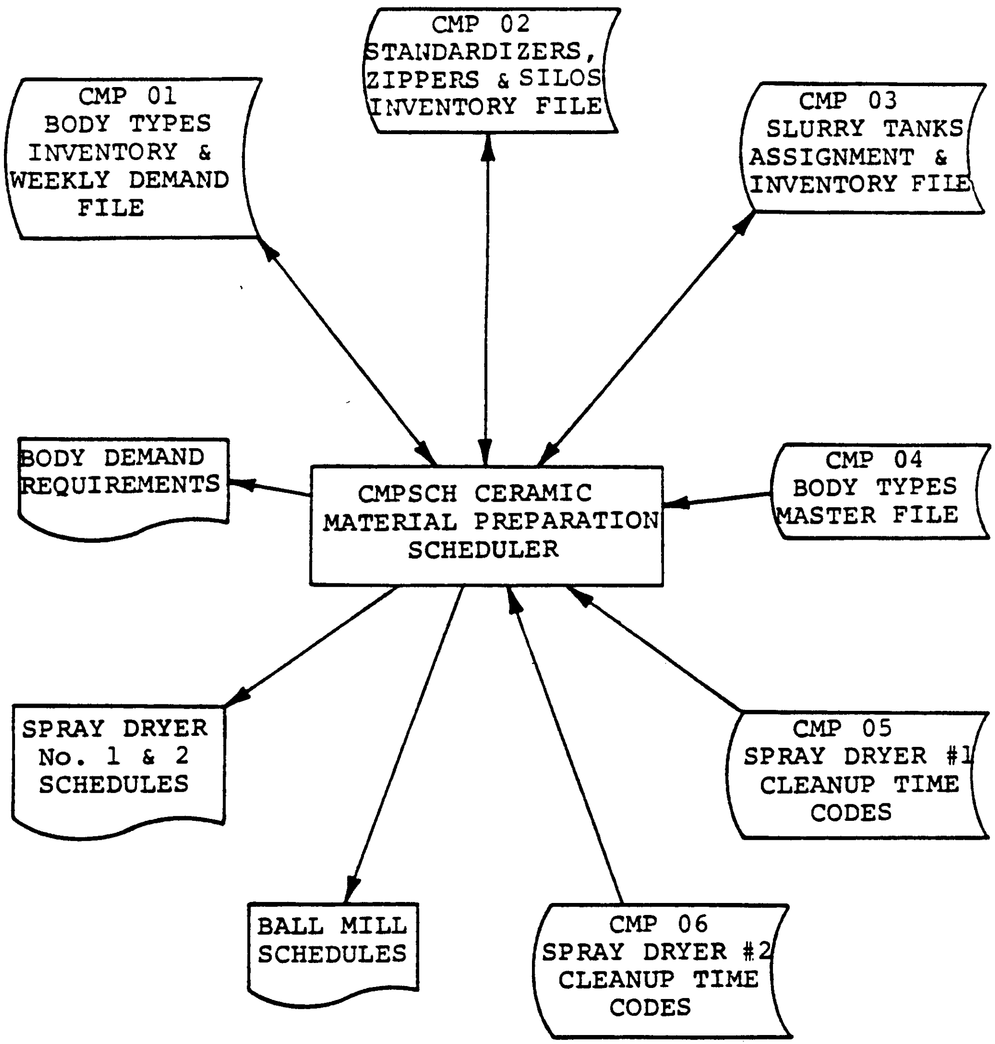

FIGURE 5

CERAMIC MATERIAL PREPARATION SCHEDULER

appears in Figure 6.

The first program, called "INV," maintains the current status of the Inventory and Weekly Demand File (CMP01), the Standardizers, Zipper Tanks, and Silos Inventory File (CMP02), and the Slurry Tanks Assignment and Inventory File (CMP03).

File CMP01 holds the following data for each body (Table 7):

1. Type
2. Current inventory in pounds
3. Demand in pounds for week 0; i.e., demand that has not been satisfied as of the current week
4. Week 1 (current week) demand in pounds
5. Week 2 demand in pounds
6. Week 3 demand in pounds
7. Week 4 demand in pounds

INV is designed so that the user can update all of file CMP01 or portions thereof depending on need.

The Standardizers, Zipper Tanks, and Silos Inventory File (CMP02) is updated by the INV program on command. This file consists of one record for each of the 19 major storage facilities so that it is economical to update the entire file for each scheduling period. The records in this

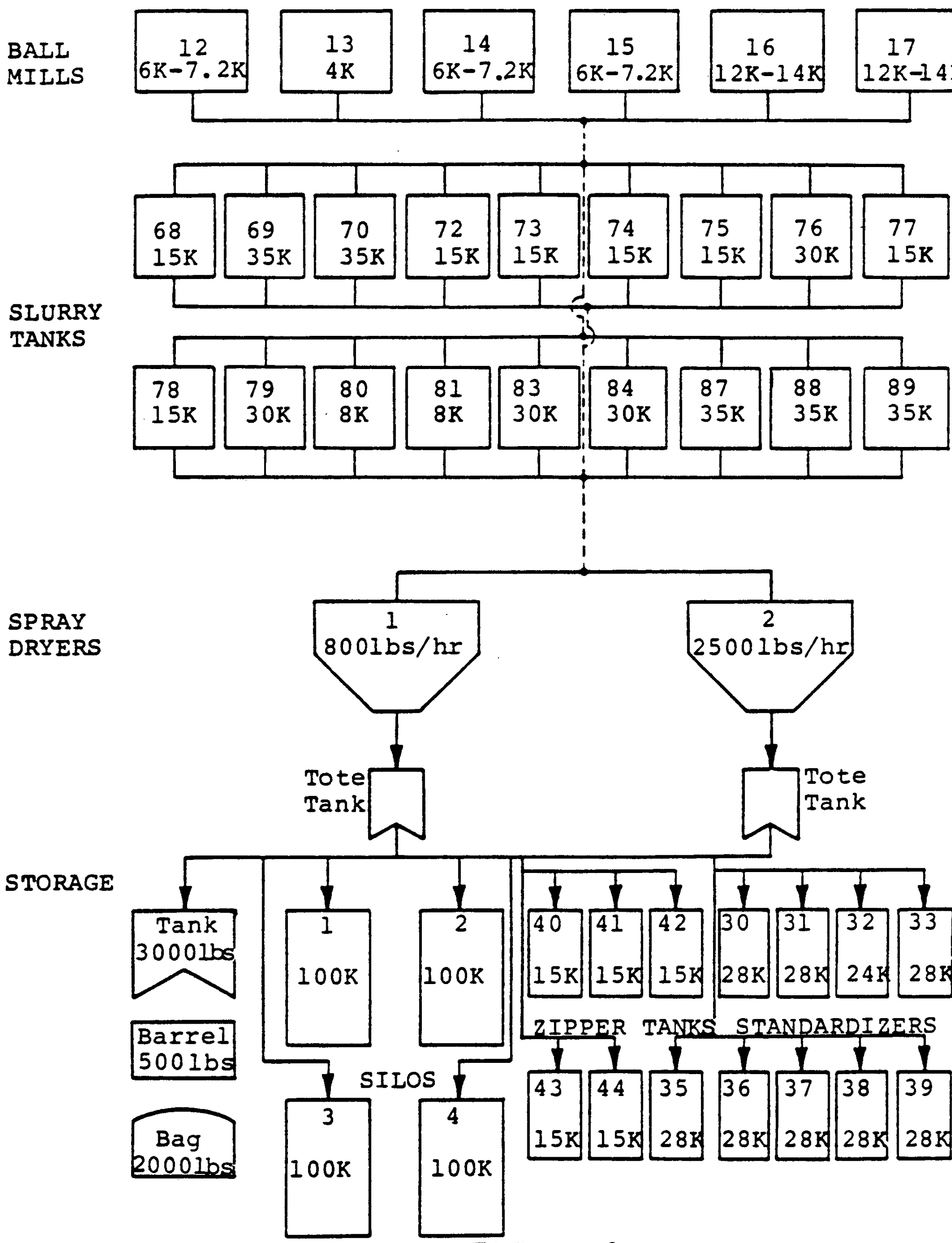

FIGURE 6

CERAMIC MATERIAL PREPARATION EQUIPMENT SCHEMATIC

TABLE 7

INVENTORY AND WEEKLY DEMAND FILE (CMP01)

body type	current inventory pounds	week 0 demand pounds	week 1 demand pounds	week 2 demand pounds	week 3 demand pounds	week 4 demand pounds
CB-01	192000	83362	145353	116571	172991	33728
CB-02	0	1572	1030	1164	1059	407
CB-03	9000	468	0	0	0	0
CB-04	7000	0	0	0	0	0
CB-05	31000	549	0	0	0	0
CB-06	7000	0	0	0	0	0
CB-07	3000	2097	0	0	0	0
CB-08	41500	1506	11760	7833	7220	2313
CB-09	1000	1800	1167	1385	57	0
CB-10	2000	0	0	0	0	0
CB-11	0	0	0	0	0	0
CB-12	92000	36288	27764	23444	25016	33388
CB-13	0	100000	0	0	0	0
CB-14	0	50000	0	0	0	0
CB-15	0	10780	10780	10780	10780	10780
CB-16	0	0	0	0	0	0
CB-17	0	0	0	0	0	0
CB-18	7000	0	0	0	0	0
CB-19	12000	17581	14348	11067	7884	3492
CB-20	18000	5122	3062	2902	3046	3785
CB-21	4000	1502	1125	0	0	121
CB-22	22000	13312	3598	0	0	0
CB-23	1000	2711	0	1	0	545
CB-24	7000	0	349	0	0	0
CB-25	7000	0	0	0	0	0
CB-26	20000	16034	15549	16607	7278	0
CB-27	16000	11540	12232	11495	1886	9835
CB-28	175500	56541	56800	56832	56890	56892
CB-29	0	0	0	0	0	0
CB-30	28000	10000	11611	10335	7347	7414
CB-31	24000	31542	30686	33867	29732	22041
CB-32	10000	2145	2736	2382	1500	1939

file consist of the following information (Table 8):

1. Storage facility number
2. Capacity in pounds
3. Current body assigned to facility
4. Current inventory in pounds

The third and final file maintained by INV is CMP03--the Slurry Tanks Assignment and Inventory File. This file is also updated each time a new CMPSCH schedule is produced. Each record in this file contains the following information (Table 9):

1. Slurry tank number
2. Capacity in pounds
3. Current body assigned to tank
4. Current inventory in pounds

The second of the series of four programs is called "SCH" and is designed to determine the demand for each ceramic body in the current production period. This program must first calculate the amount of each ceramic body that is stored in dried form in the standardizers, zipper tanks, and silos. These inventories are reduced by subtracting week 0 and week 1 demands for the corresponding ceramic bodies. The objective is to determine if these storage facilities are going to be empty within the next week. The demand for each of weeks 0, 1, 2, 3, and 4 is adjusted for each body to

TABLE 8

STANDARDIZERS, ZIPPER TANKS, AND SILOS
INVENTORY FILE (CMP02)

facility number	pounds capacity	body type	current inventory pounds
S-30	28000	CB-26	10000
S-31	28000	CB-27	4000
S-32	24000	CB-21	24000
S-33	28000	CB-30	28000
S-34	28000	CB-12	8000
S-35	28000	CB-19	0
S-36	28000	CB-12	28000
S-37	26000	CB-08	26000
S-38	28000	CB-12	28000
S-39	28000	CB-12	28000
ZT-40	15000	CB-05	15000
ZT-41	15000	CB-05	13000
ZT-42	15000	CB-22	12000
ZT-43	15000	CB-22	0
ZT-44	15000	CB-22	0
S-1	100000	CB-01	100000
S-2	100000	CB-01	80000
S-3	100000	CB-28	60000
S-4	100000	CB-28	100000

TABLE 9

SLURRY TANKS ASSIGNMENT AND INVENTORY FILE (CMP03)

facility number	pounds capacity	body type	current inventory pounds
ST-68	15000	EMPTY	0
ST-69	35000	CB-01	21000
ST-70	35000	CB-01	28000
ST-72	15000	CB-15	14000
ST-73	15000	CB-15	14000
ST-74	15000	CB-26	12000
ST-75	15000	CB-26	12000
ST-76	32000	CB-28	28000
ST-77	15000	CB-12	14000
ST-78	15000	CB-12	14000
ST-79	30000	EMPTY	0
ST-80	8000	CB-23	6000
ST-81	8000	CB-31	8000
ST-83	32000	EMPTY	0
ST-84	32000	EMPTY	0
ST-87	35000	CB-31	28000
ST-88	35000	CB-01	28000
ST-89	35000	EMPTY	0

account for the amount of each body that is presently in storage. Once the demands for weeks 0, 1, 2, 3, and 4 have been reduced to account for storage inventory, the program determines for each body the first week that has a nonzero demand. Associated with each ceramic body is a group number 0, 1, 2, 3, or 4 that tells the program the first week in which that body has a nonzero demand. This also sets up a priority scheme of bodies to be produced.

For the group 0 bodies, the adjusted demand is calculated by adding the demands for weeks 0, 1, and 2. The adjusted demand for group 1 bodies is found by adding the demands for weeks 1, 2, and 3. Demands for weeks 2, 3, and 4 are added to determine the adjusted demand for group 2 bodies. Group 3 bodies have an adjusted demand equal to the sum of the demands for weeks 3 and 4. Finally, the adjusted demand for the group 4 bodies is simply the demand for week 4. A group 5 body has no demand for weeks 0 through 4 but must be stored in a standardizer and this standardizer is empty presently or will be empty within the next week.

To determine the pounds of each ceramic body to be milled, the program subtracts the total slurry pounds from the adjusted demand. If there are presently more slurry pounds in inventory than are needed to satisfy the adjusted demand, the adjusted demand is set to zero. A comparison is now made between the pounds to be milled and the storage capacity. The pounds to be milled will be reduced, if necessary, to reflect the pounds that can be stored. If the storage pounds are less than the sum of the slurry pounds and the pounds to be milled, then the adjusted pounds to be milled is determined by subtracting the slurry pounds from the storage pounds; otherwise, the adjusted pounds to be milled is equal to the pounds to be milled.

There is one exception to this rule. The standardizers must be filled soon after they are emptied so the bodies assigned to the standardizer will automatically be produced even if the demand for that body is zero. Bodies satisfying this condition are in group 5. Using the adjusted pounds to be milled, it is now possible to determine the mill load pounds; i.e., the number of pounds of each body that is to be milled in this production schedule.

Associated with each body type on the Body Type Master File (CMP04) is the amount of the body in pounds that can be loaded into each of the six mills. Also in this file are four standard batch sizes for each of the bodies. These four sizes are arranged in ascending numerical sequence. Each record in the file CMP04 contains the following information (Table 10):

TABLE 10

BODY TYPE MASTER FILE (CMP04)

(1) body type	(2) mill 12 pounds	(3) mill 13 pounds	(4) mill 14 pounds	(5) mill 15 pounds	(6) mill 16 pounds	(7) mill 17 pounds	(8) mill hours
CB-01	7000	4000	7000	7000	14000	14000	3.0
CB-02	6000	0	0	0	0	0	11.5
CB-03	6000	4000	0	0	0	0	4.0
CB-04	6000	0	6000	0	0	12000	4.0
CB-05	6000	4000	0	0	0	0	13.0
CB-06	6000	0	0	0	0	0	20.0
CB-07	6000	0	6000	0	0	0	5.0
CB-08	6800	0	6800	0	0	13600	16.1
CB-09	6000	0	6000	0	0	0	5.0
CB-10	6000	0	6000	0	0	0	1.5
CB-11	0	0	0	0	0	0	3.0
CB-12	7000	0	0	0	0	14000	13.3
CB-13	7000	0	7000	0	0	0	5.0
CB-14	7000	0	7000	0	0	0	5.0
CB-15	7000	0	7000	0	0	14000	19.0
CB-16	7000	0	7000	0	0	14000	10.3
CB-17	7000	0	7000	0	0	14000	10.2
CB-18	7000	0	7000	0	0	14000	17.0
CB-19	7000	0	7000	0	0	14000	17.0
CB-20	6000	0	6000	0	0	12000	16.0
CB-21	7200	0	7200	0	0	0	10.5
CB-22	6000	0	6000	0	12000	12000	8.5
CB-23	6000	4000	6000	0	12000	12000	11.0
CB-24	6000	4000	6000	0	12000	12000	11.0
CB-25	6000	4000	6000	0	12000	12000	16.0
CB-26	6000	4000	6000	0	12000	12000	17.5
CB-27	6000	4000	6000	0	12000	12000	14.0
CB-28	6000	4000	6000	0	12000	12000	13.0
CB-29	6000	4000	6000	0	12000	12000	12.0
CB-30	6000	4000	6000	0	12000	12000	10.0
CB-31	6000	4000	6000	0	12000	12000	16.3
CB-32	6000	0	0	0	12000	12000	4.0

(Continued)

TABLE 10 (Continued)

BODY TYPE MASTER FILE (CMP04)

body type	(9) dryer no.1 rate	(10) dryer no.1 body	(11) dryer no.2 rate	(12) dryer no.2 body	(13) primary spray storage	(14) batch size 1	(15) batch size 2	(16) batch size 3	(17) batch size 4
CB-01	875	1	0	0	4	35000	0	0	0
CB-02	1000	2	0	0	1	18000	0	0	0
CB-03	1000	3	0	0	1	6000	0	0	0
CB-04	1000	4	0	0	1	6000	0	0	0
CB-05	1000	5	0	0	1	6000	0	0	0
CB-06	200	6	0	0	1	6000	12000	0	0
CB-07	0	0	2000	1	1	6000	12000	0	0
CB-08	0	0	2000	2	2	26000	39000	0	0
CB-09	0	0	2000	3	1	6000	12000	0	0
CB-10	0	0	1500	4	1	6000	0	0	0
CB-11	0	0	2000	5	1	2000	0	0	0
CB-12	0	0	2000	6	2	28000	0	0	0
CB-13	0	0	1800	7	5	105000	0	0	0
CB-14	0	0	1800	8	5	56000	0	0	0
CB-15	0	0	4000	9	1	14000	28000	42000	56000
CB-16	0	0	4000	10	1	14000	28000	42000	56000
CB-17	0	0	3500	11	1	14000	0	0	0
CB-18	0	0	3500	12	1	14000	0	0	0
CB-19	0	0	3500	13	2	28000	0	0	0
CB-20	0	0	2500	14	1	14000	28000	0	0
CB-21	0	0	2000	15	1	6000	0	0	0
CB-22	0	0	1500	16	3	18000	0	0	0
CB-23	0	0	2000	17	1	6000	12000	0	0
CB-24	0	0	2000	18	3	18000	0	0	0
CB-25	0	0	3000	19	1	12000	0	0	0
CB-26	0	0	3500	20	2	28000	30000	0	0
CB-27	0	0	3500	21	2	28000	30000	0	0
CB-28	0	0	3500	22	4	30000	32000	34000	0
CB-29	0	0	2000	23	2	30000	32000	34000	0
CB-30	0	0	2000	24	2	28000	30000	0	0
CB-31	0	0	3000	25	1	18000	24000	30000	0
CB-32	0	0	3000	26	1	18000	24000	30000	0

1. Body type
2. Mill #12 batch size
3. Mill #13 batch size
4. Mill #14 batch size
5. Mill #15 batch size
6. Mill #16 batch size
7. Mill #17 batch size
8. Mill time in tenths of hours
9. Spray dryer number 1 pounds/hour rate
10. Spray dryer number 1 body number
11. Spray dryer number 2 pounds/hour rate
12. Spray dryer number 2 body number
13. Primary storage

    1-tote tanks

    2-standardizers

    3-zipper tanks

    4-silos

    5-barrels
14. Batch size 1
15. Batch size 2
16. Batch size 3
17. Batch size 4

A comparison is made between the adjusted pounds to be milled and the four standard batch sizes to determine which batch size encompasses the adjusted pounds to be milled. Once this determination has been made, the number of pounds to be spray dried is determined by adding the adjusted pounds to be milled to the slurry pounds. All the above is necessary to produce a report entitled "Body Demand Requirements" (Table 11).

