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OPTIMIZATION OF ENERGY USAGE IN TEXTILE FINISHING OPERATIONS

Part 1: The Simulation of Batch Dyehouse Activities with a General Purpose Computer Model

By
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U. S. DEPARTMENT OF ENERGY

Division of Industrial Energy Conservation

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IN
TEXTILE FINISHING OPERATIONS

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Contract No. DE-AS05-76CS40092

Prepared for

The United States Department of Energy
Division of Industrial Energy Conservation
Washington, D.C. 20545

by

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1980

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I. EXECUTIVE SUMMARY

The textile industry consumes approximately 3% of the energy used by all industries in the United States. However, 75% of the textile industry is located in North Carolina, South Carolina, and Georgia, and as a result the regional impact of textile energy usage upon the Southeastern United States is far greater than the 3% figure would indicate. For example, the textile industry uses 32% of all industrial consumption and 8% of the total energy used in South Carolina. In the textile industry, dyeing and finishing plants account for approximately 60% ($\approx 1.5 \times 10^{14}$ Btu/yr) of the U.S. textile industrial energy usage while weaving and knitting greige mills consume the remaining 40% ($\approx 1.0 \times 10^{14}$ Btu/yr). The energy consumption of dyeing and finishing plants is essentially all finishing process related while that of greige mills is primarily for electricity and environmental control.

This project was directed toward the development of guidelines for optimizing energy usage in two specific types of textile finishing operations which are large consumers of energy; i.e., fabric drying in tenter frame dryers and fabric dyeing in batch operated dye becks. Drying processes consume about 50% of the energy used by textile dyeing and finishing plants and about 25% of this amount (2.0×10^{13} Btu/yr) is used in tenter frame dryers. Batch dye becks consume on the order of 8 pounds of steam per pound of cloth or about 2.5×10^{13} Btu/yr.

This volume contains the final report of Part I: The Simulation of Batch Dyehouse Activities with a General Purpose Computer Model. The final report for Part II: Energy Conservation in Textile Dryers is contained in a separate volume.

There is great variation in the process conditions used for different cloths and carpets, however, in general synthetic cloths are dyed in pressurized becks while carpets are dyed in atmospheric becks. The discussion which follows describes the dyeing of 100% polyester cloth in pressurized batch jet dye machines, however it can in a general sense be extended to atmospheric carpet becks.

In a typical dyeing, the dye beck is first filled with about 2000 gallons of hot water. Then about 1000 pounds of cloth are loaded into the beck where it is continuously moved through the dye bath by the action of a water jet. The bath temperature is then raised at a controlled rate (2° per minute) from 160°F up to 260°F , followed by a holding period of perhaps 60 minutes at 260°F , followed by a controlled rate of temperature decrease, (2°F per minute). The heat is often supplied by steam, indirectly through a heat exchanger, with the steam condensate returning to the boiler.

In the cool-down portion of the cycle, water is used as a coolant in the heat exchanger where it gets heated. This hot water is then stored in a tank for later use in filling the dye becks.

The minute-to-minute operation of a dyehouse is, theoretically at least, directed by the dyehouse shift supervisor. Often in practice it is the kettle tender himself who determines what task he performs next. This lack of positive direction and the limitations of the dyehouse supervisor often leads to an unbalanced workload; for example, one-half hour with nothing to do, then six becks due for unloading at the same time. This causes low personnel and equipment efficiencies. It has an additional adverse effect on energy consumption because if too many dye becks are in the cooling part of the dye cycle, they fill the hot water tank to overflowing and a large amount of hot water is wasted because there is no place to store it. Similarly, when all of these dye becks are then ready to fill with hot water at the same time, there is not enough hot water and steam must be used to heat the water.

The complexity and variability of dyehouse operations and the fact that it is not practical to experimentally manipulate some of the variables affecting the operation of an actual dyehouse such as the manning levels of different jobs, operating strategies, variations in the types and sizes of equipment available, and the number of 'seconds' obtained, make the analysis and optimization of dyehouse operations difficult to accomplish.

In order to provide a tool for industrial personnel to use in analyzing batch dyehouses and other batch processes, a computer model of a hypothetical dyehouse has been developed for use in simulating dyehouse activities.

To demonstrate the model's capabilities, the activities in a hypothetical dyehouse were simulated. By manipulating such variables as manning levels, number of adds required, and operating strategies it was possible to gain a better understanding of dyehouse operations and the variables that affect dyehouse performance. It was found that these variables not only affect the levels of productivity, but they also influence the dyehouse demand for steam and water often causing wide fluctuations in the demand. Using the model of the hypothetical dyehouse, it was demonstrated that through computer simulation the optimum manning levels could be determined, the minimum hot water storage capacity could be specified, and that with effective controls of steam demand the required boiler capacity could be reduced. The model's capabilities were further demonstrated by successfully simulating the level of production in an existing dyehouse. However, efforts to simulate the steam and water demand in the existing dyehouse were not as successful due to the lack of accurate plant data on the actual demands.

The Appendices of this report contain a listing of the computer program, sample computer inputs and outputs, and instructions for using the model.

II. INTRODUCTION

Each year the textile industry in the United States dyes approximately 3×10^9 pounds of synthetic cloth and carpet in batch dye becks. The steam consumption of these becks is on the order of 2.5×10^{10} pounds of steam per year or 10% of the energy consumed annually by the textile industry. A 20% reduction in steam consumption would amount to a fuel savings of 5×10^{12} Btu per year or a dollar savings of \$10 million per year.

Actual process conditions for dyeing different cloths and carpets vary greatly. In general, synthetic cloths are dyed in pressurized becks while carpets are dyed in atmospheric becks. Although the process conditions vary widely, there is much similarity in the basic batch dyeing procedure. The discussion which follows describes in general terms the batch dyeing of 100% polyester cloth in pressurized jet dye becks. The procedure, after some modification, can be extended to dyeings in atmospheric carpet becks.

In a typical batch dyeing of synthetic cloth, the dye beck is first filled with approximately 2000 gallons of hot water and then loaded with about 1000 pounds of cloth. After the necessary chemicals and dyes are added, the dye bath temperature is raised at a controlled rate (2 - 3°F per minute) to 260°F. The temperature of the dye bath is held

at 260°F for a period of perhaps 60 minutes to achieve a uniform dyeing. Following this holding period, the dye bath temperature is decreased at a controlled rate (2 - 3°F per minute). When the desired temperature is reached, the dye bath is dumped, and the beck is refilled with hot rinse water. After a brief rinsing period, the dyed cloth is unloaded and the rinse water is dumped. Throughout the dyeing procedure, the cloth is continuously circulated through the dye bath by the action of a water jet. The heat required to raise the temperature of the dye bath is supplied indirectly by steam through a heat exchanger, with the steam condensate returning to the boiler. In the cool-down portion of the dye cycle, water is used as the coolant in the heat exchanger. The water exits the heat exchanger at approximately 120°F, and is stored in a tank for later use in filling the dye becks. When the volume of water in the storage tank is insufficient to meet the water demand of the becks, water heated by steam is used.

In a dyehouse there are many dye becks operating simultaneously under the direction, theoretically at least, of the dyehouse shift supervisor. However, it is often the beck operator himself rather than the supervisor who decides what task will be performed next. This lack of positive direction and the limitation of the dyehouse supervisor often leads to an unbalanced workload; for example, one-half hour with nothing to do, then six becks due for unloading at the same time. Such events cause low personnel and equipment

efficiencies, and have adverse effects on energy consumption. When too many dye becks are in the cooling part of the dye cycle, they fill the hot water tank to overflowing and a large amount of hot water is wasted. Similarly, when all of these dye becks are then ready to fill, there is not enough hot water available, and steam must be used to heat the water. Furthermore, this imbalance can cause too many dye becks to be in the heating portion of the dye cycle at the same time causing peaks in the steam demand. In many dyehouses, an extra boiler is kept on-line just to accommodate such peaks. To avoid these problems in dye-house operation and to conserve energy, a system needs to be developed that will keep the beck cycles spread out to insure a constant workload, a relatively constant steam demand, and a relatively constant rate of hot water generation and demand. This will lead to increased dyeing capacity at lower manning levels and to lower energy consumption (3).

Batch dyeing operations can be viewed as a series of beck operations and operator duties performed within a decision making framework. The work patterns that develop from these activities are complex and highly variable, making it difficult to predict the effect of changes in operation on dyehouse efficiency. Although it is necessary to study dyehouse operations in order to identify the controlling variables and determine their effects on dyehouse performance, traditional methods are of little help. The manipulation of such variables as the manning levels of different

jobs, operating strategies, and the number of adds required is not practical in the operation of an actual dyehouse since it would entail lengthy and expensive full-scale trials and would adversely affect production levels. In their investigation of the effects of automation on the productivity of batch dyeing processes, Connor, et al. (8) demonstrated the feasibility of developing a mathematical model of a dyehouse. By developing a general-purpose computer model of batch dyeing processes, they were able to study the effects of changes in dyehouse operations, and assess rapidly and accurately the benefits of these changes. The success of their work suggested that, by using a mathematical model of dyehouse activities, a system of guidelines could be developed to insure optimal dyehouse operation.

The objective of this study was to develop a mathematical model capable of simulating the activities found in a typical batch dyeing process. Once developed, the model could be used to study the effects of changes in dyehouse operation, and to determine effective guidelines for optimal dyehouse performance. The use of simulation could prove beneficial in providing a greater understanding of batch dyehouse operation, allowing quantitative comparisons of alternative modes of dyehouse operation, and verifying intuitive assumptions concerning dyehouse operations. In the future, such simulation studies could be useful in implementing computer control of dyehouse activities. Simulation

provides an effective tool for analyzing the system to identify which variables must be controlled to insure optimal dyehouse performance.

III. LITERATURE REVIEW

The rising cost of energy and strict environmental regulations have made it mandatory that the American textile industry optimize the utilization of water and energy while minimizing the volume of waste and sewage. No longer can water and energy be considered low cost items of production (1). As the cost of these items increases, the proportion of the total production cost attributable to energy becomes more significant. Reduced consumption means lower production costs and greater profitability in addition to the conservation of dwindling energy resources. The increasing cost of energy supplies makes new developments in conservation an economic must for the textile industry.

The implementation of an effective conservation program begins with a complete energy study of the overall production process (10, 16). This study should identify the areas that consume the most energy since in all likelihood, these areas will also be the most wasteful. On the average, it is estimated that dyeing and finishing accounts for 63% of the energy consumed in going from yarn to finished fabric. Of this energy, an estimated 86 - 95% is consumed by heating air and water (24). The two process areas that consume the bulk of this energy are the dyeing operations and the drying operations. New developments in energy conservation

in drying operations have been reported by Beard (4) and Gross (11). Recent investigations of existing dyehouse operations have identified boiler efficiency, water management, and waste-water heat recovery as the three most important areas for energy conservation in the dyehouse (20, 22, 23, 25). The boiler represents the single largest user of energy and is therefore the logical starting point in any dyehouse conservation program.

Increased boiler efficiency can often be obtained by the addition of economizers, air heaters, and super heaters to the existing boiler system (14, 17). Provided that the boiler and burners were designed properly, these equipment changes can significantly enhance boiler efficiency. Unfortunately, the gains made by improvements in boiler performance can soon be cancelled by the occurrence of peaks in the steam demand and inefficiencies in the steam distribution system (9). McCartney (13) has identified the generation of steam, and its use as the source of energy to heat dye baths, as two incompatible processes, each a handicap to the other. The peak loads required by batch dyeing processes lower boiler efficiency and hinder operation. On the other hand, the inability of the boiler to cope with peaks in steam demand retards production. This problem can be overcome by using a stand-by boiler to handle the peaks, or by generating steam at a constant rate and storing the surplus in an accumulator. Hot water storage and staggered

starting times in the dyehouse are also helpful in handling these peaks in steam demand (22). Inefficiencies in the steam system itself can be overcome by insulating steam lines, repairing leaks, and returning steam condensate to the boiler (23).