The third program in this series is called "DRYER" and is designed to print the Body Demand Requirements report as well as to determine the starting times and finishing times of each body to be dried. This program also prints the Spray Dryer Number 1 Schedule (Table 12) and the Spray Dryer Number 2 Schedule (Table 13). The user enters either the last body spray dried or the first body that the user wants spray dried. The sequence of bodies to be spray dried for each of these dryers is determined according to the technique discussed in Chapter 3. The group 0 and group 1 bodies are first scheduled and then the group 2, 3, 4, and 5 bodies are allowed to enter the schedule. The algorithm also determines the type of cleanup that is necessary after each of the bodies in the schedule.

The program is designed so that the user controls the starting month, day, and hour for each of the spray dryers. The program then calculates the start month, day, and hour as well as the finish month, day, and hour for each

TABLE 11

BODY DEMAND REQUIREMENTS

body type		adjusted demand	slurry lbs	lbs to mill	dry storage pounds	adjusted mill lbs	adjusted mill batch	spray dry lbs	batches
CB-01	0	360005	77000	283005	200000	123000	140000	217000	1
CB-02	0	5232	0	5232	18000	5232	18000	18000	1
CB-08	5	0	0	0	26000	26000	26000	26000	1
CB-09	0	3409	0	3409	6000	3409	6000	6000	1
CB-12	2	80865	28000	52865	84000	56000	56000	84000	1
CB-15	0	53900	28000	25900	56000	25900	28000	56000	2
CB-19	2	42372	0	42372	28000	28000	28000	28000	1
CB-22	5	0	0	0	30000	30000	36000	36000	1
CB-23	1	2257	6000	0	6000	6000	0	6000	1
CB-26	0	35468	24000	11468	28000	4000	4000	28000	1
CB-27	2	30985	0	30985	28000	28000	28000	28000	1
CB-28	1	140544	28000	112544	100000	72000	90000	118000	1
CB-30	3	0	0	0	28000	28000	28000	28000	1
CB-31	0	123868	36000	87868	126000	90000	90000	126000	2
CB-32	2	702	0	702	18000	702	18000	18000	1

TABLE 12

SPRAY DRYER NO. 1 SCHEDULE

body type	pounds	hours	start	month	day	finish	month	day
CB-01	217000	248.0	14.0	11	4	22.0	11	14
CLEAN	0	20.0	22.0	11	14	18.0	11	15
CB-02	18000	18.0	18.0	11	15	12.0	11	16

TABLE 13

SPRAY DRYER NO. 2 SCHEDULE

body type	pounds	hours	start	month	day	finish	month	day
CB-15	28000	7.0	3.5	11	5	10.5	11	5
CLEAN	0	20.0	10.5	11	5	6.5	11	6
CB-23	6000	3.0	6.5	11	6	9.5	11	6
CLEAN	0	5.0	9.5	11	6	14.5	11	6
CB-26	28000	8.0	14.5	11	6	22.5	11	6
CB-28	118000	33.7	22.5	11	6	8.2	11	8
CB-31	36000	12.0	8.2	11	8	20.2	11	8
CLEAN	0	11.2	20.2	11	8	7.4	11	9
CB-12	84000	42.0	7.4	11	9	1.4	11	11
CLEAN	0	11.2	1.4	11	11	12.6	11	11
CB-15	28000	7.0	12.6	11	11	19.6	11	11
CLEAN	0	20.0	19.6	11	11	15.6	11	12
CB-19	28000	8.0	15.6	11	12	23.6	11	12
CLEAN	0	11.2	23.6	11	12	10.8	11	13
CB-22	36000	24.0	10.8	11	13	10.8	11	14
CLEAN	0	9.7	10.8	11	14	20.5	11	14
CB-27	28000	8.0	20.5	11	14	4.5	11	15
CB-30	28000	14.0	4.5	11	15	18.5	11	15
CB-31	90000	30.0	18.5	11	15	0.5	11	17
CB-32	18000	6.0	0.5	11	17	6.5	11	17

(Continued)

TABLE 13 (Continued)

SPRAY DRYER NO. 2 SCHEDULE

body type	pounds	hours	start	month	day	finish	month	day
CLEAN	0	16.9	6.5	11	17	23.4	11	17
CB-08	26000	13.0	23.4	11	17	12.4	11	18
CB-09	6000	3.0	12.4	11	18	15.4	11	18

of the bodies to be spray dried. The same values are determined for each of the cleanups.

"BALL" is the name of the last program in this collection of four programs and is designed to calculate and print the Ball Mill Schedule (Table 14). In this stage of the process, all of a particular body is scheduled to be milled before it is scheduled to be dried. The dryer schedules control the scheduling of the ball mills. The scheduling of the bodies to the mills follows the sequence of the bodies on the spray dry schedules. This program also determines the number of times batches of a particular body can be milled on a given mill in 24 hours.

All of the four programs in this system are designed to be user friendly as well as to provide the user with the ultimate control. The user can change any of the entities on the Body Demand Requirement Report. The sequence of the bodies to be spray dried can be controlled or changed by the user, as can the assignment of bodies to ball mills. The end result is a scheduling system that allows the user to use the system as a decision-making tool, but, of course, this tool is not meant to be the decision maker itself.

TABLE 14

BALL MILL SCHEDULE

month	day	ball mill	body type	lbs	loads
11	5	12	CB-02	6000	1
11	5	13	CB-26	4000	1
11	5	14	CB-09	6000	1
11	5	15	CB-01	7000	3
11	5	16	CB-31	12000	1
11	6	12	CB-02	6000	1
11	6	13	CB-30	4000	1
11	6	14	CB-22	6000	2
11	6	15	CB-01	7000	3
11	6	16	CB-27	12000	1
11	6	17	CB-12	14000	1
11	7	12	CB-02	6000	1
11	7	13	CB-27	4000	1
11	7	14	CB-22	6000	2
11	7	15	CB-01	7000	3
11	7	16	CB-30	12000	1
11	7	17	CB-12	14000	1
11	8	12	CB-15	7000	1
11	8	13	CB-31	4000	1
11	8	14	CB-15	7000	1
11	8	15	CB-01	7000	3
11	8	16	CB-30	12000	1
11	8	17	CB-12	14000	1
11	9	12	CB-22	6000	2
11	9	13	CB-31	4000	1
11	9	14	CB-31	6000	1
11	9	15	CB-01	7000	3
11	9	16	CB-31	12000	1
11	9	17	CB-15	14000	1

(Continued)

TABLE 14 (Continued)

BALL MILL SCHEDULE

month	day	ball mill	body type	lbs	loads
11	10	12	CB-31	6000	1
11	10	13	CB-31	4000	1
11	10	14	CB-09	6000	1
11	10	15	CB-01	7000	3
11	10	16	CB-31	12000	1
11	10	17	CB-19	14000	1
11	11	12	CB-32	6000	1
11	11	13	CB-31	4000	1
11	11	14		0	0
11	11	15	CB-01	7000	3
11	11	16	CB-31	12000	1
11	11	17	CB-19	14000	1
11	12	12		0	0
11	12	13	CB-31	4000	1
11	12	14		0	0
11	12	15		0	0
11	12	16	CB-31	12000	1
11	12	17	CB-08	13000	1
11	13	12		0	0
11	13	13		0	0
11	13	14		0	0
11	13	15		0	0
11	13	16	CB-31	12000	1
11	13	17	CB-08	13000	1
11	14	12		0	0
11	14	13		0	0
11	14	14		0	0
11	14	15		0	0
11	14	16		0	0
11	14	17	CB-32	12000	1

CHAPTER 6

RESULTS AND SUGGESTIONS

The use of the scheduling system CMPSCH resulted in major improvements within the CMP department. It had been the contention of that department that there was not enough capacity in any of the four stages.

The result of the work described was to convince management that CMP was scheduling its equipment in the best possible manner and that there was indeed a capacity problem. The program also demonstrated that the production departments using the CMP finished bodies were not actually able to maintain the production schedules that had been set for them. The result was a queuing of finished body inventory that backed up the entire four-stage CMP process.

In specifically relating back to the objectives noted on page 2 of the introduction, the following was determined:

1. It was discovered early in the process that the lot scheduling algorithms in the literature addressed the problem from a point of inventory control and not production control. Thus, the decision was made to develop a new algorithm to emphasize production control in order to satisfy the objective of minimizing total cleanup time.

2. It was impractical to determine if the present method of scheduling was producing optimal results. The method was neither documented nor understood by management. Very little attempt was made to follow a predefined schedule due to the day-to-day changes in production demand. It was indeed a classic example of management by exception.
3. After a manual method of production scheduling was developed, tested, and accepted as worthy, the method was computerized. The manual method took approximately four hours per week to complete so the objective and result of computerization was to minimize the amount of time to produce the schedule for a seven-day period.
4. Alternate scheduling methods were considered. An attempt was made to formulate the problem as an integer programming model. That method proved not to be cost effective because of the number of constraints involved. The problem was also formulated as a network model. That model proved not to be feasible because of the number of arcs necessary to construct the network.
5. A complete analysis of the physical plant was performed. The layout of the four stages was

documented and routing between stages was drawn into a schematic. After many production runs of the computerized procedure, it was realized that there was not enough capacity in each of the four stages. Additional spray drying capacity was needed as well as storage, slurry tank, and ball mill capacity. Results of this analysis were the purchase of the appropriate equipment instead of the prior budgeted capital expenditures. Savings totalled over $1 million.

The resulting improvements to this four-stage process were the addition of a spray dryer (with a rated capacity of 1,000 pounds per hour at a capital investment in excess of $1 million), three slurry tanks (each with a capacity of 35,000 thousand pounds), and one 14,000 pound ball mill. Thus, three of the four stages had their capacities increased and the fourth stage, storage, was improved by reducing the amount of time any body type would be stored. This was accomplished, in part, by producing only bodies for which there was a two-week demand and also by monitoring and attempting to control the production capacities of the departments that used the output from CMP.

This thesis has addressed the scheduling of a four-stage process as it exists in a front-end department of a particular company. It would be challenging to extend this process to the production of the finished product. There are several departments at Coors Porcelain using the output of CMP. A natural extension of this scheduling algorithm process would take into consideration the remaining stages necessary to produce the end product. For this particular company, this would include manufacturing stages such as pressing the part, firing it in kilns, machining/grinding the part, and final inspection and packing prior to shipment. By tying together all stages, it would be possible to make the initial four-stage process scheduling even more effective because of changes that would necessarily have to be made to the demand requirements.

The industrial revolution brought about major changes in the way that products are manufactured. Certainly most items that are produced today for mass consumption are processed through a series of stages. The application of this procedure to other manufacturing situations is inevitable and reasonable. There are companies which produce food products for which this procedure would be applicable. A. E. Staley Manufacturing Company in Decatur, Illinois, produces hundreds of products using corn as the primary raw material, as well as products with soybeans as the principal raw material. Many of these products use the same machinery at stages as they are being produced, and cleaning of the machines is a necessary function, especially, when toxic products are being processed. The conclusion is that scheduling of these products through these machines could well use the procedure developed in this thesis to minimize the total amount of set-up/tear-down time.

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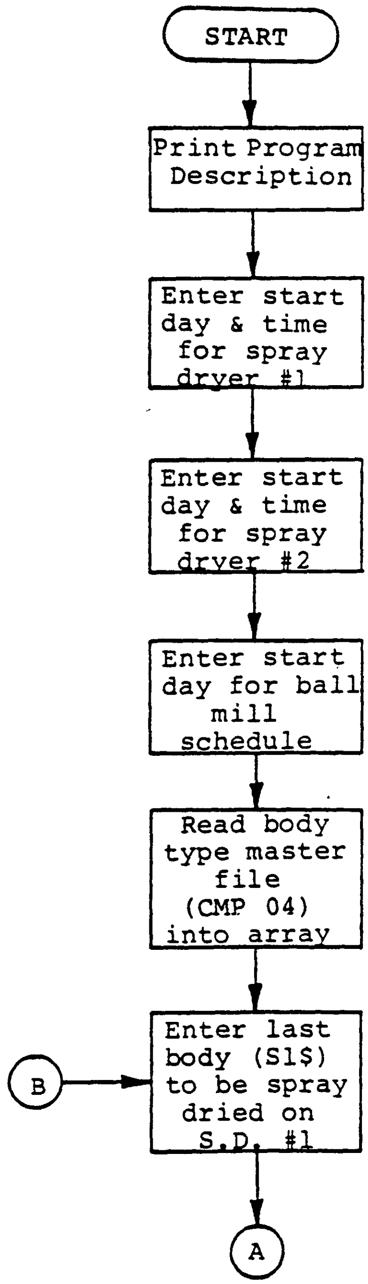
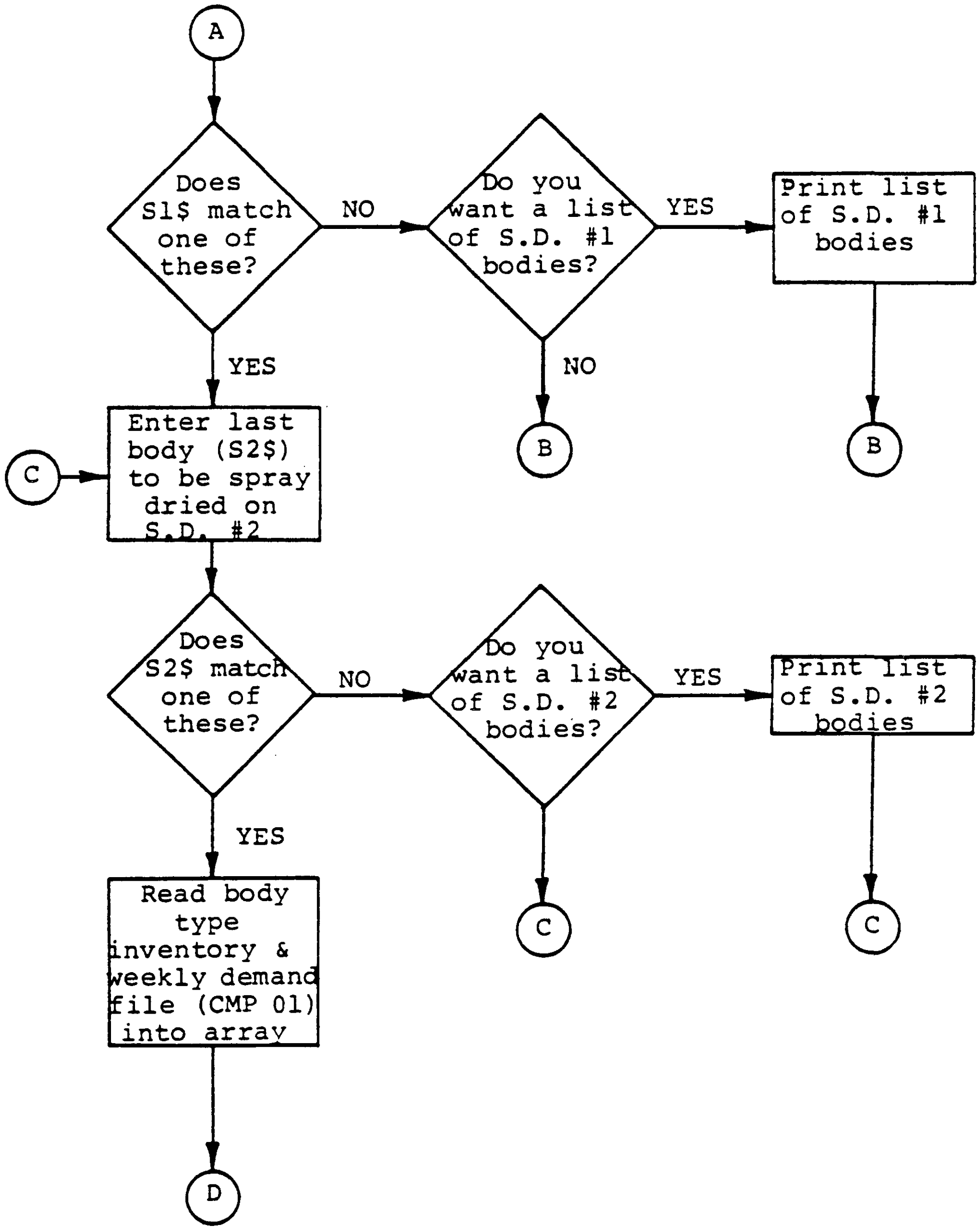
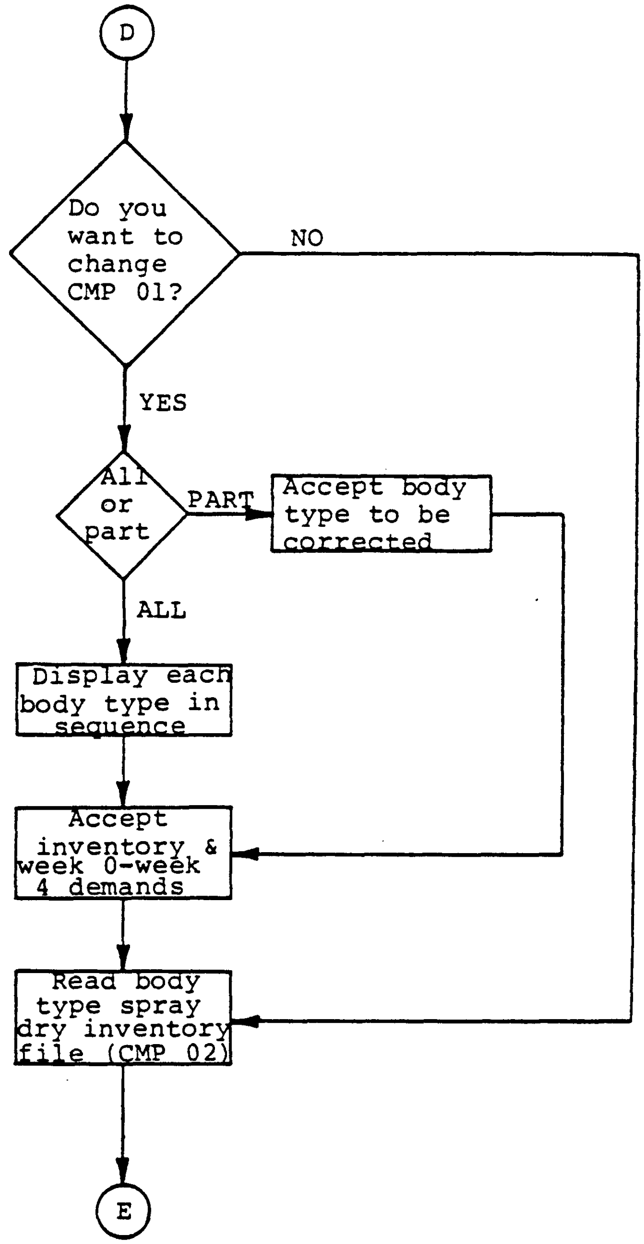
APPENDIX A