Water management and waste-water heat recovery are of paramount importance in the reduction of the dyehouse steam demand. As much as 83% of the energy consumed in dyeing is required to heat the dye and scour baths using the latent heat of vaporization of steam (24), and 37% of this energy is subsequently lost as hot waste-water discharged to the waste treatment system (25). By reducing the volume of water used in the dye bath there is less water present to be heated and cooled during the dye cycle, thereby reducing the energy and water demands of the dyehouse (6). This reduction in dye bath volume also reduces the volume of effluent to be treated. This is significant since effluent disposal in dyehouse operations accounts for an estimated 70% of the water cost (21). The recovery of waste-water heat can further reduce dyehouse energy consumption since the effluent contains much of the energy put into the dyeing process.

In addition to making these and other changes in the dyeing process and boiler operation, Beard (3) suggested that further reductions in energy consumption in the dyehouse could be realized through the proper scheduling of the heating and cooling operations of the dye becks.

Through proper scheduling, peaks in steam demand, waste of hot water by storage tank overflow, and unbalanced workloads could be eliminated. To determine the necessary guidelines to insure the optimum scheduling of these activities, Beard recommended developing a mathematical model to simulate dyehouse operations. By doing so, dyehouse variables can be experimentally manipulated without adversely affecting the quality of dyeing or the level of production. Connor, et al. (8) have already demonstrated the feasibility of using computer simulation in assessing batch dyehouse operations. In fact, the success of their investigations of the effects of automation on dyehouse productivity led them to suggest that the dyeing model be extended to simulate all activities associated with a dyeing and finishing operation.

Simulation

Simulation is the process of conducting experiments on a model of a system rather than experimenting directly with the system. The model may be a physical or an abstract representation of the system as dictated by the needs of the real-life situation. In either case, it is used experimentally to study the effects of changes in the variables of the system (15). This technique has been used for years in one form or another to evaluate the performance of a wide range of real-life situations. Physical models of bridges and aircraft have been studied in wind tunnels to determine the effect of high wind velocities on a particular design.

Mathematical models, abstract representations of real systems, have been used in war games. This approach, using a computer-processed mathematical model, can be used to advantage in an advance evaluation of military equipment, tactics, and even strategy (7). Other mathematical models have been used to simulate transportation systems, the scheduling of jobs, the allocation of limited resources, equipment performance under different conditions, manufacturing processes, and operating policies.

A mathematical model describes the system being simulated in terms of its logical and mathematical rules. It should be simple enough for manipulation and understanding by those who use it, yet complex enough to accurately represent the system under study. Since computers function as logic machines and symbol manipulators, they are ideal for modeling real systems in an abstract mathematical form. The computer model itself can be made to represent the real-world problem as it exists or as it is anticipated to be. The computer offers the additional advantages of being capable of rapidly calculating the answers to mathematical problems while at the same time processing large masses of data (2). The thought processes involved in constructing this type of simulation model often yield very valuable results by creating a clearer understanding of the problems to be studied (5).

Simulation forces the experimenter to closely observe and completely understand the problem being studied before

the system can be accurately modeled. Simulation brings together all of the important aspects of the system and permits the study of their relationships to each other. Although the technique used to model a particular system differs from the techniques used in other situations, the overall technique of simulation is the same; experimentation on a model of the system (18).

The usefulness of simulation, regardless of the type of model being used, depends on its applicability to the real world. Quite often the motive behind a simulation is to find ways to make the variables of the system work better together. Conflicts of interest among system variables require that the best set of compromises be determined. These conflicts force the user to observe and understand the behavior of the system being studied, and to identify those factors which are most important to the problem. As an aid to decision making, simulation augments the experimenter's ability to study the potential of decisions before they are actually implemented (2, 19). Simulation techniques allow systems that normally would be too dangerous or too expensive to experiment with to be studied.

Simulation of Batch Dyehouse Processes

Connor, et al. (8) have successfully simulated batch dyeing processes with a general-purpose computer model. They developed their model to assess the benefits of

adopting automation in a dyehouse handling sewing threads. Computer simulation was chosen to handle the complex and highly variable work patterns typically associated with batch dyehouses. This choice made it possible to handle the random occurrences in dyehouse activities. By using the computer to generate random numbers, the investigators were able to simulate the randomness of the add requirements for each dyeing. These adds are needed to obtain the desired color match. Furthermore, the computer model made it possible, through simulation, to study the interferences in dyehouse operation that occur when one operator looks after more than one dye beck. These investigators suggested that improper manning levels could be responsible for a loss of dyehouse efficiency, and could possibly have an adverse effect on the quality of the dyeing.

When the results of their simulation of existing dyehouse conditions were compared with the actual dyehouse results, Connor and his co-investigators found a very close agreement. In the actual dyehouse 379 dyeings were completed as compared to the 372 dyeings completed by the simulation of the existing dyehouse conditions. Having thus verified the capabilities of their model, they demonstrated with the model the increase in dyehouse productivity made possible by the adoption of automation. They also reported, though not in specific terms, being successful in modeling, after suitable modifications had been made to their model,

a dyehouse handling synthetic fabrics. Because of their success, they felt that there was sufficient uniformity in the general batch dyeing process to expect that a simulation study of one dyehouse could enable a model to be constructed which would be generally applicable, at least in its basic framework, to all batch dyeing processes. Their success in modeling the batch dyeing process encouraged them to suggest that the simulation of a complete finishing works be attempted to remove interferences and bottlenecks in the overall operation of dyehouses.

IV. MODEL DEVELOPMENT

The computer simulation of batch dyeing processes promises to be valuable in assessing the benefits of changes in dyehouse operation. This approach avoids lengthy and expensive full-scale trials which reduce dyehouse productivity. To simulate dyehouse activities a vast amount of information must be continuously gathered and processed by the model. Using the computer, this can be done both rapidly and accurately. Also, the computer can easily handle the occurrence of chance events such as dye adds and pH adjustments that typically interrupt the normal sequence of dyehouse activities. Because local textile industries have expressed an interest in this type of study, the model presented here was specifically developed to simulate the batch dyeing of synthetic cloth in pressurized dye becks. However, because of the many similarities found in all batch dyeing processes it is generally believed that this model could be used, after the suitable modifications had been made, to simulate any batch dyeing process.

The dye cycle presented in Table 1 is typical of the dyeing procedures used to dye synthetic cloth in the textile industry. As indicated, a number of the steps involved in this procedure require the services of a floor operator. The preparation of chemicals and dyes requires a drug room operator. These activities are coordinated by the dye cycle,

TABLE I. Example of a Typical Dyeing Procedure Used to Dye Synthetic Cloth in Batch Dye Becks

Cycle Step	Description	Time Required min	Starting Temperature °F	Stopping Temperature °F
1	Set Level #1 and Check Manual Settings. Floor Operator Required.	5	90	90
2	Fill at 100°F.	8	100	100
3	Load Cloth. Floor Operator Required.	22	100	100
4	Circulate to 160°F at 5°F/min and Deliver Chemicals.	12	100	160
5	Set Level #5 and Partially Drain.	2	160	160
6	Deliver Dye.	9	160	160
7	Check pH and Manual Settings. Floor Operator Required.	5	160	160
8	Raise Temperature to 260°F at 3°F/min.	33	160	260
9	Circulate at 260°F.	30	260	260
10	Lower Temperature to 150°F at 3°F/min.	36	260	150
11	Partially Drain.	1	150	150
12	Sample. Floor Operator Required.	5	150	150
13	Prepare Rinse.	1	150	150
14	Drain.	5	90	90
15	Set Level #2.	1	90	90
16	Fill at 100°F.	8	100	100
17	Circulate at 100°F.	4	100	100
18	Unload Cloth. Floor Operator Required.	20	100	100
19	Drain.	5	90	90

which specifies when and for what task an operator is needed. The dye cycle, when implemented by a computer or automatic instrumentation, also controls the actual operation of the dye beck. To be successful, the model must be capable of simulating these activities coordinated by the dye cycle. In addition to modeling these physical events of the batch dyeing process, the model must also be capable of simulating the logic and rules that define the operating policies and the decision making framework of the dyehouse management. The model must be able to decide which dye beck is to be assigned an operator when more than one dye beck needs an operator and only one operator is available. Likewise, when more than one operator is available to perform the same job, the model must choose which operator will be assigned to that job. Not only must the model handle the assignments of operators and dye becks, it must give the operators their coffee and meal breaks at the appropriate times, and for the proper duration as in an actual dyehouse. By including these and other rules of operation, the complexity of the computer model is greatly increased. However, this is necessary if the model is to be a realistic representation of the complexities of the real-life situation.

Figure 1 is representative of the complex and highly variable work patterns expected in a typical batch dyehouse. As the temperature profiles indicate, the first ten dye becks use a dye cycle significantly longer than the dye cycle used in the last ten dye becks. In the plot of the

Figure 1. Temperature Profiles for Twenty Dye Becks Operating Continuously for One Week

dye cycle's temperature profiles, a dye cycle is completed every time the temperature plot returns to the 0°F reference line for a dye beck. Referring to Figure 1, the uppermost horizontal reference line represents 300°F for the temperature profiles plotted for the first dye beck. The next horizontal reference line represents 0°F for the first dye beck and 300°F for the second dye beck. This continues until the lowest horizontal reference line is reached which is the 0°F reference line for the twentieth dye beck. As the temperature profiles show, dyeings begin and end at different times. Some dye becks are heating-up while others are loading or unloading, cooling down, holding, etc. Some dyeings require one, two, or no adds to dye the desired shade as illustrated by the random occurrence of adds in the temperature profiles plotted in Figure 1. An add appears as an additional heating, holding, and cooling cycle step combination in the plot of the temperature profile of the dye cycle. For example, the first dyeing completed in the first dye beck in Figure 1 required one add; the second, third and fourth dyeings required no adds; and the fifth dyeing required two adds. On closer examination many apparently identical dye cycles differ in length. The difference is attributed to the different lengths of time each dyeing spends waiting for an operator. This is illustrated by comparing the first and second dyeings completed in the twentieth dye beck. The first dyeing had to wait longer than the second dyeing for a floor operator to load and unload the cloth being dyed.

Not only does Figure 1 illustrate the complex and highly variable nature of actual dyehouse operations, it demonstrates the capabilities of the computer model developed in this study to simulate these operations. In addition, the model has the capabilities of simulating the minute to minute changes in dyehouse steam demand, water demand, and hot water storage capacity as shown by Figures 2, 3, and 4 respectively. These plots, generated by the model, should prove useful in evaluating actual dyehouse performance. A complete presentation of the output generated by an example simulation run can be found in Appendix E. The output includes a description of the dyehouse being simulated and a summary of the results considered most significant.

Although the immediate objective of this study is to develop a general-purpose computer model to simulate batch dyeing processes, a clear perspective of the model's ultimate usefulness as an experimental tool for assessing the benefits of changes in dyehouse operation must be kept at all times. In lieu of a detailed discussion of the computer program itself, the discussion which follows focuses on the conceptual development of the dyehouse model from an over simplified and specific representation of a hypothetical dyehouse, into a general model capable of effectively simulating the complex and often variable activities found in a typical batch dyehouse. Throughout the discussion, major emphasis will be placed on what can be learned about

Figure 2. Example of a Dyehouse Steam Demand Plot Generated by the Computer Model

Figure 3. Example of a Dyehouse Water Demand Plot Generated by the Computer Model

Figure 4. Example of a Hot Water Storage Capacity Plot Generated by the Computer Model

typical batch dyehouse operation from computer simulation. This new understanding of dyehouse operations will be helpful in improving the utilization of energy in existing dyehouses and in designing new dyehouses that are energy efficient. The model, as finally developed, should prove most useful in establishing the guidelines necessary to insure the efficient use of energy, water, equipment, and manpower resources.

Modeling a Hypothetical Dyehouse

The operation of a hypothetical dyehouse is described in detail in Appendix A. The activities of this dyehouse are representative of the activities typically associated with the dyeing of synthetic cloth in batch dyehouses. By using this hypothetical dyehouse in the development of the model, two major problems are avoided that could appear if, in the initial attempts, an actual dyehouse is modeled. The first problem is that the results of a simulation study of an existing dyehouse are considered proprietary. This precludes the use of these results to illustrate the model's capabilities and usefulness. Secondly, by modeling an existing dyehouse, too much emphasis is placed on incorporating into the model the specific details of the dyehouse in question rather than on formulating a general-purpose model. However, once the model has been developed, its ultimate success will certainly depend on how well it can simulate

the activities in a real dyehouse with minimal modification, and assess the benefits of changes in operation before they are implemented.