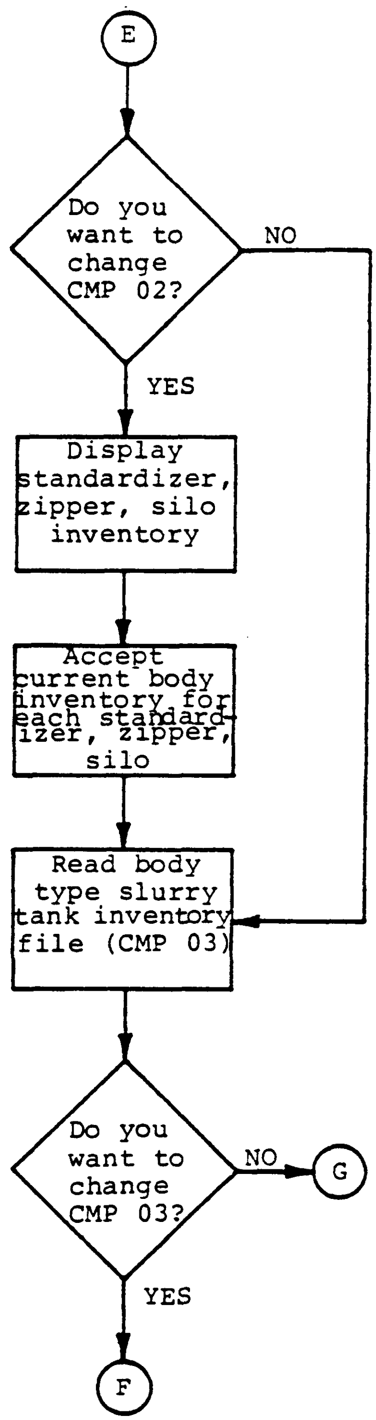
LOGIC FLOWCHART AND COMPUTER PROGRAM

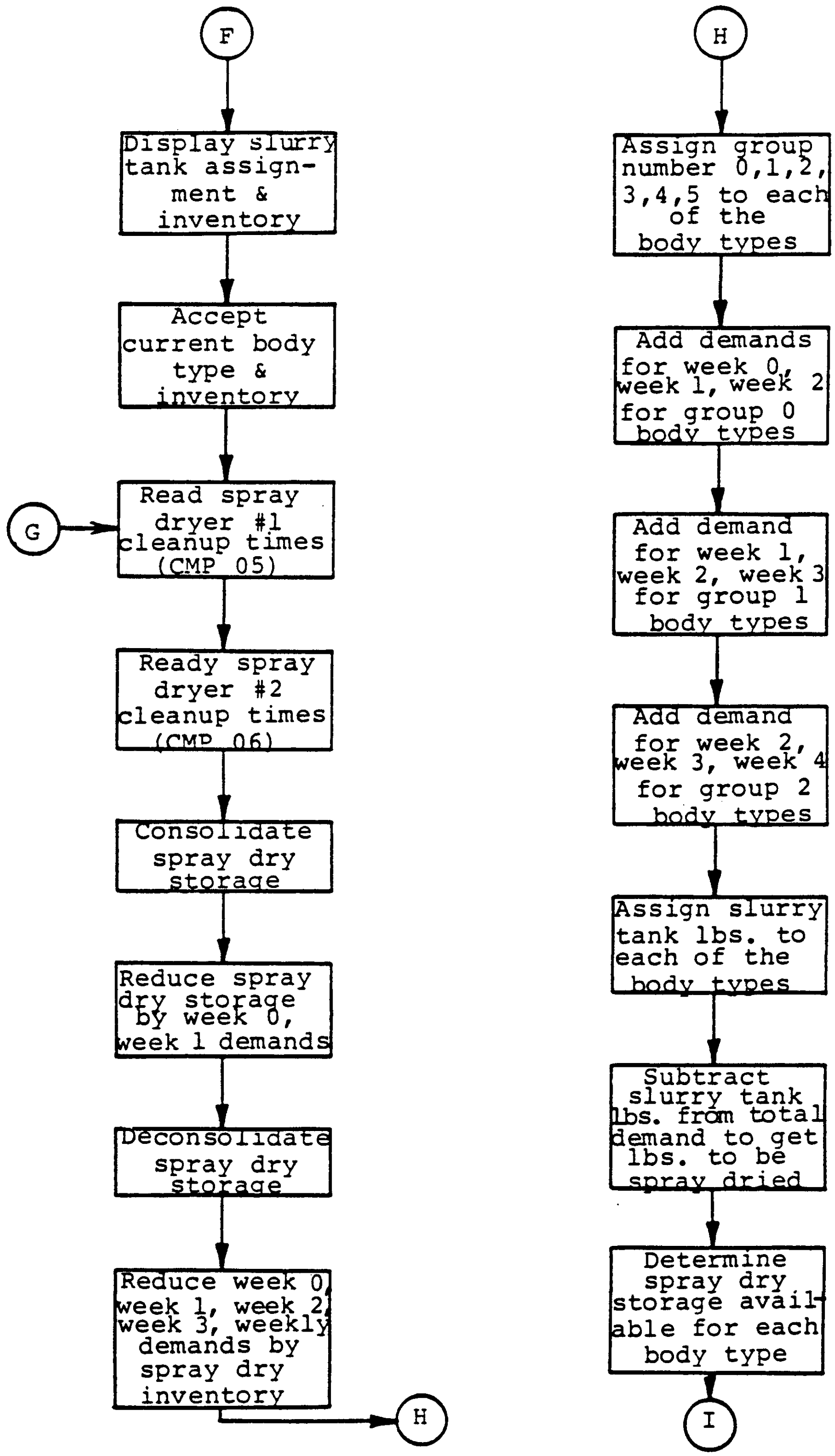
LOGIC FLOWCHART

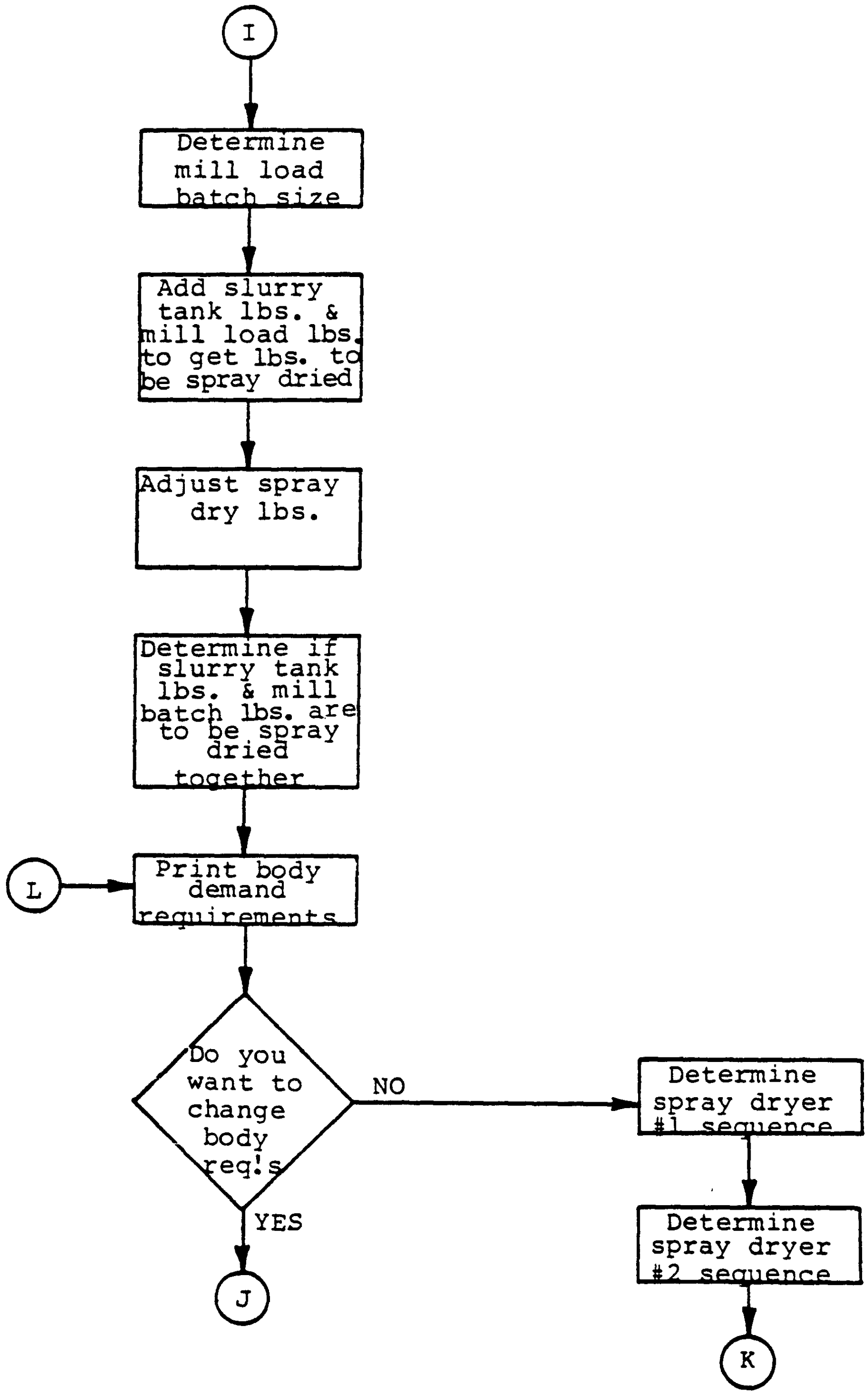


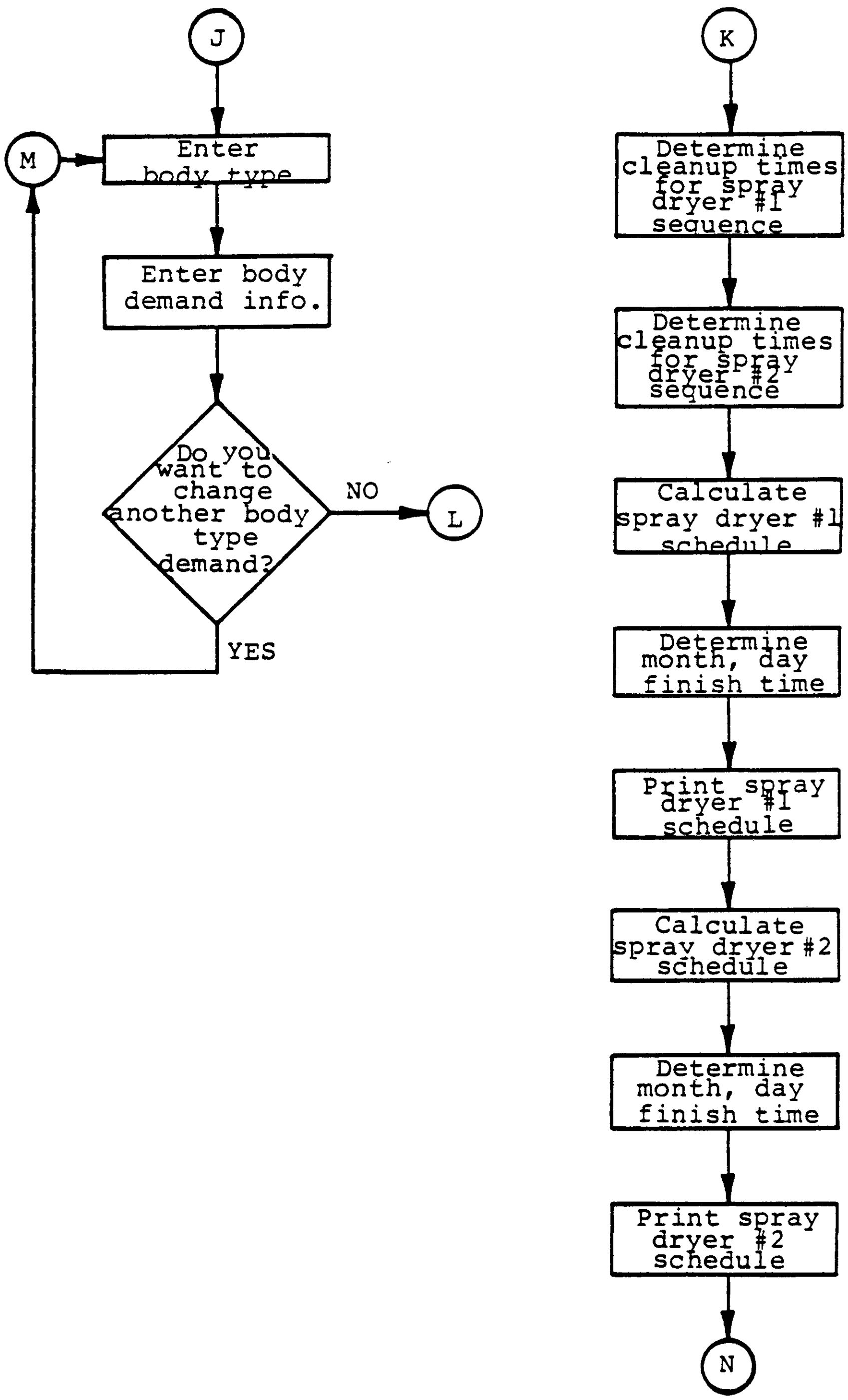

A
Does S1$ match one of these?
NO
Do you want a list of S.D. #1 bodies?
YES
Print list of S.D. #1 bodies
NO
B
B
YES
Enter last body (S2$) to be spray dried on S.D. #2
C
Does S2$ match one of these?
NO
Do you want a list of S.D. #2 bodies?
YES
Print list of S.D. #2 bodies
YES
Read body type inventory & weekly demand file (CMP 01) into array
C
C
D

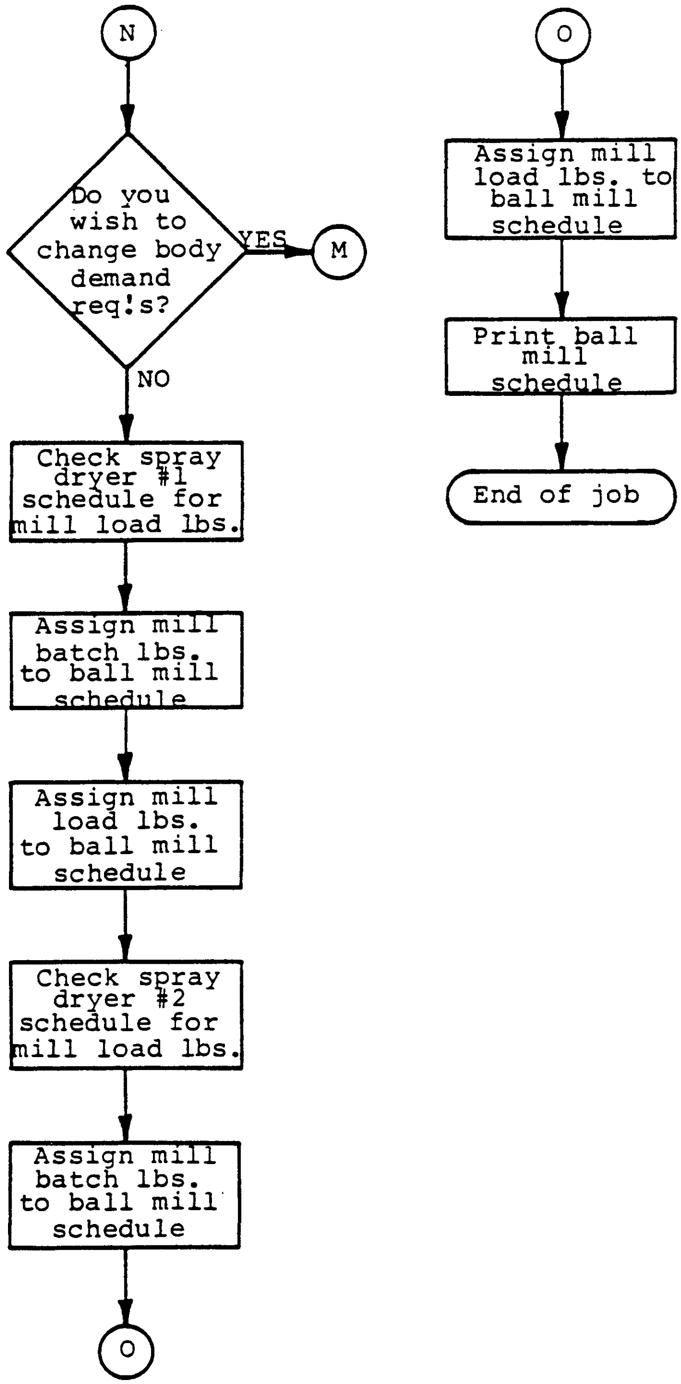

D
Do you want to change CMP 01?
NO
YES
All or part
PART
Accept body type to be corrected
ALL
Display each body type in sequence
Accept inventory & week 0-week 4 demands
Read body type spray dry inventory file (CMP 02)
E


E
Do you want to change CMP 02?
NO
YES
Display standardizer, zipper, silo inventory
Accept current body inventory for each standardizer, zipper, silo
Read body type slurry tank inventory file (CMP 03)
Do you want to change CMP 03?
NO
G
YES
F


F
Display slurry tank assignment & inventory
Accept current body type & inventory
G
Read spray dryer #1 cleanup times (CMP 05)
Ready spray dryer #2 cleanup times (CMP 06)
Consolidate spray dry storage
Reduce spray dry storage by week 0, week 1 demands
Deconsolidate spray dry storage
Reduce week 0, week 1, week 2, week 3, weekly demands by spray dry inventory
H
H
Assign group number 0,1,2, 3,4,5 to each of the body types
Add demands for week 0, week 1, week 2 for group 0 body types
Add demand for week 1, week 2, week 3 for group 1 body types
Add demand for week 2, week 3, week 4 for group 2 body types
Assign slurry tank lbs. to each of the body types
Subtract slurry tank lbs. from total demand to get lbs. to be spray dried
Determine spray dry storage available for each body type
I


I
Determine mill load batch size
Add slurry tank lbs. & mill load lbs. to get lbs. to be spray dried
Adjust spray dry lbs.
Determine if slurry tank lbs. & mill batch lbs. are to be spray dried together
L
Print body demand requirements
Do you want to change body req!s
NO
YES
J
Determine spray dryer #1 sequence
Determine spray dryer #2 sequence
K


J
M
Enter body type
Enter body demand info.
Do you want to change another body type demand?
NO
L
YES
K
Determine cleanup times for spray dryer #1 sequence
Determine cleanup times for spray dryer #2 sequence
Calculate spray dryer #1 schedule
Determine month, day finish time
Print spray dryer #1 schedule
Calculate spray dryer #2 schedule
Determine month, day finish time
Print spray dryer #2 schedule
N


N
Do you wish to change body demand req's?
YES
M
NO
Check spray dryer #1 schedule for mill load lbs.
Assign mill batch lbs. to ball mill schedule
Assign mill load lbs. to ball mill schedule
Check spray dryer #2 schedule for mill load lbs.
Assign mill batch lbs. to ball mill schedule
O
O
Assign mill load lbs. to ball mill schedule
Print ball mill schedule
End of job

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INV

```
00100 Z9$=" \        \ ######  ######  ###### ###### ###### &
      #####"
00180 PRINT : PRINT "       CMP BODY AND INVENTORY UPDATING"
00190 PRINT

02380 REM-READ BODY TYPE INVENTORY AND WEEKLY DEMAND
02390 REM-FILE(CMP01)
02560 INPUT "-YES OR NO  ";Y$ : PRINT
02660 IF Y$="NO" THEN 4700
02680 IF Y$="YES" THEN 02740
02700 PRINT "YOUR RESPONSE SHOULD HAVE BEEN YES OR NO"
02710 PRINT : GO TO 02560

02740 OPEN "CMP01.DAT" AS FILE 1%
02760 DIM #1%, L(50%)=8%, B1$(50%)=8%, C1(50%,7%)=8%
02780 INPUT "ALL OR PART";P$ : PRINT
02840 IF P$="ALL" THEN 3780
02860 IF P$="PART" THEN 2940
02880 PRINT "YOUR RESPONSE SHOULD HAVE BEEN ALL OR PART"
02900 PRINT : GO TO 02780
02940 INPUT "ENTER BODY TYPE";T$ : PRINT
03000 J%=1%
03020 IF B1$(J%)="END" THEN 03480
03040 IF T$<>B1$(J%) THEN J%=J%+1% : GO TO 03020
03080 PRINT "ENTER INVENTORY,WEEK0,WEEK1,WEEK2,WEEK3,WEEK4 &
      FOR THIS BODY"
03100 PRINT "SEPARATED BY COMMAS"
03120 PRINT
03140 PRINT USING 03150 Z9$,B1$(J%),C1(J%,2%),C1(J%,3%), &
      C1(J%,4%),C1(J%,5%),C1(J%,6%),C1(J%,7%)
03200 INPUT "CORRECT-(YES OR NO)";Q$ : PRINT
03260 IF Q$="YES" THEN 3460
03280 IF Q$="NO" THEN 3360
03300 PRINT "YOUR RESPONSE SHOULD HAVE BEEN YES OR NO"
03310 PRINT : GO TO 03200
03360 PRINT "ENTER CORRECT INVENTORY AND WEEKLY DEMANDS"
03380 PRINT
03400 INPUT C1(J%,2%),C1(J%,3%),C1(J%,4%),C1(J%,5%), &
      C1(J%,6%),C1(J%,7%)
```

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INV

```
03420 PRINT
03440 GO TO 3200
03460 GO TO 3920

03480 PRINT "BODY DOES NOT MATCH EXISTING BODY ON &
       INVENTORY FILE"
03500 PRINT "DO YOU WANT A LIST OF THE BODIES ON THE &
       INVENTORY FILE";
03520 INPUT "(CMP01)-YES OR NO ";Y$ : PRINT
03580 IF Y$="NO" THEN 2940
03600 IF Y$="YES" THEN 3680
03620 PRINT "YOUR RESPONSE SHOULD HAVE BEEN YES OR NO"
03640 PRINT : GO TO 03500
03680 N%=1%
03700 IF B1$(N%)="END" THEN 03760
03720 PRINT B1$(N%), : N%=N%+1% : GO TO 03700
03740 PRINT
03760 GO TO 2940
03780 PRINT "ENTER INVENTORY, WEEK0,WEEK1,WEEK2,WEEK3, &
       WEEK4 DEMANDS FOR EACH"
03800 PRINT "OF THE BODIES, SEPARATED BY COMMAS"
03820 PRINT
03840 GO TO 4120
03920 INPUT "DO YOU WISH TO CHANGE ANOTHER BODY TYPE-YES &
       OR NO";Y9$ : PRINT
03980 IF Y9$="NO" THEN 04620
04000 IF Y9$="YES" THEN 2940
04020 PRINT "YOUR RESPONSE SHOULD HAVE BEEN YES OR NO"
04030 PRINT : GO TO 03920
04080 PRINT
04120 I%=0%
04140 I%=I%+1%
04160 IF B1$(I%)="END" THEN 04620
04180 PRINT USING Z9$ B1$(I%),C1(I%,2%),C1(I%,3%), &
       C1(I%,4%),C1(I%,5%),C1(I%,6%),C1(I%,7%)
04240 INPUT "CORRECT-YES OR NO";Q$ : PRINT
04300 IF Q$="YES" THEN 4520
04320 IF Q$="NO" THEN 4420
04340 PRINT "YOUR RESPONSE SHOULD HAVE BEEN YES OR NO"
```

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INV

```
04350 PRINT : GO TO 04240
04400 PRINT
04420 PRINT "ENTER CORRECT INVENTORY AND WEEKLY DEMANDS"
04430 PRINT
04460 INPUT C1(I%,2%),C1(I%,3%),C1(I%,4%),C1(I%,5%), &
      C1(I%,6%),C1(I%,7%)
04480 PRINT : GO TO 04240
04520 PRINT : GO TO 04140

04620 REM
04680 REM-READ BODY TYPE SPRAY DRY INVENTORY FILE(CMP02)
04700 PRINT "DO YOU WISH TO CHANGE STANDARDIZER, ZIPPER &
      TANK, AND SILO       INVENTORY"
04720 INPUT "FILE (CMP02)-YES OR NO ";Y$
04740 PRINT : PRINT
04820 IF Y$="NO" THEN 05680
04840 IF Y$="YES" THEN 04880
04860 PRINT "YOUR RESPONSE SHOULD HAVE BEEN YES OR NO"
04870 GO TO 04700
04880 OPEN "CMP02,DAT" AS FILE 2%
04900 DIM #2%, L1(20%)=8%, C2(20%,4%)=8%,B2$(20%)=8%
04920 PRINT "ENTER CURRENT SPRAY DRY INVENTORY LBS"
04940 PRINT
04960 I%=0%
05000 I%=I%+1%
05020 IF B2$(I%)="END" THEN 05580
05080 PRINT C2(I%,1%),C2(I%,2%),B2$(I%),C2(I%,4%)
05140 INPUT "CORRECT-(YES OR NO) ";Q$ : PRINT
05200 IF Q$="YES" THEN 5400
05220 IF Q$="NO" THEN 5300
05240 PRINT "YOUR RESPONSE SHOULD HAVE BEEN YES OR NO"
05250 PRINT : GO TO 05140
05300 PRINT
05320 INPUT "ENTER CORRECT BODY LBS. ";C2(I%,4%)
05360 PRINT : GO TO 05140
05380 GO TO 5140
05400 PRINT : GO TO 05000
05580 CLOSE #2%
```

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INV

```
05660 REM-READ BODY TYPE SLURRY TANK INVENTORY FILE(CMP03)
05680 PRINT "DO YOU WISH TO CHANGE SLURRY TANK INVENTORY"
05700 INPUT "FILE (CMP03)-YES OR NO ";Y$
05740 PRINT : PRINT
05780 IF Y$="NO" THEN 32000
05800 IF Y$="YES" THEN 05840
05820 PRINT "YOUR RESPONSE SHOULD HAVE BEEN YES OR NO"
05830 PRINT : GO TO 05680
05840 OPEN "CMP03.DAT" AS FILE 3%
05850 OPEN "CMP01.DAT" AS FILE 1%
05860 DIM #3%, L2(21%)=8%, C3(21%,4%)=8%, B3$(21%)=8%
05880 PRINT "ENTER BODY TYPE AND SLURRY TANK LBS SEPARATED &
      A COMMA"
05900 PRINT
05940 I%=0%
05960 I%=I%+1%
05980 IF B3$(I%)="END" THEN 06560
06040 PRINT C3(I%,1%), C3(I%,2%), B3$(I%), C3(I%,4%)
06100 INPUT "CORRECT-(YES OR NO) ";Q$ : PRINT
06160 IF Q$="NO" THEN 6280
06180 IF Q$="YES" THEN 6380
06200 PRINT "YOUR RESPONSE SHOULD HAVE BEEN YES OR NO"
06210 PRINT : GO TO 06100
06260 PRINT
06280 PRINT "ENTER CORRECT BODY TYPE AND LBS"
06300 PRINT
06320 INPUT B3$(I%),C3(I%,4%) : PRINT
06322 IF C3(I%,1%)=80 OR C3(I%,1%)=81 THEN 06100
06324 J%=0%
06328 J%=J%+1%
06332 IF B1$(J%)="END" THEN 06344
06336 IF B3$(I%)<>B1$(J%) THEN 06328
06340 GO TO 06100
06344 PRINT "BODY DOES NOT EXIST ON CMP01 FILE" : PRINT
06346 PRINT
06348 GO TO 06280
06380 PRINT : GO TO 05960
06560 CLOSE #1%,#3%
32000 END
```

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SCH

```
00020 OPEN "CMP01.DAT" FOR INPUT AS FILE 1%
00040 OPEN "CMP02.DAT" FOR INPUT AS FILE 2%
00060 OPEN "CMP03.DAT" FOR INPUT AS FILE 3%
00080 OPEN "CMP04.DAT" FOR INPUT AS FILE 4%
00100 OPEN "CMP07.DAT" AS FILE 7%

00180 PRINT : PRINT"                    *****CMP &
      SCHEDULE*****" : PRINT

00500 DIM #1%, L(50%)=8%, Y1$(50%)=8%, Y1(50%,7%)=8%
00520 DIM #2%, L1(20%)=8%, Y2(20%,4%)=8%, Y2$(20%)=8%
00540 DIM #3%, L2(21%)=8%, C3(21%,4%)=8%, B3$(21%)=8%
00560 DIM #4%, L3(50%)=8%, B4$(50%)=8%, C4(50%,17%)=8
00580 DIM #7%, B7$(50%)=8%, C7(50%,L3%)=8%
00600 DIM B1$(50%) : DIM C1(50%,7%) : DIM C2(20%,4%)
00610 DIM B2$(20%)

00700 REM-ESTABLISH LENGTH, N(FILE#)%, OF FILES CMP01 TO
00710 REM-CMP04.  1% TO N(#)%
00720 N1%=34% : N2%=19% : N3%=20% : N4%=34%

04900 REM-INITIALIZE ARRAYS
05000 FOR I%=1% TO 50%
05020 B7$(I%)="    "
05040 C7(I%,J%)=0 FOR J%=0% TO 13%
05060 NEXT I%

06680 REM-READ CMP01 AND CMP02 FILES INTO ARRAY
06700 I%=0%
06720 I%=I%+1% : IF Y1$(I%)="END" THEN 06800
06740 B4$(I%)=Y1$(I%)
06760 C1(I%,J%)=Y1(I%,J%) FOR J%=2% TO 7%
06780 GO TO 06720
06800 I%=0%
06820 I%=I%+1% : IF Y2$(I%)="END" THEN 07080
06840 B2$(1%)=Y2$(I%)
06860 C2(I%,1%)=Y2(I%,1%) : C2(I%,2%)=Y2(I%,2%)
06870 C2(I%,4%)=Y2(I%,4%) : GO TO 06820
07080 CLOSE 1%, 2%
```

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SCH

```
07100 REM-CONSOLIDATE SPRAY DRY STORAGE
07120 FOR N%=1% TO N2%-1%
07140 K%=N%+1%

07160 FOR J%=K% TO N2%
07180 IF B2$(N%)<>B2$(J%) THEN 07240
07200 C2(N%,4%)=C2(N%,4%)+C2(J%,4%)  : C2(J%,4%)=0
07240 NEXT J%
07260 NEXT N%

07300 REM-REDUCE SPRAY DRY STORAGE BY WEEK0, WEEK1 DEMANDS
07320 FOR N%=0% TO N1%
07340 FOR J%=0% TO N2%
07360 IF B2$(J%)<>B1$(N%) THEN 07480
07380 IF C2(J%,4%)=0 THEN 07480
07400 C2(J%,4%)=C2(J%,4%)-C1(N%,3%)-C1(N%,4%)
07410 IF C2(J%,4%)>0 THEN 07500
07440 C2(J%,4%)=0
07460 GO TO 7500
07480 NEXT J%
07500 NEXT N%

07540 REM-DECONSOLIDATE SPRAY DRY STORAGE
07550 PRINT "SPRAY DRY STORAGE CONSOLIDATED"
07560 FOR N%=1% TO N2%-1%
07580 K%=N%+1%
07600 FOR J%=K% TO N2%
07620 IF C2(N%,4%)=0 THEN 07780
07640 IF B2$(N%)<>B2$(J%) THEN 07720
07660 C2(N%,4%)=C2(N%,4%)-C2(J%,2%)
07670 IF C2(N%,4%)<0 THEN 07760
07700 C2(J%,4%)=C2(J%,2%)
07720 NEXT J%
07740 C2(J%,2%)=0
07760 C2(N%,4%)=C2(J%,2%)+C2(N%,4%)
07780 NEXT N%

07820 REM-REDUCE WEEK0, WEEK1, WEEK2, WEEK3, WEEK4, DEMANDS
07840 REM-BY CURRENT INVENTORY
```