In the following discussion, the dyehouse described in Appendix A will be used to illustrate the model's capabilities and to investigate the variables that control dyehouse activities. Of particular interest in this study is the identification of the dyehouse variables that have the greatest impact on productivity and efficient energy consumption. Once identified, these variables can be studied using simulation and the results obtained used to establish guidelines to insure optimal dyehouse performance. Even though the dyehouse used in these studies is strictly hypothetical, the results can be extended to predict actual dyehouse performance in general terms because of the vast similarities among batch dyehouses.

The Ideal Dyehouse. Preliminary visits to existing dyehouses revealed the complexities of batch dyeing processes that must be treated in a comprehensive dyehouse model. From this understanding of actual dyehouse activities an ideal dyehouse was conceived that included only the details of typical dyehouse operation. In this ideal dyehouse, just like in the dyehouses visited, floor operators load and unload the dye becks with cloth, drug room operators prepare the necessary chemicals and dyes, and a dye cycle controls the execution of the dyeing procedure in the

dye beck. Unlike real dyehouses, in the ideal dyehouse no dye adds are required to dye the cloth to the desired shade, no pH adjustments need to be made to the dye baths, and an unlimited steam and water supply is available to meet the dyehouse demands. Also, operators perform their duties when they are supposed to and in precisely the allotted time span. Although this is an idealization of the real-life situation, the simulation of the ideal dyehouse is most useful in developing the initial model and in studying the relationships between manning levels, number of dye becks engaged, and dyehouse productivity. By excluding the effects of chance events such as adds and pH adjustments in the initial investigations, and not being restricted by a limited supply of steam or water, it becomes possible to isolate the effect of manning levels and the number of dye becks used on dyehouse productivity, and to define dyehouse performance in terms that allow the performance of different dyehouses to be compared quantitatively.

In simulating dyehouse activities, whether those in an ideal dyehouse or in a real dyehouse, the events that take place are treated on a minute by minute basis within the operating framework of the dyehouse. Each minute of operation provides a vast amount of information that when compiled for a number of complete simulation runs as in Table II can be used to determine dyehouse productivity and performance. The data reported in Table II represents the results

TABLE II. A Study of Dyehouse Productivity as a Function of Manning Levels in an Ideal Dyehouse Dyeing Synthetic Cloth in Twenty Batch Dye Becks Over a One Week Period

Number of Drug Room Operators	Number of Floor Operators	Number of Dyeings Completed	Dye Cycle Execution Time min	Combined Idle Time min	Steam Consumed lb	Water Consumed lb	Combined Idle Time Per Dyeing	Combined Idle Time Per Min- ute of Dye Cy- cle Execution
1	1	145	31617	175437	901006	10907226	1209.9	5.547
1	2	292	63215	140075	1787869	21715728	479.7	2.216
1	3	362	78006	128270	2172722	26816896	354.3	1.644
1	4	362	78019	137498	2170662	26813952	379.8	1.762
1	5	362	78013	146738	2170187	26825440	405.4	1.881
1	6	362	78024	155972	2170873	26825600	430.9	1.999
1	7	362	78075	165145	2172593	26834523	456.2	2.115
1	8	362	78075	174385	2172596	26834523	481.7	2.234
2	1	145	31627	184677	901006	10907225	1273.6	5.839
2	2	290	63254	149274	1800280	21799535	514.7	2.360
2	3	437	94775	113963	2670566	32487728	260.8	1.202
2	4	580	125220	80208	3496645	42884256	138.3	0.640
2	5	716	153907	49018	4265445	52778123	68.5	0.318
2	6	724	155234	56284	4292606	53215952	77.7	0.362
2	7	724	155376	65374	4293694	53282592	90.3	0.421

TABLE II. (Continued)

Number of Drug Room Operators	Number of Floor Operators	Number of Dyeings Completed	Dye Cycle Execution Time min	Combined Idle Time min	Steam Consumed lb	Water Consumed lb	Combined Idle Time Per Dyeing	Combined Idle Time Per Min- ute of Dye Cy- cle Execution
2	8	724	155434	74546	4294585	53281856	103.0	0.480
2	1 9	724	155432	83779	4294021	53293782	115.7	0.539
3	1	145	31627	193917	901006	10907226	1337.4	6.131
3	2	290	63254	158514	1800280	21799536	546.6	2.506
3	3	438	94707	123296	2672247	32483264	281.5	1.302
3	4	586	126088	88258	3517235	43192048	150.6	0.700
3	5	726	156121	55118	4327857	53554784	75.9	0.353
3	6	831	178421	32899	4931305	61136080	39.6	0.184
3	7	878	188081	28479	5191599	64475456	32.4	0.151
3	8	895	191882	32376	5294449	65744080	36.2	0.169
3	9	904	193788	38937	5346177	66406240	43.1	0.201
3	10	912	195449	45847	5390945	66993072	50.3	0.234
4	1	145	31627	203157	901006	10907226	1401.1	6.424
4	2	290	63254	167754	1800280	21799536	578.5	2.652
4	3	438	94707	132536	2672247	32483264	302.6	1.399
4	4	572	123336	101388	3439850	42157600	177.2	0.822
4	5	726	156136	64350	4327673	53579680	88.6	0.412

TABLE II. (Continued)

Number of Drug Room Operators	Number of Floor Operators	Number of Dyeings Completed	Dye Cycle Execution Time min	Combined Idle Time min	Steam Consumed lb	Water Consumed lb	Combined Idle Time Per Dyeing	Combined Idle Time Per Min- ute of Dye Cy- cle Execution
4	6	812	173842	48586	4807968	59601216	59.8	0.279
4	7	880	188672	36850	5206203	64652336	41.9	0.195
4	8	868	186648	49068	5156360	63834864	56.5	0.263
4	9	910	195241	46148	5384015	66950816	50.7	0.236
4	10	912	195814	54584	5401585	67103408	59.8	0.279
4	11	916	196299	63123	5414191	67279968	68.9	0.322

of simulation studies investigating the effect of manning levels on dyehouse performance in an ideal dyehouse of twenty dye becks operating continuously for one week. As these results indicate, the productivity of the dyehouse can either be measured by the total number of dyeings completed during the simulation run or by the minutes of dye cycle execution time. Although dyeings partially completed are not included, the total number of dyeings completed is an adequate measure of dyehouse productivity when only one dye cycle is being used. The use of the minutes of dye cycle execution time is a good alternative since it represents the actual cumulative time that the dye becks are in use and accounts for the partial completion of dyeings. When the manning level for the twenty dye becks in Table II is increased from three drug room operators and four floor operators to three drug room operators and five floor operators the weekly productivity, as measured by the number of dyeings completed, increases 1.239 times from 586 dyeings completed to 726 dyeings completed. This is paralleled by the 1.238 times increase in the minutes of cumulative dye cycle execution time. Other such comparisons yield similar results and illustrate the effectiveness of both measures of productivity to assess the effects of changes in dyehouse operation, such as the effect of different manning levels for a given number of dye becks, on dyehouse productivity.

When the number of dyeings completed in twenty dye becks for different manning levels is plotted as a function of the manning levels, as in Figure 5, the relationship between dyehouse productivity and the number of operators employed is illustrated. As shown in Figure 5, dyehouse productivity is limited by the number of operators or by the number of dye becks being used. For example, regardless of the number of floor operators manning the dye becks, the maximum number of dyeings that can be completed in the dyehouse when only one drug room operator prepares the chemicals and dyes is 362. A maximum of 724 dyeings can be completed when two drug room operators are utilized. By the same token, no matter how many drug room operators are being used, only 145 dyeings can be completed in the dyehouse when only one floor operator is servicing the dye becks. The addition of more floor and drug room operators increases the productivity of the dyehouse to a level restricted only by the number of dye becks used in the dyehouse. In the ideal dyehouse as represented in Figure 5, after the dyehouse reaches a level of approximately 916 completed dyeings no additional increase in the manning levels can significantly increase the number of dyeings completed. At this point, the level of dyehouse productivity becomes limited by the number of dye becks being used. By manning the dyehouse with twenty drug room operators and twenty floor operators, a maximum of 940 dyeings can be completed. In reality this

Figure 5. Number of Dyeings Completed in Twenty Dye Becks Operating Continuously for One Week as a Function of the Number of Operators Manning the Dye Becks

is impractical since at such manning levels each floor operator would be idle 73% of every dye cycle when using the dye cycle presented in Table I, and each drug room operator would be idle 89% of every dye cycle. These limiting situations suggest that an optimum manning level may exist that makes the best use of all operators and all dye becks at reasonably high levels of production.

When the idle times of the dye becks and the operators are summed and divided by the number of dyeings completed, a measure of dyehouse performance is attained which can be used to determine the optimum dyehouse manning levels. As Figure 6 shows, when the combined idle time per dyeing is plotted as a function of manning levels, a minimum exists that corresponds to optimum dyehouse performance with respect to manning levels. When the manning levels are too low, the beck idle time is great and the production as measured by the number of dyeings is low. This causes the combined idle time per dyeing to be high. The more idle time per dyeing, the poorer the performance of the dyehouse. As more operators are used, the beck idle time decreases, the operator idle time increases, and production increases. Initially, the increase in production and the decrease in beck idle time is greater than the increase in operator idle time causing a sharp decrease in the combined idle time per dyeing. Eventually, the increase in operator idle time begins to get greater and the increase in production and the decrease in beck idle time slows down. As this happens,

Figure 6. Minutes of Combined Operator and Dye Beck Idle Time Per Dyeing as a Function of Manning Levels in a Dyehouse of Twenty Dye Becks Operating Continuously for One Week.

the combined idle time per dyeing decreases to a minimum and then increases as the operator idle time increases faster than the increase in production and the decrease in dye beck idle time. In the ideal dyehouse represented in Figure 6, the minimum occurs at a manning level of three drug room operators and seven floor operators. At this manning level, 878 dyeings can be completed which is 93.4% of the maximum number of dyeings that can be completed in twenty dye becks in the ideal dyehouse.

In Figure 6 it is assumed that all idle time has the same value whether for dye becks or operators. It is important to realize that in a real dyehouse the different idle times will have a different value and when weighted accordingly may cause a shift in the optimum manning levels. Regardless, the ratio of combined idle times, whether weighted or unweighted, to the level of productivity can be used to define the manning levels for optimum dyehouse performance. When productivity is measured in minutes of dye cycle execution time figures quite similar to Figures 5 and 6 result, as illustrated by Figures 7 and 8 respectively. This alternative approach in defining dyehouse performance is particularly useful in evaluating dyehouses where more than one dyeing procedure is used, and when adds and pH adjustments must be made. In addition, when adds, pH adjustments, and heat recovery systems are present in the dyehouse being modeled, the steam and water consumed per dyeing must

Figure 7. Minutes of Dye Cycle Execution Time for Twenty Dye Becks Operating Continuously for One Week as a Function of Manning Levels

Figure 8. Minutes of Combined Operator and Dye Beck Idle Time Per Minute of Dye Cycle Execution Time as a Function of Manning Levels in a Dyehouse of Twenty Dye Becks Operating Continuously for One Week

also be taken into consideration when choosing the manning levels of optimum dyehouse performance. This is not necessary in the ideal dyehouse since all dyeings require the same amount of water and steam with slight variations in steam consumption occurring when dye becks are waiting at an elevated temperature and heat losses must be made up. However, a minimum in steam consumption occurs in the same region of manning levels as the minimum in the combined idle time per dyeing. Since at the optimum manning levels beck idel time is at a minimum, the steam consumed to make up heat losses for holding at elevated temperatures in the dye cycle is also at a minimum.

The overall effect of manning levels on dyehouse performance can be illustrated in a comparison of temperature profile plots for a dyehouse manned at three different levels. In Figure 9, the dyehouse is optimally manned by three drug room operators and seven floor operators. As seen in Figure 9 and reported in Table III, each dye beck completes nearly the same number of dycings during the simulation run. When one less floor operator is assigned to the dyehouse the total number of dyeings is significantly reduced, as indicated in Figure 10 and reported in Table III. The greatest change in the number of dyeings completed occurs in the higher numbered dye becks. As Figure 11 shows, there is an even greater reduction in the number of dyeings completed when two drug room operators and seven floor operators man the dyehouse. Table III indicates

Figure 9. Temperature Profiles for Twenty Dye Becks Optimally Manned by Three Drug Room Operators and Seven Floor Operators in an Ideal Dyehouse Operating for One Week

TABLE III. Comparison of the Number of Dyeings Completed in Each Dye Beck in an Ideal Dyehouse Manned by Three Drug Room Operators and Seven Floor Operators (Run 1), Three Drug Room Operators and Six Floor Operators (Run 2), and Two Drug Room Operators and Seven Floor Operators (Run 3)

Dye Beck Number	Number of Dyeings Completed		
	Run 1	Run 2	Run 3
1	46	45	46
2	46	45	46
3	46	45	45
4	46	45	45
5	45	44	45
6	45	44	45
7	45	44	45
8	45	43	45
9	44	42	45
10	44	42	44
11	44	42	44
12	44	42	43
13	44	41	41
14	43	41	41
15	43	40	41
16	43	40	34
17	42	38	24
18	41	38	5
19	41	36	0
20	41	34	0
Total	878	831	724

Figure 10. Temperature Profiles for Twenty Dye Becks Manned by Three Drug Room Operators and Six Floor Operators in an Ideal Dyehouse Operating for One Week

Figure 11. Temperature Profiles for Twenty Dye Becks Manned by Two Drug Room Operators and Seven Floor Operators in an Ideal Dyehouse Operating for One Week

that no dyeings were completed in dye becks nineteen and twenty during the simulation run. The system used in the model to assign operators as described in the discussion of the hypothetical dyehouse in Appendix A is responsible for this. Essentially in the situation in Figure 11, a drug room operator is never assigned to the last two dye becks because the drug room operators are always occupied by the demands of the other eighteen dye becks. As these figures indicate, ideal dyehouse performance is greatly influenced by the manning levels as related to the number of dye becks used. Increasing the manning levels improves the utilization of the dye becks but wastes manpower. Decreasing the manning levels makes maximum use of the available operators, but reduces the dyehouse output and makes inefficient use of the dye becks. The proper manning levels assures the best utilization from an economic standpoint of both manpower and dyehouse equipment.

Control of Peaks in Steam and Water Demand. In the ideal dyehouse, no effort was made to control the steam and water demand since an unlimited supply of both was assumed to be available. This made it possible to study the influence of manning levels on dyehouse performance without any restrictions being imposed on dyehouse operation by limitations in the steam and water supply. The plots of the steam and the water demand for the ideal dyehouse of twenty

dye becks optimally manned by three drug room operators and seven floor operators for one week exhibit large fluctuations in the demands for steam and water from one minute to the next as illustrated by Figure 12 and Figure 13, respectively. The severe peaks in both plots during the initial hours of simulated operation are representative of the extreme demands for steam and water during the start-up period for the dyehouse with all dye becks initially empty. At this time in the ideal dyehouse, a dye beck can start-up whenever it is ready. As a result, many dye becks begin filling and heating-up at the same time, creating a great demand for steam and water. This large demand appears as the first sharp peak in the steam and water demand plots for the ideal dyehouse. If boilers happened to be available in 50000 lb/hr capacity, two boilers would be required to meet the start-up steam demand and to handle future peaks in the steam demand in the simulated dyehouse.

In a real dyehouse, it would be preferable to use only one 50000 lb/hr boiler or even a boiler of less capacity operating as close to total capacity as possible at all times. In the case of the ideal dyehouse, this would require a significant reduction in the peaks in steam demand before less total boiler capacity would be adequate. As can be seen in Figures 12 and 13, respectively, there are also many times when the demands for steam and water are low.

Figure 12. Steam Demand for One Week in the Ideal Dyehouse of Twenty Dye Becks Optimally Manned by Three Drug Room Operators and Seven Floor Operators

Figure 13. Water Demand for One Week in the Ideal Dyehouse of Twenty Dye Becks
Optimally Manned by Three Drug Room Operators and Seven Floor Operators

These extremes in the steam demand and the water demand result from many dye becks needing steam or water at the same time followed by simultaneous cessation of the demand moments later. By leveling the steam demand in particular, less boiler capacity would be required to meet the needs of the dyehouse. In addition, the boiler would operate more efficiently in the absence of these wide fluctuations in demand. Since the peaks in demand arise any time a number of dye becks simultaneously require large amounts of steam or water, it would seem likely that these wide fluctuations could be eliminated by controlling the number of dye becks allowed to execute at the same time the cycle steps with large steam or water demands.

In the typical dye cycle, the cycle steps that consume the largest amounts of steam are the dye cycle steps that fill the dye beck with preheated water, and the dye cycle steps in which the dye bath and cloth are heated to the desired dyeing temperature. By controlling the number of dye becks executing these steps simultaneously, peaks in the steam demand could possibly be leveled out. As a first attempt to regulate the steam demand, the start-up of dye becks in the heating and filling dye cycle steps is restricted to one dye beck each minute. This significantly reduces the steam demand during the initial minutes of the simulation as shown in Figure 14, and reduces the number and severity of the peaks in steam demand throughout the

Figure 14. Steam Demand in a Dyehouse of Twenty Dye Becks Manned by Three Drug Room Operators and Seven Floor Operators with the Start-up of Dye Becks in the Heating and Filling Dye Cycle Steps Limited to One Dye Beck during the Same Minute of Operation

simulation in comparison to the situation in the ideal dye-house. This can be seen by comparing Figures 14 and 12. In Figure 12, two 50000 lb/hr boilers would be required to meet the steam demand. If boilers were also available in 25000 lb/hr capacity, one 50000 lb/hr boiler and one 25000 lb/hr boiler would adequately meet the reduced steam demand in Figure 14. Similar reductions in the peaks in the water demand, particularly during the initial minutes of the simulation, also result from this control of cycle step start-ups as illustrated by Figures 15 and 13. By controlling the execution of the cycle steps that fill the dye machines to eliminate peaks in the steam demand, the water demand is also leveled out. From the results reported in Table IV, there is no significant change in dyehouse productivity when this new operating approach is implemented in the ideal dye-house.

When additional control is put on the steam demand by allowing no heating or filling dye cycle steps to begin execution when the steam demand is already above a predetermined level, the peaks in steam demand can be further reduced, and also make it possible to operate the dyehouse within the limits set by the dyehouse boiler capacity. In the situation investigated in Table IV, a dyehouse of twenty dye becks optimally manned with three drug room operators and seven floor operators is again used. The dyehouse is assumed to have a total boiler capacity of 50000 lb/hr and no more than one dye beck is allowed to begin a heating

Figure 15. Water Demand in a Dyehouse of Twenty Dye Becks Manned by Three Drug Room Operators and Seven Floor Operators with the Start-up of Dye Becks in the Heating and Filling Dye Cycle Steps Limited to One Dye Beck during the Same Minute of Operation -

TABLE IV. Determination of the Set Point to Control the Steam Demand in a Dyehouse with a Boiler Capacity of 50000 lb/hr and Twenty Dye Becks Manned by Three Drug Room Operators and Seven Floor Operators

Set Point lb/hr	Number of Dyeings Completed	Dye Cycle Execution Time min	Average Steam Consumption lb/hr	Average of Peaks in Steam Demand lb/hr	Number of Peaks Above Boiler Capacity
0	878	188081	30902	65192	499
(IDEAL DYEHOUSE - NO CONTROL OVER START-UPS)					
0	879	188468	30954	61924	474
(CONTROLLED START-UPS)					
50000	875	187458	30799	56848	368
47500	878	188287	30928	56377	303
45000	873	187153	30742	54880	180
42500	878	188257	30924	52142	102
40000	872	186978	30720	50895	100
37500	870	186438	30643	49717	33
35000	867	186095	30568	47640	0
32500	859	183985	30236	45730	0
30000	840	180211	29617	43023	0
25000	774	166103	27307	38022	0
20000	669	143743	23629	33165	0
15000	545	117132	19267	28243	0

or filling dye cycle step during the same minute. As the set point controlling the filling of the dye becks and the heating of the dye baths is decreased from 50000 lb/hr to 15000 lb/hr, the fluctuations in steam demand can be regulated at a level below the 50000 lb/hr boiler capacity. As illustrated in Table IV, this can be accomplished without reducing the level of production. For example, when the set point is 35000 lb/hr, 867 dyeings can be completed as compared to 878 completed dyeings in the ideal dyehouse, or a 1.2% decrease in the number of dyeings completed. The same comparison is possible between the 867 dyeings completed when the set point is 35000 lb/hr and the 879 dyeings completed when the start-up of dye cycle steps is controlled. When the steam demand is plotted for the situation where a set point of 35000 lb/hr is used, it can be seen that the peaks in steam demand have been significantly reduced as shown in Figure 16. Unlike the situations represented by Figures 12 and 14, the steam demand is kept well within the limits of the dyehouse boiler capacity of 50000 lb/hr. Likewise, Figure 17 shows that this additional control on the steam demand also levels the peaks in the demand for water. The comparison of Figure 17 with Figures 13 and 15 gives sufficient indication that by controlling the steam demand, the dyehouse not only benefits from the reduced peaks in steam demand and lower boiler capacity requirements, but also from a significant reduction in the peaks in the dyehouse water demand.

Figure 16. Steam Demand in a Dyehouse of Twenty Dye Becks Manned by Three Drug Room Operators and Seven Floor Operators with the Start-up of Dye Becks in the Heating and Filling Dye Cycle Steps Limited to One Dye Beck during the Same Minute of Operation, and the Steam Demand Controlled at a Set Point of 35000 lb/hr

Figure 17. Water Demand in a Dyehouse of Twenty Dye Becks Manned by Three Drug Room Operators and Seven Floor Operators with the Start-up of Dye Becks in the Heating and Filling Dye Cycle Steps Limited to One Dye Beck during the Same Minute of Operation, and the Steam Demand Controlled at a Set Point of 35000 lb/hr

For the operating strategies used in the dyehouse modeled in this study, the effect of these controls on dyehouse activities can be seen in the dye cycle temperature profiles plotted in Figure 18. The controls on steam demand have a limited effect on the length and number of dyeings completed in the dye becks. However, in the higher numbered dye becks there is slightly more waiting time evident in the temperature profiles as the dye becks wait to start a filling or heating dye cycle step. This is a direct result of the manner in which the model executes the controls on steam demand. When more than one dye beck is ready to fill or to heat-up, the model looks at the lowest numbered dye beck first. If the current steam demand is less than the control level, this dye beck is allowed to start executing the dye cycle step. Any remaining dye becks ready to start executing controllable dye cycle steps are put on hold to be dealt with during the next minute of the simulation. In contrast to the higher numbered dye becks, the lower numbered dye becks spend relatively little time waiting to execute a filling or heating dye cycle step since they are always given first priority. As Figure 18 shows, these controls spread out the dye beck activities thereby limiting the number of dye becks executing a filling or heating cycle step at the same time. The results in Table IV have shown that this has a limited effect on dyehouse productivity but greatly reduces the peaks in the dyehouse steam demand as

Figure 18. Temperature Profiles for the Dyeings Completed in a Dyehouse of Twenty Dye Becks Manned by Three Drug Room Operators and Seven Floor Operators with the Start-up of Dye Becks in the Heating and Filling Dye Cycle Steps Limited to One Dye Beck during the Same Minute of Operation, and the Steam Demand Controlled at a Set Point of 35000 lb/hr

illustrated by Figure 16. Figure 17 shows that a similar reduction occurs in the dyehouse water demand,