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SCH

```
07860 FOR N%=1% TO N1%
07880 C1(N%,2%)=C1(N%,2%)-C1(N%,3%)
07890 IF C1(N%,2%)<=0 THEN 08200
07920 C1(N%,3%)=0 : C1(N%,2%)=C1(N%,2%)-C1(N%,4%)
07930 IF C1(N%,2%)<=0 THEN 08240
07980 C1(N%,4%)=0 : C1(N%,2%)=C1(N%,2%)-C1(N%,5%)
07990 IF C1(N%,2%)<=0 THEN 08280
08040 C1(N%,5%)=0 : C1(N%,2%)=C1(N%,2%)-C1(N%,6%)
08050 IF C1(N%,2%)<=0 THEN 08320
08100 C1(N%,6%)=0 : C1(N%,2%)=C1(N%,2%)-C1(N%,7%)
08110 IF C1(N%,2%)<=0 THEN 08360
08160 C1(N%,7%)=0 : GO TO 08380
08200 C1(N%,3%)=-C1(N%,2%)  : GO TO 08380
08240 C1(N%,4%)=-C1(N%,2%)  : GO TO 08380
08280 C1(N%,5%)=-C1(N%,2%)  : GO TO 08380
08320 C1(N%,6%)=-C1(N%,2%)  : GO TO 08380
08360 C1(N%,7%)=-C1(N%,2%)
08380 NEXT N%

08580 REM-ASSIGN GROUP NUMBER 0,1,2,3,4,OR 5 TO EACH OF THE
08585 REM-BODIES
08590 PRINT "DEMANDS APPLIED AGAINST INVENTORY"
08600 FOR N%=1% TO N1%
08620 IF C1(N%,3%)=0 THEN 08680
08640 C7(N%,2%)=0 : GO TO 08940
08680 IF C1(N%,4%)=0 THEN 08740
08700 C7(N%,2%)=1 : GO TO 08940
08740 IF C1(N%,5%)=0 THEN 08800
08760 C7(N%,2%)=2 : GO TO 08940
08800 IF C1(N%,6%)=0 THEN 08860
08820 C7(N%,2%)=3 : GO TO 08940
08860 IF C1(N%,7%)=0 THEN 08920
08800 C7(N%,2%)=4 : GO TO 08940
08920 C7(N%,2%)=5
08940 B7$(N%)=B1$(N%)
08960 C7(N%,1%)=C1(N%,1%)
08980 NEXT N%
```

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SCH

```
09020 REM-ADD DEMANDS FOR WEEK0,WEEK1,WEEK2 TO GET TOTAL
09030 REM-DEMAND FOR GROUP 0 BODIES
09060 FOR N%=1% TO N1%
09080 IF C7(N%,2%)<>0 THEN 09140
09100 C7(N%,3%)=C1(N%,3%)+C1(N%,4%)+C1(N%,5%)
09140 NEXT N%

09160 REM-ADD DEMANDS FOR WEEK1, WEEK2, WEEK3 TO GET TOTAL
09180 REM-DEMAND FOR GROUP 1 BODIES

09200 FOR N%=1% TO N1%
09220 IF C7(N%,2%)<>1 THEN 09280
09240 C7(N%,3%)=C1(N%,4%)+C1(N%,5%)+C1(N%,6%)
09280 NEXT N%

09300 REM-ADD DEMANDS FOR WEEK2, WEEK3, WEEK4 TO GET TOTAL
09310 REM-DEMAND FOR GROUP 2 BODIES
09340 FOR N%=1% TO N1%
09360 IF C7(N%,2%)<>2 THEN 09420
09380 C7(N%,3%)=C1(N%,5%)+C1(N%,6%)+C1(N%,7%)
09420 NEXT N%

09480 REM-ASSIGN SLURRY TANK LBS TO EACH OF THE BODIES
09490 PRINT "TOTAL DEMANDS ADDED FOR GROUPS"
09500 FOR N%=1% TO N3%
09520 FOR I%=1% TO N1%
09540 IF B3$(N%)<>B1$(I%) THEN 09580
09560 C7(I%,4%)=C7(I%,4%)+C3(N%,4%)
09580 NEXT I%
09600 NEXT N%

09680 REM-SUBTRACT SLURRY TANK LBS FROM TOTAL DEMAND TO GET
09690 REM-LBS TO BE MILLED
09720 FOR N%=1% TO N1%
09740 C7(N%,5%)=C7(N%,3%)-C7(N%,4%)
09760 IF C7(N%,5%)>0 THEN 09800
09780 C7(N%,5%)=0
09800 C7(N%,6%)=C7(N%,5%) : IF B7$(N%)<>"CB-13" THEN 09940
09820 IF C7(N%,5%)=0 THEN 10040
```

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SCH

```
09840 W9=C7(N%,5%)/3 : Q4=C7(N%,2%)
09850 C7(N%,5%)=C7(N%,5%)*2/3
09860 C7(N%,6%)=C7(N%,5%) : GO TO 10040
09940 IF B7$(N%)<>"CB-14" THEN 10040
09960 IF W9=0 THEN 10040
09980 C7(N%,2%)=Q4 : C7(N%,5%)=C7(N%,5%)+W9
09990 C7(N%,6%)=C7(N%,5%)
10040 NEXT N%

10220 REM-DETERMINE SPRAY DRY STORAGE LBS
10240 FOR I%=1% TO N1%
10260 IF C4(I%,13%)=1 THEN 10320
10280 IF C4(I%,13%)=5 THEN 10880
10200 GO TO 10380
10320 IF C7(I%,4%)=0 THEN 10880
10330 IF C7(I%,4%)>C7(I%,3%) THEN C7(I%,6%)=0 : GO TO 10880
10340 C7(I%,6%)=C7(I%,3%) : GO TO 10880
10380 H3=0
10400 FOR N%=1% TO N2%
10420 IF B2$(N%)<>B7$(I%) THEN 10780
10440 IF C2(N%,1%)<30 THEN 10640
10460 IF C2(N%,1%)>39 THEN 10560
10480 IF C2(N%,4%)>0 THEN 10780
10500 C2(N%,4%)=0 : H3=H3+C2(N%,2%) : GO TO 10780
10560 IF C2(N%,4%)>0 THEN 10780
10580 C2(N%,4%)=0 : H3=H3+C2(N%,2%) : GO TO 10780
10640 IF C2(N%,1%)=1 THEN 10700
10660 IF C2(N%,1%)=2 THEN 10700
10680 GO TO 10740
10700 H3=H3+C2(N%,2%)-C2(N%,4%) : GO TO 10780
10740 IF C2(N%,4%)>0 THEN 10780
10760 H3=H3+C2(N%,2%)
10780 NEXT N%
10800 C7(I%,9%)=H3 : C7(I%,6%)=C7(I%,9%)-C7(I%,4%)
10810 IF C7(I%,6%)>0 THEN 10880
10860 C7(I%,6%)=0
10880 IF B7$(I%)<>"CB-13" THEN 10890
10885 IF C7(I%,9%)-84000 THEN C7(I%,9%)=56000
10890 NEXT I%
```

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SCH

```
10900 REM-DETERMINE MILL LOAD BATCH SIZE
10920 FOR N%=1% TO N4%
10940 IF C7(N%,6%)=0 THEN 11380
10960 IF C4(N%,13%)=4 THEN 11100
10980 IF C4(N%,13%)=1 THEN 11100
11000 IF C4(N%,13%)=5 THEN 11100
11020 IF C7(N%,9%)=0 THEN 11100
11040 IF C7(N%,4%)=0 THEN 11100
11060 C7(N%,7%)=C7(N%,9%)-C7(N%,4%)  : GO TO 11400
11100 FOR J=1 TO 10
11120 IF C7(N%,6%)<=C4(N%,14%)*J THEN 11220
11140 IF C7(N%,6%)<=C4(N%,15%)*J THEN 11260
11160 IF C7(N%,6%)<=C4(N%,16%)*J THEN 11300
11180 IF C7(N%,6%)<=C4(N%,17%)*J THEN 11340
11200 NEXT J

11220 C7(N%,7%)=C4(N%,14%)*J  : GO TO 11400
11260 C7(N%,7%)=C4(N%,15%)*J  : GO TO 11400
11300 C7(N%,7%)=C4(N%,16%)*J  : GO TO 11400
11340 C7(N%,7%)=C4(N%,17%)*J  : GO TO 11400
11380 C7(N%,7%)=0
11400 IF C4(N%,13%)=1 THEN 11455
11420 IF C4(N%,13%)=5 THEN 11450
11440 GO TO 11600
11450 IF B7$(N%)="CB-13" THEN 11500
11455 IF C7(N%,4%)>C7(N%,3%) THEN 11500
11460 C7(N%,7%)=C7(N%,7%)-C7(N%,4%)
11470 C7(N%,6%))=C7(N%,3%)-C7(N%,4%)
11500 C7(N%,9%)=C7(N%,7%)+C7(N%,4%)
11510 IF C7(N%,7%)>0 THEN 11560
11540 C7(N%,7%)=0
11560 IF C7(N%,6%)>0 THEN 11600
11580 C7(N%,6%)=C7(N%,9%)-C7(N%,4%)
11600 NEXT N%

11680 REM-ADD SLURRY TANK LBS AND MILL LOAD LBS TO GET LBS
11690 REM-TO BE SPRAY DRIED
11700 FOR N%=1% TO N1%
11720 C7(N%,8%)=C7(N%,7%)+C7(N%,4%)
```

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SCH

```
11740 IF C7(N%,4%)<=C7(N%,9%) THEN 11780
11760 C7(N%,8%)=C7(N%,9%)
11780 IF C7(N%,9%)>0 THEN 11820
11800 C7(N%,9%)=C7(N%,8%)
11820 NEXT N%

11860 REM-ADJUST SPRAY DRY LBS FOR CB-13 AND CB-14
11870 PRINT "MILL LOAD BATCH SIZES DETERMINED"
11880 FOR N%=1% TO N1%
11900 IF B7$(N%)<>"CB-13" THEN 12020
11920 IF C7(N%,6%)=0 THEN 12020
11940 W8=C7(N%,9%)/2 : C7(N%,9%)=C7(N%,9%)*3/2
11960 C7(N%,8%)=C7(N%,9%)  : GO TO 12120
12020 IF B7$(N%)<>"CB-14" THEN 12120
12040 IF C7(N%,6%)=0 THEN 12120
12060 IF W8=0 THEN 12120
12080 C7(N%,9%)=C7(N%,9%)-W8 : C7(N%,8%)=C7(N%,9%)
12120 IF C7(N%,9%)=0 THEN 12160
12140 GO TO 12180

12160 C7(N%,8%)=0
12180 NEXT N%

13000 CLOSE 3%,4%,7%
15000 CHAIN "DRYER"
32701 END
```

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DRYER

```
00020 OPEN "CMP04.DAT" FOR INPUT AS FILE 4%
00040 OPEN "CMP05.DAT" FOR INPUT AS FILE 5%
00060 OPEN "CMP06.DAT" FOR INPUT AS FILE 6%
00080 OPEN "CMP07.DAT" AS FILE 7%
00100 OPEN "CMP08.DAT" AS FILE 8%

00120 I1$=" \    \ #  #######  #######  #######  #######  &
      #######        #######         #######  #"
00140 I2$="  \    \    #######     ###.#       ##.#    ##  &
      ##                 ##.#           ##   ##"
00180 PRINT : PRINT "                          ***** CMP SCHEDULE &
      *****" : PRINT : PRINT
00260 PRINT "ENTER START DAY AND TIME FOR SPRAY DRYER NO. 1&
       SCHEDULE"
00280 INPUT "MM,DD,HH.H "; M9,D9,H9 : PRINT : PRINT
00340 PRINT "ENTER START DAY AND TIME FOR SPRAY DRYER NO. 2&
       SCHEDULE"
00360 INPUT "MM,DD,HH.H ";M,D,H : PRINT : PRINT

00520 DIM #5%, L4(7%)=8%, B5%(7%,8%)=4%
00540 DIM #6%, L5(27%)=8%, B6%(27%,28%)=4%
00560 DIM #4%, L3(50%)=8%, B4$(50%)=8%, C4(50%,17%)=8%
00580 DIM #7%, B7$(50%)=8%, C7(50%,13%)=8%
00600 DIM #8%, B8$(15%)=8%, B9$(65%)=8%, S8(15%,10%)=8%, &
      S9(65%,10%)=8%,F8(4%)=8%
00620 DIM C5(15%) : DIM C6(65%) : DIM D5(15%) : DIM D6(65%)

00700 REM-ESTABLISH LENGTH, N(FILE#)%, OF FILES
00710 REM-CMP01,CMP04.  1% TO N#%
00720 N1%=34% : N4%=34%
00740 FOR I%=1% TO 15%
00745 B8$(I%)="      " : S8(I%,J%)=0 FOR J%=0% TO 10%
00750 NEXT I%
00760 FOR I%=1% TO 65%
00765 B9$(I%)="      " : S9(I%,J%)=0 FOR J%=0% TO 10%
00770 NEXT I%
00860 PRINT "ENTER LAST BODY TO BE SPRAY DRIED ON SPRAY &
      DRYER NO. 1"
00880 INPUT "BODY ";S1$ : PRINT : PRINT
```

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```
00980 I%=0%
01000 I%=I%+1% : IF C4(I%,10%)=0 THEN 01100
01060 IF S1$<>B4$(I%) THEN 01000
01080 GO TO 1500
01100 PRINT "BODY DOES NOT MATCH WITH SPRAY DRYER NO. 1 &
      BODIES";
01120 PRINT S1$ : PRINT : PRINT
01180 PRINT "DO YOU WANT A LIST OF THE SPRAY DRYER NO. 1 &
      BODIES"
01200 INPUT "-YES OR NO "; Y$ : PRINT
01260 IF Y$="NO" GO TO 860
01280 IF Y$="YES" THEN 1360
01300 PRINT "YOUR RESPONSE SHOULD HAVE BEEN YES OR NO"
01310 PRINT : GO TO 01180
01360 PRINT B4$(N%), FOR N%=1% TO I%
01380 PRINT : PRINT
01480 GO TO 860
01500 PRINT "ENTER FIRST BODY TO BE SPRAY DRIED ON SPRAY &
      DRYER NO. 2"
01520 INPUT "BODY"; S2$ : PRINT : PRINT
01600 I%=0%
01620 I%=I%+1%
01640 IF B4$(I%)="END" THEN 01720
01660 IF C4(I%,12%)=0 THEN 01620
01680 IF S2$<>B4$(I%) THEN 01620
01700 GO TO 12380
01720 PRINT "BODY DOES NOT MATCH WITH SPRAY DRYER NO. 2 &
      BODIES";
01740 PRINT S2$ : PRINT
01780 PRINT "DO YOU WANT A LIST OF THE SPRAY DRYER NO. 2 &
      BODIES"
01800 INPUT "-YES OR NO "; Y$ : PRINT
01860 IF Y$="NO" GO TO 1500
01880 IF Y$="YES" THEN 1960
01900 PRINT "YOUR RESPONSE SHOULD HAVE BEEN YES OR NO"
01910 PRINT : GO TO 01780
01960 FOR N%=1% TO I%
01980 IF C4(N%,12%)=0 THEN 02020
02000 PRINT B4$(N%),
```

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```
02020 NEXT N%
02080 PRINT : PRINT : GO TO 01500

12380 REM-DETERMINE IF SLURRY BATCH AND MILL BATCH ARE TO BE
12390 REM-SPRAY DRIED TOGETHER
12420 FOR N%=1% TO N1%
12430 IF B7$(N%)="CB-01" THEN 12480
12440 IF C7(N%,4%)=0 THEN 12720
12460 IF C7(N%,4%)<C7(N%,9%) THEN 12520
12480 C7(N%,10%)=0 : GO TO 12720
12520 C7(N%,10%)=1
12540 FOR J=1 TO 10
12560 IF C7(N%,4%)=C4(N%,14%)*J THEN 12680
12580 IF C7(N%,4%)=C4(N%,15%)*J THEN 12680
12600 IF C7(N%,4%)=C4(N%,16%)*J THEN 12680
12620 IF C7(N%,4%)=C4(N%,17%)*J THEN 12680
12640 NEXT J
12660 GO TO 12720
12680 IF C7(N%,2%)>1 THEN 12720
12700 C7(N%,10%)=0
12720 NEXT N%

12740 REM-PRINT BODY DEMAND REQUIREMENTS
12760 PRINT : PRINT : PRINT
12840 PRINT "         $$$$$$$$$$ BODY DEMAND REQUIREMENTS &
      $$$$$$$$$$" : PRINT
12900 PRINT "BODY     ADJUSTED SLURRY  LBS TO    DRY &
      ADJUSTED  ADJUSTED   *SPRAY DRY*"
12920 PRINT "TYPE WEEK DEMAND   LBS     MILL   STORAGE &
      MILL LBS MILL BATCH LBS BATCHES"
12960 PRINT
12980 FOR N%=1% TO N1%
13000 X9=0
13020 FOR J%=3% TO 9%
13040 X9=X9+C7(N%,J%)
13060 NEXT J%
13080 IF X9=0 THEN 13340
```

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```
13100 PRINT USING I1$,B7$(N%),C7(N%,2%),C7(N%,3%),&
      C7(N%,4%),C7(N%,5%),C7(N%,9%),C7(N%,6%),&
      C7(N%,7%),C7(N%,8%),C7(N%,10%);
13220 IF C7(N%,12%)=9 THEN 13280
13240 P$=" " : GO TO 13300
13280 P$="*"
13300 PRINT P$
13340 NEXT N%
13360 PRINT

13500 REM-ADJUST BODY DEMAND REQUIREMENTS
13520 PRINT "DO YOU WISH TO CHANGE THE ABOVE BODY DEMAND &
      REQUIREMENTS"
13540 INPUT "(Y=YES, N=NO)"; Y$
13580 PRINT : IF ASCII(Y$)=78% THEN 14460
13700 INPUT "ENTER BODY TYPE"; H9$
13760 N%=0%
13780 N%=N%+1% : IF N%>N1% THEN 13860
13820 IF H9$<>B7$(N%) THEN 13780
13840 GO TO 13920
13860 PRINT "NO MATCH FOR"; H9$; "ON BODY TYPE ARRAY - C7"
13880 PRINT : GO TO 13700
13920 PRINT "ENTER SLURRY LBS, MILL BATCH LBS, SPRAY DRY &
      LBS, BATCH"
13960 PRINT
13980 INPUT C7(N%,4%),C7(N%,7%),C7(N%,8%),C7(N%,10%)
14000 PRINT
14020 INPUT "CORRECT (Y=YES, N=NO)"; Q$
14060 PRINT : IF ASCII(Q$)=78% THEN 13920
14200 C7(N%,12%)=9
14240 INPUT "CHANGE ANOTHER (Y=YES, N=NO)";Y$
14280 PRINT : IF ASCII(Y$)=89% THEN 13700
14320 GO TO 12740