In most dyehouses the water used to cool the dye bath and cloth during the dye cycle is recovered and later used as fill and rinse water. Because this water is recovered at or above the temperature at which the dye beck is filled, the dependence on steam to preheat the filling water is reduced. Not only does this lower the dyehouse dependence on steam, it also lowers the volume of water needed for each dyeing. The results reported in Table V are used to determine the best storage capacity for the twenty beck dyehouse optimally manned by three drug room operators and seven floor operators with the steam demand controlled at a set point level of 35000 lb/hr. The level of production with a storage capacity of 10000 gal or more is essentially the same as in the optimum case of the ideal dyehouse. However, on closer examination of the results in Table V, it can be seen that though the level of productivity is basically the same, there is a large difference in the steam and water consumed per dyeing. In the ideal dyehouse 5913 lb of steam and 73434 lb of water are required per dyeing as compared to 4202 lb of steam and 48071 lb of water in the dyehouse where demand is regulated and the cooling water is recovered in a 10000 gal storage tank. The addition of steam controls and heat recovery decreases the consumption of steam by 28.9% and water by 34.5% as compared to the ideal dyehouse. As

TABLE V. Comparison of Steam and Water Consumption for Different Hot Water Storage Capacities in a Dyehouse of Twenty Dye Becks Manned by Three Drug Room Operators and Seven Floor Operators with the Start-up of Dye Becks in the Heating and Filling Dye Cycle Steps Limited to One Dye Beck during the Same Minute of Operation, and the Steam Demand Controlled at a Set Point of 35000 lb/hr

Storage Capacity	Number of Dyeings Completed	Dye Cycle Execution Time	Steam Consumed Per Dyeing	Water Consumed Per Dyeing	Average Steam Consumption	Average of Peaks in Steam Demand
gal		min	lb	lb	lb/hr	lb/hr
50000	877	187996	4187	47824	21857	40619
45000	877	187996	4187	47824	21857	40619
40000	877	187996	4187	47824	21857	40619
35000	877	187996	4187	47824	21857	40619
30000	877	187996	4187	47831	21859	40619
25000	877	187996	4191	47878	21876	40619
20000	877	187996	4194	47925	21892	40619
15000	877	187996	4197	47972	21909	40983
10000	873	188159	4202	48071	21962	41106
5000	873	187053	4245	48684	22058	41118
0	867	186095	5923	73590	30568	47640
(IDEAL)	873	188081	5913	73434	30902	65192

Figure 19 shows, in this dyehouse where the steam demand is controlled and a heat recovery capacity of 10000 gal exists, there are no peaks in steam demand that exceed the dyehouse boiler capacity, and the fluctuations in the steam demand are not as great as in the ideal dyehouse represented by Figure 12 or in the dyehouses represented by Figures 14 and 16. There is also a great reduction in the peaks in water demand as shown in Figure 20. Figure 21 shows that when there is sufficient storage capacity the tank approaches empty on occasion and in a few instances even empties completely. A storage capacity of 15000 gal as in Figure 22 would be too great by approximately 5000 gal for the dyehouse described above. As Table V indicates, this additional capacity does not increase dyehouse production. However, it would make the initial cost of the heat recovery system higher, and increase the operating expenses necessary to maintain the water at the desired temperature. When the storage capacity is too small, much of the heat available for recovery is lost in the overflow from the storage tank. Regardless of the storage capacity available, the dyehouse benefits from the reductions in the total steam and water required for each dyeing. In general, the larger the storage capacity, the greater these reductions.

If, instead of 50000 lb/hr, the boiler capacity had been 40000 lb/hr a different set of dyehouse controls and a different heat recovery capacity would be necessary. For

Figure 19. Steam Demand in a Dyehouse of Twenty Dye Becks Manned by Three Drug Room Operators and Seven Floor Operators with the Start-up of Dye Becks in the Heating and Filling Dye Cycle Steps Limited to One Dye Beck during the Same Minute of Operation, and the Steam Demand Controlled at a Set Point of 35000 lb/hr with a Heat Recovery Capacity of 10000 gal

Figure 20. Water Demand in a Dyehouse of Twenty Dye Becks Manned by Three Drug Room Operators and Seven Floor Operators with the Start-Up of Dye Becks in the Heating and Filling Dye Cycle Steps Limited to One Dye Beck during the Same Minute of Operation, and the Steam Demand Controlled at a Set Point of 35000 lb/hr with a Heat Recovery Capacity of 10000 gal

Figure 21. Changes in the Volume of Hot Water in Storage in a Dyehouse of Twenty Dye Becks Manned by Three Drug Room Operators and Seven Floor Operators with the Start-up of Dye Becks in the Heating and Filling Dye Cycle Steps Limited to One Dye Beck during the Same Minute of Operation, and the Steam Demand Controlled at a Set Point of 35000 lb/hr with a Heat Recovery Capacity of 10000 gal

Figure 22. Changes in the Volume of Hot Water in Storage in a Dyehouse of Twenty Dye Becks Manned by Three Drug Room Operators and Seven Floor Operators with the Start-up of Dye Becks in the Heating and Filling Dye Cycle Steps Limited to One Dye Beck during the Same Minute of Operation, and the Steam Demand Controlled at a Set Point of 35000 lb/hr with a Heat Recovery Capacity of 15000 gal

this case the most dyeings can be completed when the steam demand is controlled by a set point of 25000 lb/hr and a hot water storage capacity of 10000 gal is available. Under these conditions 843 dyeings can be completed as compared to 878 in the ideal dyehouse. The reduction in dyehouse productivity illustrates just how important the proper boiler capacity is to an efficient dyehouse; not only for handling the peaks in steam demand during dyehouse operation, but in also fulfilling the steam requirements at the highest possible levels of dyehouse productivity.

pH Adjustments, Adds. In a real dyehouse, the adjustment of dye bath pH and the need for dye adds can unexpectedly interrupt the normal dyehouse activities. These events occur at random, and increase both the time required to complete the dyeing and the work load of the operators. Figures 23 and 24 compare the temperature profiles of two interrupted dyeings, one requiring a single pH adjustment and the other a single add, with the normal uninterrupted dye cycle. These figures and the corresponding results in Table VI show the effects of pH adjustments and adds on dyehouse operation in the hypothetical dyehouse, and are representative of how these events affect typical batch dyehouse operation.

A single pH adjustment, as in Figure 23, increases the dye cycle length by fourteen minutes or 6.6%. While this increase has no effect on the water consumption and only a slight effect on the steam consumption, a significant

Figure 23. Comparison of Normal Dye Cycle with Normal Dye Cycle Having One pH Adjustment

Figure 24. Comparison of Normal Dye Cycle with Normal Dye Cycle Having One Add

TABLE VI. Comparison of Dye Cycle Having No pH Adjustment and No Add with a Dye Cycle Having One pH Adjustment, and a Dye Cycle Having One Add

Number of pH Adjust- ments	Number of Adds	Time Required	Water Consumed	Steam Consumed	Floor Operator Work Time	Drug Room Operator Work Time
		min	lb	lb	min	min
0	0	212	72833	4123	57	24
1	0	226	72833	4139	62	27
0	1	332	107666	6950	67	40

increase in operator working time is required to meet the needs of the dye cycle. A single pH adjustment increases the time a floor operator is required by 8.8%, and the time a drug room operator is required by 12.5%.

When a single add interrupts the normal dye cycle, as in Figure 24, the dye cycle length increases 120 minutes or 56.6%. As Figure 24 indicates, an add requires another heating-up of the cloth and dye bath to the dyeing temperature, followed by a holding period and then a cooling period similar to the steps in the normal dye cycle. When this occurs, the water and steam consumed during the dyeing is greatly increased. For the dye cycles presented in Figure 24, Table VI reports that a single add increases the steam consumed by 68.6% and the water consumed by 47.8%. This is accompanied by an increase of 17.5% in the required working time of the floor operator assigned to the dyeing, and an increase of 66.7% in the required working time of the drug room to prepare the necessary chemicals and dyes.

The frequency at which these random events occur varies from dyehouse to dyehouse, but the effect is always a reduction in the dyehouse dyeing capacity. In the ideal dyehouse, twenty dye becks optimally manned by three drug room operators and seven floor operators can complete 878 dyeings. If 20% of the dyeings completed require a single pH adjustment, then only 858 dyeings can be completed. If 20% of the dyeings completed require an add, then the dyeing

capacity is reduced to 787 completed dyeings. Further reduction in the dyeing capacity to 771 completed dyeings occurs when 20% of the dyeings completed require a pH adjustment and 20% of the dyeings completed require an add. These results and the corresponding effects on steam and water consumption are reported in Table VII. By including these random occurrences in the dyehouse model, the events in real dyehouses can be more accurately represented.

Alternative Operating Strategies

Many dyehouses operate only six days each week, for twenty-four hours each day. This presents a new problem for the dyehouse model that was not present in the study of the hypothetical dyehouse which operated continuously after start-up. Not only must the model have instructions to start-up the dyehouse activities, it must also include instructions for shutting down the dyehouse operations at the end of every week. Two strategies are commonly used in the textile industry to cope with the weekly start-ups and shut-downs. In the first approach, all dye becks are empty when the weekly start-up begins, and they end the week empty after being unloaded and drained. This involves setting a time during the final day of the week after which no new dyeings may begin, and all dye becks are left empty upon completion of the dye cycle they are currently executing. The second approach starts each week with the dye becks filled with water and loaded with the cloth to be dyed. When the week

TABLE VII. Effect of pH Adjustments and Adds on Dyehouse Productivity, Steam Consumption, and Water Consumption in a Dyehouse of Twenty Dye Becks Optimally Manned

Frequency of pH Adjustments		Frequency of Adds		Number of Dyeings Completed	Steam Consumed Per Dyeing	Water Consumed Per Dyeing
<u>0</u>	<u>1</u>	<u>0</u>	<u>1</u>			
					lb	lb
100	0	100	0	878	5913	73434
80	20	100	0	858	5932	73552
100	0	80	20	787	6491	80567
80	20	80	20	771	6484	80424

comes to an end, the dyehouse shuts down after refilling and reloading the dye becks in preparation for the next start-up.

If, in the ideal dyehouse of twenty dye becks optimally manned, and using the first shut-down strategy, no new dyeings are allowed to begin 3.5 hours before the end of the sixth day, all twenty dye becks will end the week empty as desired. By starting to shut down the dyehouse at this time, 750 dyeings can be completed during the six days of simulated operation. As Table VIII shows, this is the most dyeings that can be completed for this situation. If the shut-down of dyehouse operation begins any earlier, a reduction in the number of dyeings completed occurs. For example, if the shut-down is implemented five hours before the end of the sixth day only 744 dyeings are completed. Figure 25 illustrates the effect of the shut-down procedure with the dye cycle temperature profiles. As can be seen, the last dye cycle in all twenty dye becks ends before the end of the sixth day, some sooner than others. The shut-down of the dyehouse is also accompanied by a reduction in the steam and water demand until there is no demand for either when all dye becks have completed their last dye cycle as shown in Figures 26 and 27, respectively.

When the second approach is used, 749 dyeings can be completed with all dye becks ending filled with water and loaded with cloth for the next dyehouse start-up if the shut-down procedure is implemented 4.5 hours before the end

TABLE VIII: Determination of the Time before the End of the Simulation to Begin Shut-Down Procedures that Leave All of the Dye Becks Empty in the Ideal Dyehouse of Twenty Dye Becks Optimally Manned

Time Remaining hr	Number of Dyeings Completed	Number of Dye Becks Operating at End of Simulation
0	750	20
0.5	750	16
1.0	750	14
1.5	750	10
2.0	750	9
2.5	750	5
3.0	750	3
3.5	750	0
4.0	749	0
4.5	745	0
5.0	744	0
5.5	740	0
6.0	736	0
6.5	735	0
7.0	731	0

Figure 25. Temperature Profiles for Six Days of Operation in a Dyehouse of Twenty Dye Becks Optimally Manned and Shutting Down with All Dye Becks Empty

Figure 26. Steam Demand Corresponding to the Dyehouse Operation in Figure 25

Figure 27. Water Demand Corresponding to the Dyehouse Operation in Figure 25

of the sixth day as indicated in Table IX. The refilling and reloading cycle steps appear as a very short dye cycle at the end of every temperature profile plot in Figure 28. As with the other approach, each dye beck ends its operation at a different time but always prior to the end of the sixth day. The trends in the steam and water demand are the same as those exhibited by the first shut-down approach in Figures 26 and 27, respectively.

There has been some question within the textile industry as to which of the two approaches is the most effective. The two investigations conducted in the ideal dyehouse developed in this study suggest that one approach is no more successful than the other at shutting down dyehouse operation while maintaining a high level of productivity. However, leaving the dye beck empty seems preferable since it removes any possibility of off quality dyeings resulting from the cloth being immersed in the water bath between shut-down and start-up.

Multiple Dye Cycles

The dye cycle used to dye a particular synthetic fabric is dependent on the fiber content of the fabric, the shade to be dyed, and the dyes and chemicals to be used. In a typical batch dyehouse, many different fabrics are dyed. This requires the formulation and use of more than one dye cycle to assure quality dyeings. Although the selection of dye cycles is beyond the scope of this study, the fact that

TABLE IX. Determination of the Time before the End of the Simulation to Begin Shut-Down Procedures that Leave All of the Dye Becks Refilled with Water and Reloaded with Cloth in the Ideal Deyhouse of Twenty Dye Becks Optimally Manned

Time Remaining hr	Number of Dyeings Completed	Number of Dye Becks Operating at End of Simulation
0	752	20
0.5	752	20
1.0	752	18
1.5	752	14
2.0	752	12
2.5	752	11
3.0	752	7
3.5	752	4
4.0	751	3
4.5	749	0
5.0	746	0
5.5	742	0
6.0	739	0
6.5	736	0
7.0	735	0

Figure 28. Temperature Profiles for Six Days of Operation in a Dyehouse of Twenty Dye Becks Optimally Manned and Shutting Down with All Dye Becks Refilled with Water and Reloaded with Cloth

more than one dye cycle is commonly used in real dyehouses has a bearing on the development of the model. To be representative of typical batch dyehouses, the model must be able to handle the additional complexity of multiple dye cycles. The addition of this capability greatly enhances the overall scope of the dyehouse model.

In Table X, a second dye cycle is presented. This dye cycle is a modified version of the dye cycle in Table I. The two dye cycles differ in the rates of temperature increase from 100°F to 160°F and from 160°F to 260°F . The dye cycle in Table X circulates longer at 260°F ; and cools down slower to 150°F , than the dye cycle in Table I. As will be seen later, these differences are quite apparent in the temperature profiles of the two dye cycles.

In a study conducted in a hypothetical dyehouse of twenty dye becks using the dye cycle in Table X in the first ten dye becks and the dye cycle in Table I in the last ten dye becks, 674 dyeings were completed at the optimum operating conditions. For this situation, the dyehouse operated the most efficiently when manned by three drug room operators and six floor operators. At this optimum manning level, a hot water storage capacity of 10000 gal, a steam control set point of 30000 lb/hr, and a boiler capacity of 40000 lb/hr are required. As the temperature profiles plotted in Figure 29 show, the dye cycle used in the first ten dye becks is considerably longer than the dye cycle used in the last ten dye becks. Because of this additional

TABLE X. Modified Version of the Dyeing Procedure Presented in Table I

Cycle Step	Description	Time Required min	Starting Temperature °F	Stopping Temperature °F
1	Set Level #1 and Check Manual Settings. Floor Operator Required.	5	90	90
2	Fill at 100°F.	8	100	100
3	Load Cloth. Floor Operator Required.	22	100	100
4	Circulate to 160°F at 2°F/min and Deliver Chemicals.	30	100	160
5	Set Level #2 and Partially Drain.	2	160	160
6	Deliver Dye.	9	160	160
7	Check pH and Manual Settings. Floor Operator Required.	5	160	160
8	Raise Temperature to 260°F at 1°F/min.	100	160	260
9	Circulate at 260°F.	60	260	260
10	Lower Temperature to 150°F at 2°F/min.	55	260	150
11	Partially Drain.	1	150	150
12	Sample. Floor Operator Required.	5	150	150
13	Prepare Rinse.	1	150	150
14	Drain.	5	90	90
15	Set Level #2.	1	90	90
16	Fill at 100°F.	8	100	100

TABLE X. (Continued)

Cycle Step	Description	Time Required min	Starting Temperature °F	Stopping Temperature °F
17	Circulate at 100°F.	22	100	100
18	Unload Cloth. Floor Operator Required.	20	100	100
19	Drain.	5	90	90

length in the dye cycle, fewer dyeings are completed in the first ten dye becks. In addition, Figure 29 illustrates the model's ability to handle more than one dye cycle. This capability will be important to the successful modeling of existing dyehouses.

Modeling an Existing Dyehouse

Although much information has been gained from the simulation of the hypothetical dyehouse, the final success of the computer model developed in this study comes from its ability to accurately simulate the activities in an existing dyehouse. The complexities of the hypothetical dyehouse are compounded in an existing dyehouse by such events as tangles in the cloth being dyed and mechanical failures of the dye becks. In addition, all dye becks cannot be expected to have the same physical dimensions or be loaded with the same amounts of water, chemicals, dyes and cloths. These characteristics combine with the features of the hypothetical dyehouse to create a highly complex and variable situation for the model to simulate.

Through an agreement with a local textile manufacturer the information needed to model an existing dyehouse has been provided, with the understanding that the name of the firm and the specific information not be divulged. Using this information, one week of actual dyehouse operation was compared with one week of simulated dyehouse operation. The

Figure 29. Temperature Profiles for Twenty Dye Becks Optimally Manned by Three Drug Room Operators and Six Floor Operators in a Hypothetical Dyehouse Having a Hot Water Storage Capacity of 10000 gal, a Steam Control Set Point of 30000 lb/hr, and a Boiler Capacity of 40000 lb/hr Operating Continuously for One Week

model differed in the number of dyeings completed by only 1.8%. This agreement in the number of dyeings completed provides some verification of the model's capabilities and potential usefulness. As accurate plant data becomes available, the simulation of the corresponding steam and water demands for this dyehouse should also prove successful.

V. CONCLUSIONS

The results of this investigation support the following conclusions:

1. The dyehouse model can accurately simulate the activities and decision making policies typically found in batch dyehouses dyeing synthetic fabric as demonstrated by the modeling of the hypothetical and existing dyehouses.
2. The model of the hypothetical dyehouse permits the quantitative study of the effects of manning levels, number of dye becks, pH adjustments, adds, control of steam and water demand, heat recovery, multiple dye cycles, and operating strategies on dyehouse performance.
3. Wide fluctuations in the steam and water demand in the hypothetical dyehouse can be decreased by controlling the number of dye becks being filled and the number of dye baths being heated with respect to the current level of steam consumption.
4. The recovery of cooling water in the hypothetical dyehouse for later use in filling dye becks, reduces the dyehouse demand for steam and water in addition to reducing peaks in demand.
5. The chance occurrence of such events as pH adjustments and adds in real dyehouses can be simulated by the model using the generation of random numbers to specify when and at what frequencies these events will occur during the simulation.
6. When operating six days a week, the best procedure is to begin and end each week with the dye becks empty. This minimizes the chances of off quality dyeings.

VI. RECOMMENDATIONS

The implementation of the following recommendations should increase the usefulness of the dyehouse model developed in this study:

1. In real dyehouses tangles and mechanical failures occur. The treatment of these events should be added to the computer model. Since these events occur at random, it seems likely that they could be handled in a manner analogous to pH adjustments and adds.
2. The volume, contents, and temperature of the effluent streams existing in the dyehouse should be monitored on a minute to minute basis. This information could be used in a feasibility study of heat recovery from effluent streams in a batch dyehouse.
3. Each time a floor operator loads or unloads a dye beck, or performs one of his other functions in a real dyehouse, the time required to complete the task may vary. This also holds true for the drug room operators. The model needs to be modified to treat this aspect of actual dyehouse operation, and an investigation conducted to determine what effect, if any, it has on dyehouse performance. A possible approach would be to use random numbers to vary the time required to complete the task.
4. A complete study of an existing dyehouse should be undertaken to verify the capabilities and potential of the dyehouse model. Once the model can accurately depict the existing dyehouse, simulation studies should be conducted to determine what changes in operation could improve dyehouse performance. If possible, the effects of the actual implementation of these changes should be studied, and the results compared with the outcome predicted by the model.

VII. APPENDICES

Appendix A

Description of Hypothetical Dyehouse

The hypothetical dyehouse described in this section was useful in the development of the computer model to simulate typical batch dyehouse operation. In this dyehouse, all dye becks have the same physical dimensions, use the same dye cycle, and are always loaded with the same amounts of water, chemicals, dyes, and cloth. The activities of the drug room operators and the floor operators are always completed in the time allotted for each particular job. Dyehouse operation is further simplified by assuming that tangles never occur during the dyeings and that there are never any mechanical failures of the dye becks. These simplifying assumptions pertain only to the hypothetical dyehouse and not to the capabilities of the model, which can accurately simulate these characteristics of actual dyehouse operation. The discussion of the details of this hypothetical dyehouse is broken down as follows:

1. Description of dye cycle.
2. Preparation of chemicals and dyes.
3. pH adjustments and adds.
4. Assignment of operators and dye becks.
5. Assignment of breaks.
6. Heat Recovery system.
7. Estimation of steam and water consumption.

Description of Dye Cycle. The dye cycle used to control the dyeing procedure in each dye beck of the hypothetical dyehouse is presented in Table A-I. As indicated, certain cycle steps require the services of a floor operator. In each case, the operator must be assigned to the dye beck before the cycle step can be executed. At the earliest, this assignment may be made one minute prior to the beginning of the cycle step.

The drug room is responsible for the preparation of the chemicals and dyes that are delivered to the dye beck during the execution of the dye cycle. The preparation of these chemicals and dyes may begin at or after the time a floor operator is assigned to load the dye beck. Until such an assignment is made, chemical and dye preparation may not begin, even if a drug room operator is available.

When the pH of the dye bath needs adjusting or an add must be made, the drug room is notified at the appropriate time to prepare the necessary chemicals and dyes. The details of pH adjustment and adds are treated in a later discussion.

Preparation of Chemicals and Dyes. Chemical preparation, which cannot begin until a floor operator has been assigned to load the dye beck with cloth, takes a drug room operator eight minutes. When the preparation is complete, the drug room operator signals that the chemicals have been prepared and begins preparation of the dyes. Dye

TABLE A-I. Description of the Dye Cycle Used in the Hypothetical Dyehouse

Cycle Step	Description	Time Required min	Starting Temperature °F	Stopping Temperature °F
1	Set Level #1 and Check Manual Settings. Floor Operator Required.	5	90	90
2	Fill at 100°F.	8	100	100
3	Load Cloth. Floor Operator Required.	22	100	100
4	Circulate to 160°F at 5°F/min and Deliver Chemicals.	12	100	160
5	Set Level #2 and Partially Drain.	2	160	160
6	Deliver Dye.	9	160	160
7	Check pH and Manual Settings. Floor Operator Required.	5	160	160
8	Raise Temperature to 260°F at 3°F/min.	33 33	160	260
9	Circulate at 260°F.	30	260	260
10	Lower Temperature to 150°F at 3°F/min.	36	260	150
11	Partially Drain.	1	150	150
12	Sample. Floor Operator Required.	5	150	150
13	Prepare Rinse.	1	150	150
14	Drain.	5	90	90
15	Set Level #2.	1	90	90
16	Fill at 100°F.	8	100	100
17	Circulate at 100°F.	4	100	100
18	Unload Cloth. Floor Operator Required.	20	100	100
19	Drain.	5	90	90

preparation requires sixteen minutes. Upon completing the dye preparation, the drug room operator signals that the dyes have been prepared and is then free to perform other drug room activities. Cycle Step 4 in Table A-I cannot be executed until chemical preparation has been completed. Likewise, Cycle Step 6 cannot be executed until dye preparation has been completed.

pH Adjustments and Adds. After the chemicals and dyes have been delivered to a dye beck, the pH of the dye bath is checked by a floor operator. To simulate the chance occurrence of this event, a random number is generated between 0 and 999 during Cycle Step 7. The number generated is then used to determine how many pH adjustments, if any, must be made before the dye bath pH is corrected. In the example in Table A-II, if the random number generated is between 850 and 949 inclusive, the dye bath requires one pH adjustment. If a thousand dyeings were completed, 10% would require one pH adjustment according to Table A-II. The adjustment of dye bath pH requires additional chemicals to be added to the dye bath. The preparation of these chemicals by a drug room operator takes three minutes and their delivery to the dye beck six minutes. Before the execution of the dye cycle continues, the pH is again checked to insure that the dye bath has been properly corrected.