14440 REM-DETERMINE SPRAY DRYER NO. 1 SEQUENCE
14460 FOR N%=1% TO 15%
14480 D5(N%)=0 : C5(N%)=0
14520 NEXT N%
14540 J%=0%
```

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```
14600 J%=J%+1% : IF J%>N4% THEN 14700
14640 IF S1$<>B4$(J%) THEN 14600
14660 D5(0%)=C4(J%,10%) : GO TO 14760
14700 PRINT "NO MATCH FOR THIS BODY ON BODY TYPE MASTER &
      FILE";
14720 PRINT "-CMP04", S1$
14740 STOP
14760 P1%=0% : K8=D5(0%)
14800 FOR I%=1% TO 4%
14920 FOR N%=1% TO N4%
14830 IF C7(N%,8%)=0 THEN 15220
14840 IF C7(N%,10%)=0 THEN 14880
14860 C7(N%,10%)=1
14880 IF C4(N%,10%)=0 THEN 15220
14900 IF I%<3% THEN 14940
14920 GO TO 14980
14940 IF C7(N%,4%)=0 THEN 15220
14960 GO TO 15020
14980 IF C7(N%,7%)=0 THEN 15220
15000 IF C7(N%,10%)=1 THEN 15220
15020 IF I%=1% THEN 15080
15040 IF I%=3% THEN 15080
15060 GO TO 15120
15080 IF C4(N%,10%)>K8 THEN 15160
15100 GO TO 15220
15120 IF C4(N%,10%)<=K8 THEN 15160
15140 GO TO 15220
15160 GO TO 15180
15180 P1%=P1%+1% : IF P1%>15% THEN 15340
15200 D5(P1%)=C4(N%,10%)
15220 NEXT N%
15240 IF I%=2% THEN 15280
15260 GO TO 15300
15280 K8=D5(P1%)
15300 NEXT I%
15320 GO TO 15500
15340 PRINT "TOO MANY BODIES IN SPRAY DRYER NO. 1 SEQUENCE"
15360 PRINT "INCREASE SIZE OF D5(N) ARRAY"
15380 STOP
```

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```
15480 REM-DETERMINE SPRAY DRYER NO. 2 SEQUENCE
15500 FOR N%=1% TO 65%
15520 D6(N%)=0 : C6(N%)=0
15560 NEXT N%
15580 J%=0%
15600 J%=J%+1% : IF J%>N4% THEN 15700
15640 IF S2$<>B4$(J%) THEN 15600
15660 D6(0%)=C4(J%,12%) : GO TO 15800
15700 PRINT "NO MATCH FOR THIS BODY ON BODY TYPE MASTER &
      FILE";
15720 PRINT "-CMP04", S2$
15780 STOP
15800 P2%=0% : K8=D6(0%)
15840 FOR I%=1% TO 4%
15850 IF I%=3% THEN K8=K8+1
15855 IF I%=4% THEN K8=K8+1

15860 FOR N%=1% TO N4%
15870 IF C7(N%,8%)=0 THEN 16260
15880 IF C7(N%,10%)=0 THEN 15920
15900 C7(N%,10%)=1
15920 IF C4(N%,12%)=0 THEN 16260
15940 IF I%<3% THEN 15980
15960 GO TO 16020
15980 IF C7(N%,4%)=0 THEN 16260
16000 GO TO 16060
16020 IF C7(N%,7%)=0 THEN 16260
16040 IF C7(N%,10%)=1 THEN 16260
16060 IF I%=1% THEN 16120
16080 IF I%=3% THEN 16120
16100 GO TO 16160

16120 REM
16130 IF C4(N%,12%)>=K8 THEN 16200
16140 GO TO 16260
16160 REM
16170 IF C4(N%,12%)<K8 THEN 16200
16180 GO TO 16260
16200 GO TO 16220
```

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```
16220 P2%=-2%+1% : IF P2%>65% THEN 16380
16240 D6(P2%)=C4(N%,12%)
16260 NEXT N%
16280 IF I%=2% THEN 16320
16300 GO TO 16340
16320 K8=D6(P2%)
16340 NEXT I%
16360 GO TO 16500
16380 PRINT "TOO MANY BODIES IN SPRAY DRYER NO. 2 SEQUENCE"
16400 PRINT "INCREASE SIZE OF D6(N) ARRAY"
16420 STOP

16480 REM-DETERMINE CLEANUP TIMES FOR SPRAY DRYER NO. 1
16490 REM-SEQUENCE
16500 FOR N%=1% TO P1%-1%
16520 A=D5(N%) : E7%=N%+1% : B=D5(E7%)
16580 B=B+1 : C5(N%)=B5%(A,B) : IF C5(N%)=6 THEN 16680
16640 C5(N%)=0 : GO TO 16700
16680 C5(N%)=20
16700 NEXT N%

16920 REM-DETERMINE CLEANUP TIMES FOR SPRAY DRYER NO. 2
16930 REM-SEQUENCE
16940 FOR N%=1% TO P2%-1%
16960 A=D6(N%) : Q8%=N%+1% : B=D6(Q8%)
17020 B=B+1 : C6(N%)=B6%(A,B) : IF C6(N%)=1 THEN 17220
17080 IF C6(N%)=2 THEN 17260
17100 IF C6(N%)=3 THEN 17300
17120 IF C6(N%)=4 THEN 17340
17140 IF C6(N%)=5 THEN 17380
17160 IF C6(N%)=6 THEN 17420
17180 C6(N%)=0 : GO TO 17440
17220 C6(N%)=4 : GO TO 17440
17260 C6(N%)=5 : GO TO 17440
17300 C6(N%)=9.7 : GO TO 17440
17340 C6(N%)=11.2 : GO TO 17440
17380 C6(N%)=16.9 : GO TO 17440
17420 C6(N%)=20
17440 NEXT N%
```

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```
17460 IF X7% = 7788% THEN 20380

17720 REM-CALCULATE SPRAY DRYER NO. 1 SCHEDULE
17740 FOR K%=1% TO P1%*2%-1%
17760 FOR J%=1% TO 10%
17780 S8(K%,J%)=0 : B8$(K%)="      "
17820 NEXT J%
17840 NEXT K%
17860 M1=M9 : D1=D9 : S=0 : B=0 : P=0 : T1=0 : H1=H9 : H2=H9
18020 FOR N%=1% TO P1%*2%-1%
18040 S=S+1 : X=S-(2*INT(S/2)) : W=S-INT(S/2)
18060 IF X=1 THEN 18200
18120 B=0 : T1=C5(W) : P=0 : GO TO 18880
18200 B=D5(W) : I%=0%
18240 I%=I%+1% : IF I%>N4% THEN 18380
18280 IF C4(I%,10%)=0 THEN 18240
18300 IF D5(W)<>C4(I%,10%) THEN 18240
18320 B8$(S)=B4$(I%) : Z=C4(I%,9%) : GO TO 18420
18380 PRINT "NO MATCH FOR THIS BODY TYPE MASTER &
      FILE(CMP04) ";D5(W)
18400 STOP
18420 I%=0%
18440 I%=I%+1% : IF I%>N1% THEN 18840
18480 IF B8$(S)<>B7$(I%) THEN 18440
18500 IF C7(I%,10%)=1 THEN 18760
18520 IF C7(I%,10%)=9 THEN 18680
18540 IF C7(I%,4%)=0 THEN 18740
18560 P=C7(1%,4%) : IF C7(I%,7%)=0 THEN 18780
18600 C7(I%,10%)=9 : S8(N%,0%)=7
18610 C7(I%,0%)=C7(I%,8%)-C7(I%,4%) : GO TO 18780
18680 C7(I%,10%)=0 : P=C7(I%,0%) : GO TO 18780
18740 IF N%=1% THEN 18900
18760 P=C7(I%,8%)
18780 T1=P/Z : T1=INT(T1*10+.5)/10 : GO TO 18900
18840 PRINT "NO MATCH FOR THIS BODY ON BODY TYPE ACTIVITY &
      ARRAY ";B8$(S)
18860 STOP
18880 B8$(S)="CLEAN"
```

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```
18900 REM-DETERMINE MONTH, DAY, AND FINISH TIME
18920 H1=H2 : H1=INT(H1*10+.5)/10 : IF X=1 THEN 19020
18980 H2=H1+C5(W) : GO TO 19040
19020 H2=H1+T1
19040 IF H1<24.0 THEN 19120
19060 H2=H2-24 : D1=D1+1 : GO TO 19040
19120 H2=INT(H2*10+.5)/10 : GO TO 19240
19240 IF M1=01 THEN 19540
19260 IF M1=02 THEN 19700
19280 IF M1=03 THEN 19540
19300 IF M1=04 THEN 19620
19320 IF M1=05 THEN 19540
19340 IF M1=06 THEN 19620
19360 IF M1=07 THEN 19540
19380 IF M1=08 THEN 19540
19400 IF M1=09 THEN 19620
19420 IF M1=10 THEN 19540
19440 IF M1=11 THEN 19620
19460 IF M1=12 THEN 19540
19470 IF M1=13 THEN 19540
19480 PRINT "MONTH ENTERED IS GREATER THAN 12"
19500 PRINT "CHECK MONTH ENTERED FOR SPRAY DRYER AND BALL &
      MILL SCHEDULE"
19520 STOP
19540 IF D1<32 THEN 19740
19560 D1=D1-31 : M1=M1+1 : GO TO 19740
19620 IF D1<31 THEN 19740
19640 D1=D1-30 : M1=M1+1 : GO TO 19740
19700 IF D1<29 THEN 19740
19720 D1=D1-28
19740 IF M1<14 THEN 19780
19760 M1=M1-13
19780 IF X1=1 THEN 21840
19800 IF X1=2 THEN 23160
19820 S8(N%,1%)=M1 : S8(N%,2%)=D1 : S8(N%,3%)=S
19830 S8(N%,4%)=8
19900 S8(N%,5%)=P : S8(N%,6%)=T1 : S8(N%,7%)=H1
19910 S8(N%,8%)=H2
19980 NEXT N%
```

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```
20000 REM-PRINT SPRAY DRYER NO. 1 SCHEDULE
20020 PRINT : PRINT : PRINT
20040 PRINT "          $$$$$$$$ SPRAY DRYER NO. 1 SCHEDULE &
      $$$$$$$$" : PRINT
20080 GOSUB 22760
20120 PRINT : S8(0%,1%)=M9 : S8(0%,2%)=D9
20180 FOR N%=1% TO P1%*2%-1%
20200 IF S8(N%,6%)=0 THEN 20360
20220 J%=N%-1%
20225 T4%=S8(J%,1%)
20228 T5%=S8(N%,1%)
20230 IF T4%=13 THEN T4%=01
20233 IF T5%=13 THEN T5%=01
20240 PRINT USING I2$,B8$(N%),S8(N%,5%),S8(N%,6%),&
      S8(N%,7%),T4%,S8(J%,2%),S8(N%,8%),T5%,S8(N%,2%)&
      S8(N%,9%)=S8(J%,1%) : S8(N%,10%)=S8(J%,2%) : PRINT
20360 NEXT N%
20380 PRINT : PRINT : PRINT

20480 REM-CALCULATE SPRAY DRYER NO. 2 SCHEDULE
20500 FOR K%=1% TO P2%*2%-1%
20520 FOR J%=1% TO 10%
20540 S9(K%,J%)=0 : B9$(K%)="      "
20580 NEXT J%
20600 NEXT K%
20620 M1=M : D1=D : S=0 : B=0 : P=0 : T1=0 : H1=H : H2=H
20780 FOR N%=1% TO P2%*2%-1%
20800 S=S+1 : X=S-(2*INT(S/2)) : W=S-INT(S/2)
20810 IF X=1 THEN 20960
20880 B=0 : T1=C6(W) : P=0 : GO TO 21660
20960 B=D6(W) : T%=0%
21000 I%=I%+1% : IF I%>N4% THEN 21140
21040 IF C4(I%,12%)=0 THEN 21000
21060 IF D6(W)<>C4(I%,12%) THEN 21000
21080 B9$(S)=B4$(I%) : Z=C4(I%,11%) : GO TO 21180
21140 PRINT "NO MATCH FOR THIS BODY ON BODY TYPE MASTER &
      FILE (CMP04) "; D6(W)
21160 STOP
21180 I%=0%
```

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```
21200 I%=I%+1% : IF I%>N1% THEN 21600
21240 IF B9$(S)<>B7$(I%) THEN 21200
21260 IF C7(I%,10%)=1 THEN 21520
21280 IF C7(I%,10%)=9 THEN 21440
21300 IF C7(I%,4%)=0 THEN 21500
21320 P=C7(I%,4%) : IF C7(I%,7%)=0 THEN 21520
21360 C7(I%,10%)=9 : S9(N%,0%)=7
21380 C7(I%,0%)=C7(I%,8%)-C7(I%,4%) : GO TO 21540
21440 C7(I%,10%)=0 : P=C7(I%,0%) : GO TO 21540
21500 IF N%=1% THEN 21680
21520 P=C7(I%,8%)
21540 T1=P/Z : T1=INT(T1*10+.5)/10 : GO TO 21680
21600 PRINT "NO MATCH FOR THIS BODY OR BODY TYPE ACTIVITY &
      ARRAY-C7(N,I)";
21620 PRINT B9$(S)
21640 STOP
21660 B9$(S)="CLEAN"
21680 REM-DETERMINE MONTH,DAY,AND FINISH TIME
21700 H1=H2 : IF X=1 THEN 21780
21740 H2=H1+C6(W) : GO TO 21800
21780 H2=H1+T1
21800 X1=1 : GO TO 19040
21840 S9(N%,1%)=M1 : S9(N%,2%)=D1 : S9(N%,3%)=S
21850 S9(N%,4%)=8
21920 S9(N%,5%)=P : S9(N%,6%)=T1 : S9(N%,7%)=H1
21930 S9(N%,8%)=H2
22000 NEXT N%
22120 REM-PRINT SPRAY DRYER NO. 2 SCHEDULE
22140 PRINT
22160 PRINT "          $$$$$$$$ SPRAY DRYER NO. 2 SCHEDULE &
      $$$$$$$$" : PRINT
22200 GOSUB 22760
22240 PRINT : S9(0%,1%)=M : S9(0%,2%)=D
22300 FOR N%=1% TO P2%*2%-1%
22320 IF S9(N%,6%)=0 THEN 22480
22340 J%=N%-1%
22345 T4%=S9(J%,1%)
22348 T5%=S9(N%,1%)
22350 IF T4%=13 THEN T4%=01
```

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```
22353 IF T5%=13 THEN T5%=01
22360 PRINT USING I2$,B9$(N%),S9(N%,5%),S9(N%,6%),
22370 S9(N%,7%),T4%,S9(J%,2%),S9(N%,8%),T5%,S9(N%,2%)
22420 S9(N%,9%)=S9(J%,1%) : S9(N%,10%)=S9(J%,2%) : PRINT
22480 NEXT N%
22500 PRINT : PRINT : PRINT : PRINT
22580 INPUT "DO YOU WISH TO MAKE ANOTHER CHANGE (Y=YES, &
      N=NO)"; Q$
22620 PRINT : S1$=S1$ : S2$=S2$
22680 IF ASCII(Q$)=78% THEN 22800
22720 IF ASCII(Q$)=89% THEN CLOSE 4%,5%,6%,7%,8%
22730 CHAIN "PART2"
22740 PRINT "INCORRECT RESPONSE" : PRINT : GO TO 22580
22760 PRINT" BODY TYPE    LBS       HOURS      START  &
      MONTH  DAY       FINISH   MONTH   DAY"
22780 RETURN
22800 F8(1%)=N1% : F8(2%)=N4% : F8(3%)=P1% : F8(4%)=P2%
22810 INPUT "DO YOU WISH TO CHANGE SPRAY DRYER NO. 2 &
      SEQUENCE (Y=YES, N=NO)"; Q$ : PRINT
22818 IF ASCII(Q$)=89% THEN 22834
22822 IF ASCII(Q$)=78% THEN 22900
22826 PRINT "INCORRECT RESPONSE" PRINT " GO TO 22810
22834 FOR N%=1% TO P2%
22836 PRINT "ENTER BODY TYPE IN SPRAY DRYING POSITION NO.";&
       N%; : INPUT B$ : PRINT
22840 J%=0%
22844 J%=J%+1%
22848 IF B4$(J%)="END" THEN 22864
22852 IF B4$(J%)<>B$ THEN 22844
22856 D6(N%)=C4(J%,12%)
22860 GO TO 22872
22864 PRINT "BODY DOES NOT MATCH WITH CMP04 BODIES"
22868 PRINT : GO TO 22836
22872 NEXT N%
22874 X7%=7788%
22876 GO TO 16920
22900 CLOSE 4%,5%,6%,7%,8%
23000 CHAIN "BALL"
30000 END
```

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BALL

```
00020 OPEN "CMP04.DAT" FOR INPUT AS FILE 4%
00080 OPEN "CMP07.DAT" AS FILE 7%
00100 OPEN "CMP08.DAT" AS FILE 8%

00200 I3$="   ##   ##   ##       \    \       #####    #"
00560 DIM #4%, L3(50%)=8%, B4$(50%)=8%, C9(50%,17%)=8%
00580 DIM #7%,B7$(50%)=8%,C7(50%,13%)=8%
00600 DIM #8%,B8$(15%)=8%, B9$(65%)=8%, S8(15%,10%)=8%, &
      S9(65%,10%)=8%, F8(4%)=8%
00610 DIM C4(50%,17%)
00620 DIM T(84%,5%) : DIM T9$(84%)

00630 PRINT : PRINT : PRINT
00640 PRINT "ENTER START DAY FOR BALL MILL SCHEDULE"
00660 INPUT "MM,DD"; M5,D5 : PRINT : PRINT
00700 N1%=F8(1%) : N4%=F8(2%) : P1%=F8(3%) : P2%=F8(4%)

00780 FOR N%=1% TO 34%
00790 FOR J%=1% TO 17%
00800 C4(N%,J%)=C9(N%,J%)
00810 NEXT J%
00825 NEXT N%

00840 INPUT "ARE BALL MILLS 12-17 IN SERVICE (Y=YES, &
      N=NO)";Q$ : PRINT
00850 IF ASCII(Q$)=89% THEN 05000
03000 FOR I%=12% TO 17%
03010 PRINT "IS MILL"; : INPUT "IN SERVICE (Y=YES, N=NO)"; &
      Q$ : PRINT
03050 IF ASCII(Q$)=89% THEN 04040
04000 FOR N%=1% TO 34%
04010 J%=1%-10%
04020 C4(N%,J%)=0
04030 NEXT N%
04040 NEXT I%