In addition to handling the random occurrence of up to two pH adjustments to a dye bath, the model was designed

TABLE A-II. Example of the Relationship between the Random Numbers Generated from 0 to 999 and the Number of pH Adjustments Required

Range of Numbers	Number of pH Adjustments Required	Expected Frequency %
0-849	0	85
850-949	1	10
950-999	2	5

to handle up to five dye adds in a given dyeing. As with pH adjustments, random numbers are used to determine when, and at what frequency, adds are to be made in the dyehouse. Add preparation by a drum room operation requires sixteen minutes and the delivery to the dye beck requires nine minutes. Once the add has been delivered, the short add cycle of Table A-III is run in the dye beck. In this cycle, the temperature is raised to 260°F as before, but the circulation time at this temperature is reduced to fifteen minutes. These steps are then followed by the cooling and sampling dye cycle steps of the normal dye cycle. If the desired shade has been achieved, the normal dye cycle proceeds; otherwise, another add must be made.

Assignment of Operators and Dye Becks. In the hypothetical dyehouse each operator and dye beck is given a number. This number is used to identify which operator is assigned to which dye beck. Beginning with the first floor operator, each floor operator is checked until one is found that is free for assignment. Then, beginning with the first dye beck, the dye becks are checked until one is found that needs a floor operator. When a floor operator needing an assignment and a dye beck needing a floor operator are found, the pairing is made. These steps are repeated until all floor operators have been assigned one. The procedure is then repeated for the drug room operators. However, for a drug room operator to be assigned to prepare chemicals and dyes, a floor operator must already be assigned to the dye beck to load the cloth.

TABLE A-III. Add Cycle for the Dye Cycle Used in the Hypothetical Dyehouse

Cycle Step Description	Time Required min	Starting Temperature °F	Stopping Temperature °F
Circulate to 160°F at 5°F/min.	2	150	160
Set Level #2 and Partially Drain.	2	160	160
Deliver Add.	9	160	160
Check pH and Manual Settings. Floor Operator Required.	5	160	160
Raise Temperature to 260°F at 3°F/min.	33	160	260
Circulate at 260°F.	15	260	260
Lower Temperature to 150°F at 3°F/min.	36	260	260
Sample. Floor Operator Required.	5	150	150

Assignment of Breaks. Two ten minute coffee breaks and one twenty minute meal break are given to each operator during an eight hour shift in the hypothetical dyehouse. Operators may go on break after their current assignment has been completed if they are currently in a break period. During the first shift, operators begin taking their coffee breaks at 9:30 a.m. and 1:30 p.m. Their meal break can be taken beginning at 11:30 a.m. During the second shift, coffee breaks begin at 7:30 p.m. and 10:30 p.m., and the meal break at 5:30 p.m. During the third shift, coffee breaks begin at 1:30 a.m. and 3:30 a.m., and the meal break at 5:00 a.m.

Heat Recovery System. The heat recovery system of the hypothetical dyehouse is a hot water storage tank that recovers the heated cooling water used to cool the dye bath, cloth and dye beck after holding at 260°F . The water is recovered at 120°F , and later used to fill the dye becks. When used to fill the dye becks, the water recovered by the heat recovery system is mixed with fresh water at 60°F . A proper mixture of the two sources will supply the dye becks with water at 100°F . If the temperature of the mixture is below 100°F , the water is heated to the desired temperature with steam. This happens when the storage tank empties and a demand for water at 100°F remains. This demand must be met entirely with fresh water heated from 60°F to 100°F with steam. When the total storage capacity is reached, any additional water available for recovery overflows to the waste treatment system.

Estimation of Steam and Water Consumption. In order to estimate the steam and water requirements of the dye cycle used in the hypothetical dyehouse, the following assumptions were made:

1. The dye beck holds 19000 lb of water, chemicals, dyes, and cloth.
2. The dye beck contents exhibit the properties of water.
3. The dye beck is made of stainless steel and weighs 17000 lb.
4. The dye beck is three feet in diameter and is long enough to hold 19000 lb of water at 260°F.
5. The temperature in the dyehouse averages 90°F.
6. The overall heat transfer coefficient for heat lost to the surroundings is 2.0 Btu/hr-ft²-°F.
7. Instantaneous change of dye bath and dye beck temperature.

The fresh water supply to the dyehouse is at 60°F and the boiler supplies steam at 100 psia.

To hold 19000 lb of water at 260°F, the dye beck must have a volume of 324.7 ft³ and be 45.9 ft long according to the assumptions made earlier. With a three foot diameter, the dye beck has a surface area of 447 ft² exposed to the surroundings. The volume of the dye beck is calculated by the equation

$$V = \frac{M}{\rho} \quad (1)$$

where

V = volume of the dye beck, ft^3 ,
 M = mass of water contained, lb,
 ρ = density of water at 260°F , lb/ft^3 .

The length of the dye beck is calculated by the equation

$$L = \frac{V}{\pi R^2} \quad (2)$$

where

L = length of the dye beck, ft,
 V = volume of the dye beck, ft^3 ,
 R = radius of the dye beck, ft.

And the surface area of the dye beck is calculated by the equation

$$A = 2(\pi R^2) + 2\pi RL \quad (3)$$

where

A = surface area of the dye beck, ft^2 ,
 R = radius of the dye beck, ft,
 L = length of the dye beck, ft.

When a dye beck is filled with water at 100°F , steam is required to heat the stainless steel of the dye beck from 90°F to 100°F and to make up the heat losses to the surroundings. The heat required to raise the temperature of the dye beck from 90°F to 100°F can be calculated by the equation

$$Q_{ss} = M_{ss} C_{p_{ss}} \Delta T \quad (4)$$

where

Q_{ss} = heat required, Btu,

M_{ss} = mass of stainless steel, lb,

Cp_{ss} = heat capacity of stainless steel, Btu/lb-°F,

ΔT = temperature difference between the final and initial temperatures, °F.

The heat losses for each minute can be calculated by the equation

$$q_{hl} = UA\Delta T / (60.0 \text{ min/hr}) \quad (5)$$

where

q_{hl} = heat loss, Btu/min,

U = overall heat transfer coefficient, Btu/hr-°F-ft²,

A = surface area of dye beck, ft²,

ΔT = temperature difference between dye beck surface and surroundings, °F.

The minute to minute steam requirements can now be calculated by the equation

$$ST = \frac{Q_{ss}}{CT} + q_{hl} / \lambda_s \quad (6)$$

where

ST = steam required, lb/min,

CT = length of dye cycle step, min,

λ_s = heat of vaporization of steam, Btu/lb.

When the dye beck is held at a temperature above the temperature of the surroundings, steam is required to make up all heat losses. The steam required can be estimated by the equation

$$ST = q_{hl} / \lambda_s \quad (7)$$

To heat the dye beck and its contents to 160°F at 5°F/min and to 260°F at 3°F/min requires steam for heating the dye beck and dye bath in addition to making up heat losses. The heat required to raise the dye beck temperature is estimated by equation (4). The heat necessary to raise the dye bath temperature can be estimated by the similar equation

$$Q_{db} = M_{db}(H_{db,f} - H_{db,i}) \quad (8)$$

where

- Q_{db} = heat required, Btu,
- M_{db} = mass of dye bath, lb,
- $H_{db,f}$ = enthalpy of dye bath at end of cycle step, Btu/lb,
- $H_{db,i}$ = enthalpy of dye bath at beginning of cycle step, Btu/lb.

The heat loss that must be made up is estimated by the equation

$$q_{hl} = UA(T_a - T_s) / (60 \text{ min/hr}) \quad (9)$$

where

- T_a = arithmetic average of the initial and final temperature of the dye beck, °F,
- T_s = temperature of the surroundings, °F.

The steam requirements can then be calculated by the equation

$$ST = (Q_{ss}/CT + Q_{db}/CT + q_{hl}) / \lambda_s \quad (10)$$

To calculate the cooling water required to cool the dye bath and dye beck from 260°F to 150°F at 3°F/min the equation

$$CW = (Q_{db}/CT + Q_{ss}/CT + q_{hl}) / (H_{60} - H_{120}) \quad (11)$$

where

CW = water required, lb/min,

H_{60} = enthalpy of water at 60°F, Btu/lb,

H_{120} = enthalpy of water at 120°F, Btu/lb,

is used. When these equations are applied to the dye cycle in Table A-I, the steam and water requirements for each step are estimated to be the values presented in Table A-IV. Table A-IV also includes the values for the properties of water, steam, and stainless steel that were used in the calculations. The corresponding values for the add cycle can be estimated in a similar fashion.

TABLE A-IV. Steam and Water Requirements for the Dye Cycle Steps of the Dye Cycle Used in the Hypothetical Dyehouse

Cycle Step	Steam for Heat-up lb/min	Steam for Holding lb/min	Water lb/min
1	0.0	0.0	0.0
2	2.95	0.17	2375.0
3	0.0	0.17	0.0
4	119.04	0.0	0.0
5	0.0	1.18	0.0
6	0.0	1.18	0.0
7	0.0	1.18	0.0
8	75.28	0.0	0.0
9	0.0	4.39	0.0
10	0.0	0.0	967.59
11	0.0	1.1	0.0
12	0.0	1.1	0.0
13	0.0	1.1	0.0
14	0.0	0.0	0.0
15	0.0	0.0	0.0
16	2.95	0.0	2375.0
17	0.0	0.17	0.0
18	0.0	0.17	0.0
19	0.0	0.0	0.0

$$\rho_{260} = 58.52 \text{ lb/ft}^3$$

$$H_{60} = 28.06 \text{ Btu/lb}$$

$$H_{150} = 117.95 \text{ Btu/lb}$$

$$Cp_{ss} = 0.12 \text{ Btu/lb-}^{\circ}\text{F}$$

$$H_{100} = 67.97 \text{ Btu/lb}$$

$$H_{160} = 127.96 \text{ Btu/lb}$$

$$\lambda_s = 888.8 \text{ Btu/lb}$$

$$H_{120} = 87.92 \text{ Btu/lb}$$

$$H_{260} = 228.76 \text{ Btu/lb}$$

Appendix B

Instructions for Using Computer Model

The computer model developed in this study was written in FORTRAN IV and run on an IBM System 370/3033 computer. The program consists of a main program and a subroutine, RDM. The main program establishes the storage space for the problem, inputs the dyehouse's operating characteristics, simulates the dyehouse operation for a specified time period, and outputs the results in tables and Calcomp plots. Subroutine RDM is used to generate the random numbers that specify the chance occurrence of pH adjustments and adds. A listing of the main program and the subroutine is presented in Appendix C. When this program is supplied with a valid job accounting card and the sample input of Appendix D, the results in Appendix E are generated. For the Clemson University computer system, the job accounting has the format

```
//ABCDE JOB (XXXX-X-XXX-XX-X,F,G,H),'message',  
REGION=896K
```

where

ABCDE	= job prefix,
XXXX-X-XXX-XX-X	= user account number,
F	= time,
G	= lines,
H	= cards.

To execute a typical simulation run requires up to one minute of CPU time. Five thousand lines and three thousand cards of output must also be requested to handle the printout of the program, the results, and the Calcomp plots. A storage region of 896K must be requested to handle the extensive arrays of the program. To assist the user, an alphabetical listing of the program variables with their definitions can be found in Appendix F.

Dimension Requirements. The DIMENSION statements in the main program and subroutine listed in Appendix C must be specified to meet at least the minimum size requirements of the particular problem. In the dimension blocks at the beginning of the main program and SUBROUTINE RDM, the variables are currently dimensioned to handle problems having a maximum of 25 drug room operators, 25 dye becks, and 25 floor operators; ten different dye cycles each having a maximum of 50 cycle steps; 100 scheduled dyeings in each dye beck; and lasting no longer than 12000 minutes. In this section the variables containing the headings for the plots are also dimensioned and declared as integers.