05000 GO TO 22800

19220 D1=D1+1
```

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BALL

```
19240 IF M1=01 THEN 19540
19260 IF M1=02 THEN 19700
19280 IF M1=03 THEN 19540
19300 IF M1=04 THEN 19620
19320 IF M1=05 THEN 19540
19340 IF M1=06 THEN 19620
19360 IF M1=07 THEN 19540
19380 IF M1=08 THEN 19540
19400 IF M1=09 THEN 19620
19420 IF M1=10 THEN 19540
19440 IF M1=11 THEN 19620
19460 IF M1=12 THEN 19540
19470 IF M1=13 THEN 19540

19480 PRINT "MONTH ENTERED IS GREATER THAN 12"
19500 PRINT "CHECK MONTH ENTERED FOR SPRAY DRYER AND BALL &
      MILL SCHEDULE"
19520 STOP

19540 IF D1<32 THEN 19740
19560 D1=D1-31 : M1=M1+1 : GO TO 19740
19620 IF D1<31 THEN 19740
19640 D1=D1-30 : M1=M1+1 : GO TO 19740
19700 IF D1<29 THEN 19740
19720 D1=D1-28
19740 IF M1<14 THEN 19780
19760 M1=M1-13
19780 GO TO 23160

22800 REM-CALCULATE BALL MILL SCHEDULE
22820 PRINT : PRINT : PRINT : PRINT
22920 M6=12
22940 FOR J%=1% TO 84%
22960 T(J%,1%)=M5 : T(J%,2%)=D5 : T(J%,3%)=M6
23020 M6=M6+1 : IF M6<18 THEN 23200
23060 M6=12 : D1=D5 : M1=M5 : X1=2 : GO TO 19220
23160 D5=D1 : M5=M1
23200 NEXT J%
```

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TIME: 16:17

BALL

```
23205 FOR N%=1% TO N1%
23210 C7(N%,13%)=C7(N%,7%)
23215 NEXT N%

23220 REM-CHECK NO. 1 SPRAY DRYER SCHEDULE FOR MILL LOAD LBS
23240 FOR J%=1% TO P1%*2%-1%
23260 IF B8$(J%)="CLEAN" THEN 24860
23280 K%=0%
23300 K%=K%+1% : IF K%>N1% THEN 23380
23320 IF K%>N1% THEN 23380
23340 IF B8$(J%)<>B7$(K%) THEN 23300
23360 GO TO 23420
23380 PRINT "NO MATCH FOR THIS BODY ON ACTIVITY ARRAY-C7"; &
      B8$(J)
23400 STOP

23420 REM-ASSIGN MILL BATCH LBS TO BALL MILL SCHEDULE
23450 Z1$=B8$(J%) : Z2%=S8(J%,9%) : Z3%=S8(J%,10%)
23460 Q4%=0%
23480 Q4%=Q4%+1%
23500 ON Q4% GO TO 23520,23580,23640,23700,23760,23820,23830
23520 V%=3% : N%=2% : GO TO 23860
23580 V%=6% : N%=5% : GO TO 23860
23640 IF C4(K%,12%)>6 THEN 23700
23650 V%=7% : N%=6% : GO TO 23860
23700 V%=2% : N%=1% : GO TO 23860
23760 V%=4% : N%=3% : GO TO 23860
23820 IF C4(K%,12%)<=6 THEN 23830
23825 V%=7% : N%=6% : GO TO 23860
23830 V%=5% : N%=4%

23860 REM-ASSIGN MILL LOAD LBS TO BALL MILL SCHEDULE
23880 IF C7(K%,7%)=0 THEN 24860
23900 FOR L%=N% TO 84%-(6%-N%) STEP 6%
23910 IF X9-1 THEN 24180
23920 IF Z1$="CB-01" THEN 24180
23940 E4=T(L%,1%)*100+T(L%,2%) : IF Z1$<>"CB-14" THEN 24020
23980 E5=W4 : GO TO 24100
24020 E5=Z2%*100+Z3% : IF Z1$="CB-15" THEN 24140
```

DATE: 16-FEB-78
TIME: 16:17

BALL

```
24060 IF Z1$<>"CB-13" THEN 24100
24080 W4=E5
24100 IF E4>=E5 THEN 24460
24120 GO TO 24180
24140 IF T(L%,3%)>=8 THEN E5=E5+1
24145 IF C7(K%,13%)<=56000 THEN 24150
24147 IF E4<=E5-6 THEN 24460
24150 IF E4<=E5-4 THEN 24460
24160 IF E4>E5-1 THEN 24460
24180 IF C4(K%,V%)=0 THEN 24460
24190 IF C7(K%,7%)<=0 THEN 24820
24220 IF T(L%,4%)>0 THEN 24460
24240 T(L%,4%)=C4(K%,V%) : IF T(L%,3%)<16 THEN 24320
24280 Q=45 : GO TO 24340
24320 Q=35
24340 T(L%,5%)=INT(240/(C4(K%,8%)+Q))
24350 IF T(L%,5%)>0 THEN 24400
24380 T(L%,5%)=1
24400 T9$(L%)=Z1$ : T(L%,0%)=T(L%,4%)*T(L%,5%)
24410 C7(K%,7%)=C7(K%,7%)-T(L%,0%)
24460 IF X6=0 THEN 25620
24480 X6=0 : IF N%<>2% THEN 24580
24520 L%=L%+3% : N%=5% : V%=6%
24580 IF N%<>5% THEN 24660
24600 L%=L%-3% : N%=2% : V%=3%
24660 IF N%<>1% THEN 24740
24680 L%=L%+2% : N%=3% : V%=4%
24740 IF N%<>3% THEN 24820
24760 L%=L%-2% : N%=1% : V%=2%
24820 NEXT L%
24840 IF V%<>5% THEN 23480
24860 IF X3=9898 THEN 25280
24880 NEXT J%

24900 REM-CHECK NO. 2 SPRAY DRYER SCHEDULE FOR MILL LOAD LBS
24920 FOR J%=1% TO P2%*2%-1%
24940 IF B9$(J%)="CLEAN" THEN 25280
24960 K%=0%
24980 K%=K%+1% : IF K%>N1% THEN 25120
```

DATE: 16-FEB-78
TIME: 16:17

BALL

```
25020 IF B9$(J%)<>B7$(K%) THEN 24980
25040 IF C7(K%,7%)=0 THEN 25280
25080 IF S9(J%,0%)=7 THEN 25280
25100 GO TO 25160

25120 PRINT "NO MATCH FOR THIS BODY ON ACTIVITY ARRAY- &
      C7";B9$(J)
25140 STOP

25160 REM-ASSIGN MILL BATCH LBS TO BALL MILL SCHEDULE
25180 X3=9898 : Z1$=B9$(J%) : Z2%=S9(J%,9%)
25240 Z3%=S9(J%,10%) : GO TO 23460
25280 NEXT J%
25290 IF X9=0 THEN X9=1 ELSE 25300
25295 GO TO 24900

25300 REM-PRINT BALL MILL SCHEDULE
25310 GO TO 32700
25320 PRINT "        $$$$$$$$$$ BALL MILL SCHEDULE &
      $$$$$$$$$$
25340 PRINT : PRINT
25380 PRINT" MONTH   DAY   BALL MILL   BODY TYPE    LBS   &
      LOADS"
25400 PRINT
25420 FOR J%=1% TO 84%
25425 T3%=T(J%,1%)
25430 IF T3%=13% THEN T3%=01%
25440 PRINT USING I3$,T3$,T(J%,2%),T(J%,3%),T9$(J%), &
      T(J%,4%),T(J%,5%)
25460 FOR K%=1% TO 14%
25480 IF J%=6%*K% THEN 25540
25500 NEXT K%
25520 GO TO 25580
25540 PRINT : PRINT
25580 NEXT J%
25590 PRINT "DO YOU WISH TO CHANGE BALL MILL SCHEDULE &
      (Y=YES, N=NO)"
25600 INPUT Q$ : PRINT
25610 IF ASCII(Q$)=89% THEN 26100
```

DATE: 16-FEB-78
TIME: 16:17

BALL

```
25615 IF ASCII(Q$)=78% THEN 32730
25617 PRINT "YOUR RESPONSE SHOULD HAVE BEEN YES OR NO"
25618 GO TO 25590 : PRINT
25620 IF N%<>2% THEN 25740
25640 L%=L%+3% : N%=5% : V%=6% : X6=1 : GO TO 23920
25740 IF N%<>5% THEN 25860
25760 L%=L%-3% : N%=2% : V%=3% : X6=1 : GO TO 23920
25860 IF N%<>1% THEN 25980
25880 L%=L%+2% : N%=3% : V%=4% : X6=1 : GO TO 23920
25980 IF N%<>3% THEN 24820
26000 L%=L%-2% : N%=1% : V%=2% : X6=1 : GO TO 23920
26100 PRINT "ENTER MM,DD,BM,BT,LBS,LOADS FOR NEW &
      ASSIGNMENT": PRINT
26110 INPUT V1%,V2%,V3%,V4%,V5%,V6%
25112 PRINT

26115 FOR J%=1% TO 84%
26120 IF T(J%,1%)<>V1% THEN 26160
26125 IF T(J%,2%)<>V2% THEN 26160
26130 IF T(J%,3%)<>V3% THEN 26160
26140 T9$(J%)=V4$
26145 T(J%,4%)=V5% : T(J%,5%)=V6%
26146 GO TO 26165
26160 NEXT J%
26161 PRINT "NO MATCH" : GO TO 26100
26165 PRINT "ANOTHER CHANGE (Y=YES, N=NO) ": INPUT Q$
26166 PRINT
26168 IF ASCII(Q$)=89% THEN 26100
26170 GO TO 25320
32700 FOR N%=1% TO N1%
32710 C7(N%,7%)=C7(N%,13%)
32720 NEXT N%
32725 GO TO 25320
32730 CLOSE 4%,7%,8%
32767 END
```

APPENDIX B

SAMPLE PRODUCTION DATA FILES

RECORD FORMAT

<u>Body Type Inventory and Demand File</u> "CMP01"

1. Body type
2. Current inventory pounds
3. Week 0 demand pounds
4. Week 1 demand pounds
5. Week 2 demand pounds
6. Week 3 demand pounds
7. Week 4 demand pounds

SAMPLE DATA

Body Type Inventory and Demand File "CMP01"

```
00010 CB-01,192000,83362,145353,116571,172991,33728
00020 CB-02,0,1572,1030,1164,1059,407
00030 CB-03,9000,468,0,0,0,0
00040 CB-04,7000,0,0,0,0,0
00050 CB-05,31000,549,0,0,0,0
00060 CB-06,7000,0,0,0,0,0
00070 CB-07,3000,2097,0,0,0,0
00080 CB-08,41500,1506,11760,7833,7220,2313
00090 CB-09,1000,1800,1167,1385,57,0
00100 CB-10,2000,0,0,0,0,0
00110 CB-11,0,0,0,0,0,0
00120 CB-12,92000,36288,27764,23444,25016,33388
00130 CB-13,0,100000,0,0,0,0
00140 CB-14,0,50000,0,0,0,0
00150 CB-15,0,10780,10780,10780,10780,10780
00160 CB-16,0,0,0,0,0,0
00170 CB-17,0,0,0,0,0,0
00180 CB-18,7000,0,0,0,0,0
00190 CB-19,12000,17581,14348,11067,7884,3492
00200 CB-20,18000,5122,3062,2902,3046,3785
00210 CB-21,4000,1502,1125,0,0,121
00220 CB-22,22000,13312,3598,0,0,0
00230 CB-23,1000,2711,0,1,0,545
00240 CB-24,7000,0,349,0,0,0
00250 CB-25,7000,0,0,0,0,0
00260 CB-26,20000,16034,15549,16607,7278,0
00270 CB-27,16000,11540,12232,11495,1886,9835
00280 CB-28,175500,56541,56800,56832,56890,56892
00290 CB-29,0,0,0,0,0,0
00300 CB-30,28000,10000,11611,10335,7347,7414
00310 CB-31,24000,31542,30686,33867,29732,22041
00320 CB-32,10000,2145,2736,2382,1500,1939
```

RECORD FORMAT

<u>Spray Dry Storage File</u> "CMP02"

1. Storage facility number
2. Pounds capacity
3. Current body assignment
4. Current body inventory pounds

SAMPLE DATA

<u>Spray Dry Storage File</u> "CMP02"

```
00010 S-30,28000,CB-26,10000
00020 S-31,28000,CB-27,4000
00030 S-32,24000,CB-21,24000
00040 S-33,28000,CB-30,28000
00050 S-34,28000,CB-12,8000
00060 S-35,28000,CB-19,0
00070 S-36,28000,CB-12,28000
00080 S-37,26000,CB-08,26000
00090 S-38,28000,CB-12,28000
00100 S-39,28000,CB-12,28000
00110 ZT-40,15000,CB-05,15000
00120 ZT-41,15000,CB-05,13000
00130 ZT-42,15000,CB-22,12000
00140 ZT-43,15000,CB-22,0
00150 ZT-44,15000,CB-22,0
00160 S-1,100000,CB-01,100000
00170 S-2,100000,CB-01,80000
00180 S-3,100000,CB-28,60000
00190 S-4,100000,CB-28,100000
```

RECORD FORMAT

Slurry Tank Assignment and Pounds "CMP03"

1. Slurry tank number
2. Pounds capacity
3. Current body assignment
4. Current body inventory pounds

SAMPLE DATA

<u>Slurry Tank Assignment and Pounds</u> "CMP03"

```
00010 ST-68,15000,EMPTY,0
00020 ST-69,35000,CB-01,21000
00030 ST-70,35000,CB-01,28000
00040 ST-72,15000,CB-15,14000
00050 ST-73,15000,CB-15,14000
00060 ST-74,15000,CB-26,12000
00070 ST-75,15000,CB-26,12000
00080 ST-76,32000,CB-28,28000
00090 ST-77,15000,CB-12,14000
00100 ST-78,15000,CB-12,14000
00110 ST-79,30000,EMPTY,0
00120 ST-80,8000,CB-23,6000
00130 ST-81,8000,CB-31,8000
00140 ST-83,32000,EMPTY,0
00150 ST-84,32000,EMPTY,0
00160 ST-87,35000,CB-31,28000
00170 ST-88,35000,CB-01,28000
00180 ST-89,35000,EMPTY,0
```

RECORD FORMAT

<u>Body Type Master File</u> "CMP04"

1. Body type
2. Mill 12 batch size
3. Mill 13 batch size
4. Mill 14 batch size
5. Mill 15 batch size
6. Mill 16 batch size
7. Mill 17 batch size
8. Mill time - tenths of hours
9. Spray Dryer No. 1 pounds/hours rate
10. Spray Dryer No. 1 body number
11. Spray Dryer No. 2 pounds/hour rate
12. Spray Dryer No. 2 body number
13. Primary spray dry storage

    1 (Tote tanks) 2 (Standardizers)

    3 (Zipper tanks) 4 (Silos) 5 (Barrels)
14. Batch size 1
15. Batch size 2
16. Batch size 3
17. Batch size 4

SAMPLE DATA

<u>Body Type Master File</u> "CMP04"

```
00010 CB-01,7000,4000,7000,7000,14000,14000,30,875,1,0,0,4
00020 CB-01,35000,0,0,0
00030 CB-02,6000,0,0,0,0,0,115,1000,2,0,0,1
00040 CB-02,18000,0,0,0
00050 CB-03,6000,4000,0,0,0,0,40,1000,3,0,0,1
00060 CB-03,6000,0,0,0
00070 CB-04,6000,0,6000,0,0,12000,40,1000,4,0,0,1
00080 CB-04,6000,0,0,0
00090 CB-05,6000,4000,0,0,0,0,130,1000,5,0,0,1
00100 CB-05,6000,0,0,0
00110 CB-06,6000,0,0,0,0,0,200,6,0,0,1
00120 CB-06,6000,0,0,0
00130 CB-07,6000,0,6000,0,0,0,50,0,0,2000,1,1
00140 CB-07,6000,12000,0,0
00150 CB-08,6800,0,6800,0,0,13600,161,0,0,2000,3,1
00160 CB-08,26000,39000,0,0
00170 CB-09,6000,0,6000,0,0,0,50,0,0,2000,2,2
00180 CB-09,6000,12000,0,0
00190 CB-10,6000,0,6000,0,0,0,15,0,0,1500,4,1
00200 CB-10,6000,0,0,0
00210 CB-11,0,0,0,0,0,0,30,0,0,2000,5,1
00220 CB-11,2000,0,0,0
00230 CB-12,7000,0,0,0,0,14000,133,0,0,2000,6,2
00240 CB-12,28000,0,0,0
00250 CB-13,7000,0,7000,0,0,0,50,0,0,1800,7,5
00260 CB-13,105000,0,0,0
00270 CB-14,7000,0,7000,0,0,0,50,0,0,1800,8,5
00280 CB-14,56000,0,0,0
00290 CB-15,7000,0,7000,0,0,14000,190,0,0,4000,9,1
00300 CB-15,14000,28000,42000,56000
00310 CB-16,7000,0,7000,0,0,14000,103,0,0,4000,10,1
00320 CB-16,14000,28000,42000,56000
00330 CB-17,7000,0,7000,0,0,14000,102,0,0,3500,11,1
00340 CB-17,14000,0,0,0
00350 CB-18,7000,0,7000,0,0,14000,170,0,0,3500,12,1
00360 CB-18,14000,0,0,0
00370 CB-19,7000,0,7000,0,0,14000,170,0,0,3500,13,2
00380 CB-19,28000,0,0,0
00390 CB-20,6000,0,6000,0,0,12000,160,0,0,2500,14,1
00400 CB-20,14000,28000,0,0
```

(Continued)

SAMPLE DATA (Continued)

```
00410 CB-21,7200,0,7200,0,0,0,105,0,0,2000,15,1
00420 CB-21,6000,0,0,0
00430 CB-22,6000,0,6000,0,12000,12000,85,0,0,1500,16,3
00440 CB-22,18000,0,0,0
00450 CB-23,6000,4000,6000,0,12000,12000,110,0,0,2000,17,1
00460 CB-23,6000,12000,0,0
00470 CB-24,6000,4000,6000,0,12000,12000,110,0,0,2000,18,1
00480 CB-24,18000,0,0,0
00490 CB-25,6000,4000,6000,0,12000,12000,160,0,0,3000,19,1
00500 CB-25,12000,0,0,0
00510 CB-26,6000,4000,6000,0,12000,12000,175,0,0,3500,20,2
00520 CB-26,28000,30000,0,0
00530 CB-27,6000,4000,6000,0,12000,12000,140,0,0,3500,21,2
00540 CB-27,28000,30000,0,0
00550 CB-28,6000,4000,6000,0,12000,12000,130,0,0,3500,22,4
00560 CB-28,30000,32000,34000,0
00570 CB-29,6000,4000,6000,0,12000,12000,120,0,0,2000,23,2
00580 CB-29,30000,32000,34000,0
00590 CB-30,6000,4000,6000,0,12000,12000,100,0,0,2000,24,2
00600 CB-30,28000,30000,0,0
00610 CB-31,6000,4000,6000,0,12000,12000,163,0,0,3000,25,1
00620 CB-31,18000,24000,30000,0
00630 CB-32,6000,0,0,0,12000,12000,40,0,0,3000,26,1
00640 CB-32,18000,24000,30000,0
```

RECORD FORMAT

Spray Dryer No. 1 Cleanup Codes and Spray Drying Sequence

"CMP05"

1. From body type number
2. Cleanup code to body type number 01
3. Cleanup code to body type number 02
4. Cleanup code to body type number 03
5. Cleanup code to body type number 04
6. Cleanup code to body type number 05
7. Cleanup code to body type number 06

Cleanup Codes 0 - 0 hours

6 - 20 hours

SAMPLE DATA

Spray Dryer No. 1 Cleanup Codes and Spray Drying Sequence

"CMP05"

```
00010 CB-01,0,6,6,6,6,6
00020 CB-02,6,0,6,6,6,6
00030 CB-03,6,6,0,6,6,6
00040 CB-04,6,6,6,0,6,6
00050 CB-05,6,6,6,6,0,6
00060 CB-06,6,6,6,6,6,0
```

RECORD FORMAT

Spray Dryer No. 2 Cleanup Codes and Spray Drying Sequence

"CMP06"

1. From body type number
2. Cleanup code to body type number 07
3. Cleanup code to body type number 08
4. Cleanup code to body type number 09
5. Cleanup code to body type number 10
6. Cleanup code to body type number 11
7. Cleanup code to body type number 12
8. Cleanup code to body type number 13
9. Cleanup code to body type number 14
10. Cleanup code to body type number 15
11. Cleanup code to body type number 16
12. Cleanup code to body type number 17
13. Cleanup code to body type number 18
14. Cleanup code to body type number 19
15. Cleanup code to body type number 20
16. Cleanup code to body type number 21
17. Cleanup code to body type number 22
18. Cleanup code to body type number 23
19. Cleanup code to body type number 24
20. Cleanup code to body type number 25

21. Cleanup code to body type number 26
22. Cleanup code to body type number 27
23. Cleanup code to body type number 28
24. Cleanup code to body type number 29
25. Cleanup code to body type number 30
26. Cleanup code to body type number 31
27. Cleanup code to body type number 32
28. Cleanup code to body type number 01

Cleanup Codes	0 - 0 hours
	1 - 4 hours
	2 - 5 hours
	3 - 9.7 hours
	4 - 11.2 hours
	5 - 16.9 hours
	6 - 20 hours

SAMPLE DATA

Spray Dryer No. 2 Cleanup Codes and Spray Drying Sequence

"CMP06"

```
00010 CB-07,0,0,0,4,4,4,4,4,4,4,4,2,4,4,4,4,3,3,3,3,3,3,3,3,3,3
00020 CB-08,1,0,0,4,4,4,4,4,4,4,4,2,2,2,4,4,3,3,3,3,3,3,3,3,3,3
00030 CB-09,1,0,0,4,4,4,4,4,4,4,4,2,2,2,4,4,3,3,3,3,3,3,3,3,3,3
00040 CB-10,5,5,5,0,4,4,4,4,4,4,4,4,4,4,4,4,3,3,3,3,3,3,3,3,3,3
00050 CB-11,5,5,5,4,0,4,4,4,4,4,4,4,4,4,4,4,3,3,3,3,3,3,3,3,3,3
00060 CB-12,5,5,5,4,4,0,4,4,4,4,4,4,4,2,4,4,3,3,3,3,3,3,3,3,3,3
00070 CB-13,5,5,5,4,4,4,0,0,4,4,4,4,4,4,4,4,3,3,3,3,3,3,3,3,3,3
00080 CB-14,5,5,5,4,4,4,4,0,4,4,4,4,4,4,4,4,3,3,3,3,3,3,3,3,3,3
00090 CB-15,6,6,6,6,6,6,6,6,0,2,6,6,6,6,6,6,6,6,6,6,6,6,6,6,6,6
00100 CB-16,6,6,6,6,6,6,6,6,6,0,2,6,6,6,6,6,6,6,6,6,6,6,6,6,6,6
00110 CB-17,5,5,5,4,4,4,4,4,4,4,0,4,4,4,4,4,3,3,3,3,3,3,3,3,3,3
00120 CB-18,5,5,5,4,4,4,4,4,4,4,4,0,0,0,4,4,3,3,3,3,3,3,3,3,3,3
00130 CB-19,5,5,5,4,4,4,4,4,4,4,4,2,0,0,4,4,0,0,0,0,3,3,3,3,3,3
00140 CB-20,5,5,5,4,4,4,4,4,4,4,4,2,0,0,4,4,3,3,3,3,3,3,3,3,3,3
00150 CB-21,5,5,5,4,4,4,4,4,4,4,4,4,4,4,0,4,3,3,3,3,3,3,3,3,3,3
00160 CB-22,5,5,5,4,4,4,4,4,4,4,4,4,4,4,4,0,3,3,3,3,3,3,3,3,3,3
00170 CB-23,5,5,5,4,4,4,4,4,4,4,4,4,4,4,4,4,0,0,2,2,2,2,2,2,0,0,0
00180 CB-24,5,5,5,4,4,4,4,4,4,4,4,4,4,4,4,4,0,0,2,2,2,2,2,2,0,0,0
00190 CB-25,5,5,5,4,4,4,4,4,4,4,4,4,4,4,4,4,2,2,0,0,0,0,0,0,0,0,0
00200 CB-26,5,5,5,4,4,4,4,4,4,4,4,4,4,4,4,4,2,2,1,0,0,0,0,0,0,0,0
00210 CB-27,5,5,5,4,4,4,4,4,4,4,4,4,4,4,4,4,2,2,1,0,0,0,0,0,0,0,0
00220 CB-28,5,5,5,4,4,4,4,4,4,4,4,4,4,4,4,4,2,2,1,0,0,0,0,0,0,0,0
00230 CB-29,5,5,5,4,4,4,4,4,4,4,4,4,4,4,4,4,2,2,2,0,0,0,0,0,0,0,0
00240 CB-30,5,5,5,4,4,4,4,4,4,4,4,4,4,4,4,4,2,2,2,0,0,0,0,0,0,0,0
00250 CB-31,5,5,5,4,4,4,4,4,4,4,4,4,4,4,4,4,2,2,0,0,0,0,0,0,0,0,0
00260 CB-32,5,5,5,4,4,4,4,4,4,4,4,4,4,4,4,4,2,2,0,0,0,0,0,0,0,0,0
00270 CB-01,5,5,5,4,4,4,4,4,4,4,4,4,4,4,4,4,3,3,3,3,3,3,3,3,3,3,0
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APPENDIX C

SAMPLE PRODUCTION REPORTS

$$$$$$$$$$ BODY DEMAND REQUIREMENTS $$$$$$$$$$

BODY TYPE	WEEK	ADJUSTED DEMAND	SLURRY LBS	LBS TO MILL	DRY STORAGE	ADJUSTED MILL LBS	ADJUSTED MILL BATCH	*SPRAY DRY* LBS	BATCHES
CB-01	0	360005	77000	283005	200000	123000	140000	217000	1
CB-02	0	5232	0	5232	18000	5232	18000	18000	1
CB-08	5	0	0	0	26000	26000	26000	26000	1
CB-09	0	3409	0	3409	6000	3409	6000	6000	1
CB-12	2	80865	28000	52865	84000	56000	56000	84000	1
CB-15	0	53900	28000	25900	56000	25900	28000	56000	2
CB-19	2	42372	0	42372	28000	28000	28000	28000	1
CB-22	5	0	0	0	30000	30000	36000	36000	1
CB-23	1	2257	6000	0	6000	6000	0	6000	1
CB-26	0	35468	24000	11468	28000	4000	4000	28000	1
CB-27	2	30985	0	30985	28000	28000	28000	28000	1
CB-28	1	140544	28000	112544	100000	72000	90000	118000	1
CB-30	3	0	0	0	28000	28000	28000	28000	1
CB-31	0	123868	36000	87868	126000	90000	90000	126000	2
CB-32	2	702	0	702	18000	702	18000	18000	1

$$$$$$$$ SPRAY DRYER NO. 1 SCHEDULE $$$$$$$$

BODY TYPE	LBS	HOURS	START	MONTH	DAY	FINISH	MONTH	DAY
CB-01	217000	248.0	14.0	11	4	22.0	11	14
CLEAN	0	20.0	22.0	11	14	18.0	11	15
CB-02	18000	18.0	18.0	11	15	12.0	11	16

$$$$$$$$ SPRAY DRYER NO. 2 SCHEDULE $$$$$$$$

BODY TYPE	LBS	HOURS	START	MONTH	DAY	FINISH	MONTH	DAY
CB-15	28000	7.0	3.5	11	5	10.5	11	5
CLEAN	0	20.0	10.5	11	5	6.5	11	6
CB-23	6000	3.0	6.5	11	6	9.5	11	6
CLEAN	0	5.0	9.5	11	6	14.5	11	6
CB-26	28000	8.0	14.5	11	6	22.5	11	6
CB-28	118000	33.7	22.5	11	6	8.2	11	8
CB-31	36000	12.0	8.2	11	8	20.2	11	8
CLEAN	0	11.2	20.2	11	8	7.4	11	9
CB-12	84000	42.0	7.4	11	9	1.4	11	11
CLEAN	0	11.2	1.4	11	11	12.6	11	11
CB-15	28000	7.0	12.6	11	11	19.6	11	11
CLEAN	0	20.0	19.6	11	11	15.6	11	12
CB-19	28000	8.0	15.6	11	12	23.6	11	12
CLEAN	0	11.2	23.6	11	12	10.8	11	13
CB-22	36000	24.0	10.8	11	13	10.8	11	14
CLEAN	0	9.7	10.8	11	14	20.5	11	14
CB-27	28000	8.0	20.5	11	14	4.5	11	15
CB-30	28000	14.0	4.5	11	15	18.5	11	15
CB-31	90000	30.0	18.5	11	15	0.5	11	17
CB-32	18000	6.0	0.5	11	17	6.5	11	17
CLEAN	0	16.9	6.5	11	17	23.4	11	17

$$$$$$$$$$$ BALL MILL SCHEDULE $$$$$$$$$$$

MONTH	DAY	BALL MILL	BODY TYPE	LBS	LOADS
11	5	12	CB-02	6000	1
11	5	13	CB-26	4000	1
11	5	14	CB-09	6000	1
11	5	15	CB-01	7000	3
11	5	16	CB-31	12000	1
11	6	12	CB-02	6000	1
11	6	13	CB-30	4000	1
11	6	14	CB-22	6000	2
11	6	15	CB-01	7000	3
11	6	16	CB-27	12000	1
11	6	17	CB-12	14000	1
11	7	12	CB-02	6000	1
11	7	13	CB-27	4000	1
11	7	14	CB-22	6000	2
11	7	15	CB-01	7000	3
11	7	16	CB-30	12000	1
11	7	17	CB-12	14000	1
11	8	12	CB-15	7000	1
11	8	13	CB-31	4000	1
11	8	14	CB-15	7000	1
11	8	15	CB-01	7000	3
11	8	16	CB-30	12000	1
11	8	17	CB-12	14000	1
11	9	12	CB-22	6000	2
11	9	13	CB-31	4000	1
11	9	14	CB-31	6000	1
11	9	15	CB-01	7000	3
11	9	16	CB-31	12000	1
11	9	17	CB-15	14000	1

(Continued)

$$$$$$$$$$$ BALL MILL SCHEDULE $$$$$$$$$$$ (Continued)

MONTH	DAY	BALL MILL	BODY TYPE	LBS	LOADS
11	10	12	CB-31	6000	1
11	10	13	CB-31	4000	1
11	10	14	CB-09	6000	1
11	10	15	CB-01	7000	3
11	10	16	CB-31	12000	1
11	10	17	CB-19	14000	1
11	11	12	CB-32	6000	1
11	11	13	CB-31	4000	1
11	11	14		0	0
11	11	15	CB-01	7000	3
11	11	16	CB-31	12000	1
11	11	17	CB-19	14000	1
11	12	12		0	0
11	12	13	CB-31	4000	1
11	12	14		0	0
11	12	15		0	0
11	12	16	CB-31	12000	1
11	12	17	CB-08	13000	1
11	13	12		0	0
11	13	13		0	0
11	13	14		0	0
11	13	15		0	0
11	13	16	CB-31	12000	1
11	13	17	CB-08	13000	1
11	14	12		0	0
11	14	13		0	0
11	14	14		0	0
11	14	15		0	0
11	14	16		0	0
11	14	17	CB-32	12000	1

APPENDIX D

THE FOUR-STAGE SCHEDULING PROCEDURE

THE FOUR-STAGE SCHEDULING PROCEDURE

1. Select from weekly body demand report the week 0, week 1, week 2, week 3, and week 4 demands in pounds for each ceramic body.
2. Write in any corrections that are necessary for these weekly demands for each ceramic body.
3. Write in the weekly demands for the several bodies that are not included in the weekly body demand report.
4. Look at current spray dry inventory report and reduce demand by week until you run out of inventory or until demands for week 0, week 1, week 2, week 3, and week 4 are zero.

   Record excess inventory in week 4, if not zero, and circle it.
5. Reduce the demands by week for each body being spray dried on Friday, Saturday, and Sunday.
6. Assign group numbers to each of the bodies:

   Group 0 - Bodies with demand in week 0.

   Group 1 - Bodies with demand in week 1 but no demand in week 0.

   Group 2 - Bodies with demand in week 2 but no demand in week 0 and week 1.

Group 3 - Bodies with demand in week 3 but no demand in week 0, week 1, and week 2.

Group 4 - Bodies with demand in week 4 but no demand in week 0, week 1, week 2, and week 3.

Group 5 - Bodies with no demand in week 0, week 1, week 2, week 3, and week 4.

7. Add demands for week 0, week 1, and week 2 for group 0 bodies.

   Add demands for week 1, week 2, and week 3 for group 1 bodies.

   Add demands for week 2, week 3, and week 4 for group 2 bodies.

   Add demands for week 3 and week 4 for group 3 bodies.

   Multiply total demand for each body by 1.1 to get total demand.

8. Write in slurry tank pounds to reflect inventory at end of current ball mill and spray dryer schedule.

   Group 5 bodies with slurry pounds should be changed to group 0 bodies.

9. Subtract slurry tank pounds from total demand to get pounds to be milled.

   Enter 0 for pounds to be milled if slurry tank pounds are greater than total demand.

10. Determine mill load pounds.
11. Add slurry tank pounds to mill load pounds to get spray dry storage pounds.
12. Assign spray dry storage to each of the bodies in group 0, group 1, or group 2 that do not have spray dry storage available.
13. Make spray dry storage pounds zero for any bodies in group 0, group 1, or group 2 that do not have spray dry storage available and cannot be assigned spray dry storage.

    Bodies to be spray dried stored in standardizers should have spray dry storage pounds equal to capacity of their standardizers.

    Bodies that have spray dry storage available should be changed to group 0.

    Standardizers and silos should not be left empty.
14. List the number of the last body to be spray dried in the week for spray dryers 1 and 2.
15. List the body numbers in groups 0, 1, and 2 in numerical order for spray dryers 1 and 2.
16. List the body numbers of the slurry tank bodies in numerical order for spray dryers 1 and 2.
17. List the body numbers of the "to be milled" bodies in numerical order for spray dryers 1 and 2.

18. Write number of body last spray dried on each dryer in first position of corresponding spray dryer sequence.
    Select bodies that are common to both group 0 and slurry tank bodies.
    Do not consider slurry tank bodies that have incomplete batches.
    Arrange these body numbers in numerical sequence using the number of the body last spray dried as the starting number of the sequence.
19. Continue spray drying sequence by arranging remaining slurry tank bodies in numerical sequence.
    Use the last body in previous step as starting body for this sequence.
20. Continue spray drying sequence by arranging remaining bodies in group 0 in numerical sequence.
    Use the last body in previous step as starting body for this sequence.
21. Continue spray drying sequence by arranging remaining bodies in group 1 in numerical sequence.
    Use the last body in previous step as starting body for this sequence.

22. Finish spray drying sequence by arranging remaining bodies in group 2 in numerical sequence.
    Use the last body in previous step as starting body for this sequence.
23. Write in cleaning times for each spray dryer sequence by selecting appropriate time from spray dryer cleanup times sheet.
24. Determine spray dryer schedule by calculating number of hours required to spray dry each ceramic body from the spray dryer sequence and the number of hours for cleanup after each ceramic body.
25. Determine ball mill schedule based on spray dryer schedule, slurry tank availability, and ceramic body mill rate sheet.