Input Formats. The input required by the main program is supplied in several sections in the computer program listed in Appendix C. Using the documentation of the program, the input is supplied in the following manner:

1. ENTER DYEHOUSE DESCRIPTION.
2. ENTER PH ADJUSTMENT FREQUENCIES AND ADD FREQUENCIES IN PERCENT.
3. ENTER CONSTANTS TO GENERATE RANDOM SEQUENCE OF NUMBERS THAT DETERMINE IF A PH ADJUSTMENT OR AN ADD NEEDS TO BE MADE.
4. ENTER OPERATING VARIABLES TO SPECIFY PROCEDURES.
5. SPECIFY VARIABLES RELATED TO HEAT RECOVERY SYSTEM.
6. SPECIFY THE TIME DURING THE RUN WHEN NO MACHINES (BECKS) ARE TO BEGIN A NEW DYE CYCLE. SPECIFY WHETHER MACHINE (BECK) IS TO BE HELD BEFORE OR AFTER IT HAS BEEN REFILLED AND RELOADED.
7. INPUT HEADINGS FOR PLOTS.
8. INPUT DYEING SCHEDULE.
9. INPUT DYE CYCLE VARIABLES.

The input supplied in these sections must be in the same order and fit the format of the input cards described in Table B-I. For assistance in specifying input in the first eight sections, the user should refer to the program documentation and the definitions of the program variables in addition to Table B-I. When IA(1), IA(2), IB(1), and IB(2) are being supplied, the user must be certain that IA(1) and IA(2) be from the sequence 1,21,41,61..., and that IB(1) and IB(2) be from the sequence 1,3,7,9,11,13,17,19... This insures that the equations of SUBROUTINE RDM generate a complete sequence of random numbers (12). Special treatment will be given to the input of the dye cycle variables.

Input of Dye Cycle Variables. The specification of dye cycle variables requires more assistance than Table B-I or the program documentation has to offer. To provide the

TABLE B-I. Formatted Input of Dyehouse Parameters

Card Type	Format	Contents
ENTER DYEHOUSE DESCRIPTION.		
1	9I5	ND,NF,NM,ITF
ENTER PH ADJUSTMENT FREQUENCIES AND ADD FREQUENCIES IN PERCENT.		
2	6F6.2	PHF0,PHF1,PHF2
3	6F6.2	AFO,AF1,AF2,AF3,AF4,AF5
ENTER CONSTANTS TO GENERATE RANDOM SEQUENCE OF NUMBERS THAT DETERMINE IF A PH ADJUSTMENT OR AN ADD NEEDS TO BE MADE.		
4	9I5	IA(1),IB(1),IC(1)
5	9I5	IN(1),IX(1)
6	9I5	IA(2),IB(2),IC(2)
7	9I5	IN(2),IX(2)
ENTER OPERATING VARIABLES TO SPECIFY PROCEDURES.		
8	9I5	JBT1,JBT2,JBT3
9	9I5	(NBT(I),I=1,9)
10	9I5	(NRTL(I),I=1,9)
SPECIFY VARIABLES RELATED TO HEAT RECOVERY SYSTEM.		
11	4F12.5	STL,SW(1),SLEV,PSLEV
12	9I5	NMF,NMH,NMT
13	4F12.5	TMP1,ENDCW
14	4F12.5	TEMP2,ENSTW,SVOL
15	4F12.5	TMPS,HVAP,STMPRS
16	4F12.5	BCAP
SPECIFY THE TIME DURING THE RUN WHEN NO MACHINES (BECKS) ARE TO BEGIN A NEW DYE CYCLE. SPECIFY WHETHER MACHINE (BECK) IS TO BE HELD BEFORE OR AFTER IT HAS BEEN REFILLED AND RELOADED.		
17	9I5	IWE,IHF
INPUT HEADINGS FOR PLOTS.		
18	9I5	XH1
19	9I5	YH1
20	9I5	XH2
21	9I5	YH2
22	9I5	XH3
23	9I5	YH3

TABLE B-I. (Continued)

Card Type	Format	Contents
INPUT DYEING SCHEDULE.		
24	I2	NDSCH
25	25I2	(ISCHD(I,I1),I1=1,NDCSH)
(NDSCH/25 cards of this type for each dye machine, I = 1,NM.)		
INPUT DYE CYCLE VARIABLES.		
26	I3	NDCU
27	11I3	ICSN(I), (IPRP(I,I1),I1=1,6), ID1(I), ID2(I), ID3(I), ID4(I)
28	16I1,3I3,3F8.2	NDC1(I,I1),NDC2(I,I1),NDC3(I,I1),NDC4(I,I1), NDC5(I,I1),NDC6(I,I1),NDC7(I,I1),NDC8(I,I1), NDC9(I,I1),NDC10(I,I1),NDC11(I,I1),NDC12(I,I1), NDC13(I,I1),NDC14(I,I1),NDC15(I,I1),JBDR(I,I1), L1(I,I1),L2(I,I1),L3(I,I1),S1(I,I1),S2(I,I1), C1(I,I1)
(One card of this type for every dye cycle step in dye cycle I, I1 = 1,ICSN(I).)		
29	3F8.2,3I5	F1(I,I1),RN1(I,I1),E1(I,I1),FTS(I,I1),ITE(I,I1), ITH(I,I1)
(One card of this type for every dye cycle step in the dye cycle I, I1 = 1,ICSN(I).)		

user with a better understanding of how the variables are supplied, the dye cycle of the hypothetical dyehouse in Appendix A is used for illustration. For this situation, the cycle steps required to adjust the dye bath pH and make adds are included. Table B-II presents the dye cycle of Appendix A in an expanded form. Unlike Table A-I, Table B-II includes the cycle steps that treat pH adjustments and adds. In this form, there are 27 different cycle steps; $ICSN(I) = 27$. As noted previously for this dye cycle, sixteen minutes are required to prepare the dyes for an add; $IPRP(I,1) = 16$. The chemicals are prepared in eight minutes; $IPRP(I,2) = 8$. The dyes are prepared in sixteen minutes; $IPRP(I,3) = 16$. Three minutes are required to prepare the chemicals for a pH adjustment; $IPRP(I,4) = 3$. No salts are prepared; $IPRP(I,5) = 0$. And the combined preparation of dyes and chemicals requires twenty-four minutes; $IPRP(I,6) = 24$. If no pH adjustment is required when the pH is checked in Cycle Step 7, then the next cycle step to be executed is Cycle Step 9. To skip Cycle Step 8, $ID1(I)$ must be equal to 1. The value of $ID1(I)$ can be calculated from the equation

$$ID1(I) = CS - CS_{pH} + 1 \quad (12)$$

where

CS = cycle step executed after the pH has been checked when no pH adjustment is required,

CS_{pH} = cycle step in which pH is checked.

TABLE B-II. Dye Cycle Used in Hypothetical Dyehouse Expanded to Include pH Adjustments and Adds

Cycle Step	Description	Time Required min	Starting Temperature °F	Stopping Temperature °F
1	Set Level #1 and Check Manual Settings. Floor Operator Required.	5	90	90
2	Fill at 100°F.	8	100	100
3	Load Cloth. Floor Operator Required.	22	100	100
4	Circulate to 160°F at 5°F/min and Deliver Chemicals.	12	100	160
5	Set Level #2 and Partially Drain.	2	160	160
6	Deliver Dye.	9	160	160
7	Check pH and Manual Settings. Floor Operator Required.	5	160	160
8	Deliver Chemicals to Adjust pH.	6	160	160
9	Raise Temperature to 260°F at 3°F/min.	33	160	260
10	Circulate at 260°F.	30	260	260
11	Lower Temperature to 150°F at 3°F/min.	36	260	150
12	Partially Drain.	1	150	150
13	Sample. Floor Operator Required.	5	150	150
14	Circulate to 160°F at 5°F/min.	2	150	160
15	Set Level #2 and Partially Drain.	2	160	160
16	Deliver Add.	9	160	160
17	Check pH and Manual Settings. Floor Operator Required.	5	160	160

TABLE B-II. (Continued)

Cycle Step	Description	Time Required min	Starting Temperature °F	Stopping Temperature °F
18	Deliver Chemicals to Adjust pH.	3	160	160
19	Raise Temperature to 260°F at 3°F/min.	33	160	260
20	Circulate at 260°F	15	260	260
21	Prepare Rinse.	1	150	150
22	Drain.	5	90	90
23	Set Level #2.	1	90	90
24	Fill at 100°F.	8	100	100
25	Circulate at 100°F.	4	100	100
26	Unload Cloth. Floor Operator Required.	20	100	100
27	Drain.	5	90	90

When the pH is corrected in Cycle Step 8, ID2(I) must be equal to 2 if the dye bath pH is to be checked again. The value of ID2(I) can be calculated by the equation

$$ID2(I) = CS - CS_b \quad (13)$$

where

CS = cycle step where pH adjustment is completed,

CS_b = cycle step before the cycle step in which the pH is checked.

ID3(I) causes the model to skip the cycle steps that make an add and ID4(I) causes the model to return to the sample dye cycle step after an add is complete. For the dye cycle presented here, ID3(I) = 7 and ID4(I) = 10. The value of ID3(I) can be calculated by the equation

$$ID3(I) = CS - CS_s \quad (14)$$

where

CS = cycle step executed after the sampling step when no add must be made,

CS_s = cycle step when dyeing is sampled.

The value of ID4(I) is calculated by the equation

$$ID4(I) = CS - CS_c \quad (15)$$

where

CS = circulation cycle step of the add cycle,

CS_c = circulation cycle step of the normal dye cycle.

The values of these variables supply the input for Card Type 27.

Table B-III presents the values of NDC1 through NDC15, JBDR, L1, L2, and L3 for all of the dye cycle steps of the dye cycle presented in Table B-II. The remaining variables that must be supplied in Card Type 28 and Card Type 29 are determined in the manner discussed in Appendix A. Therefore, they are omitted in this discussion. The values of NDC1 through NDC15 can quickly be determined by answering the following questions for each cycle step in Table B-II; 1 equals yes and 0 equals no.

1. Does this cycle step require a floor operator?
(NDC1)
2. Does this cycle step require dyes for an add?
(NDC2)
3. Does this cycle step require chemicals? (NDC3)
4. Does this cycle step require dyes? (NDC4)
5. Does this cycle step require chemicals for a pH adjustment? (NDC5)
6. Does this cycle step require salts? (NDC6)
7. Does the drug room need signaling during this step? (NDC7)
8. Does the next cycle step require a floor operator?
(NDC8)
9. Are pH adjustments made in the next cycle step?
(NDC9)
10. Are pH adjustments completed in this cycle step?
(NDC10)
11. Are adds begun in the next cycle step? (NDC11)
12. Are adds completed in this cycle step? (NDC12)
13. Is this the last cycle step of the dye cycle?
(NDC13)

14. Can dye cycle hold at beginning of this cycle step? (NDC14)

15. Is dye beck loaded and filled at end of this cycle step? (NDC15)

The answers to these fifteen questions correspond to the respective values of NDC1 through NDC15. Note that an add is considered complete in the dye cycle presented in Table B-II when the circulation at the dyeing temperature for the add cycle has finished. The cool down step and sample step for the add is the same as that used in the normal dye cycle. By declaring the circulation step as the final cycle step of the add and returning to the normal cool down step, repetition of cycle steps is avoided. The add could be handled just effectively by using all of the add steps even though it would be repetitious.

Whenever question 7 is answered affirmatively (NDC7 = 1), JBDR must be given a value in the same cycle step of 1 to 6 to specify which job will be performed in the drug room when the drug room operator has been assigned. The values of JBDR have the following significance:

1. JBDR = 1, prepare add.
2. JBDR = 2, prepare chemicals.
3. JBDR = 3, prepare dyes.
4. JBDR = 4, prepare pH adjustment.
5. JBDR = 5, prepare salts.
6. JBDR = 6, prepare chemicals and dyes.

TABLE B-III. Input Parameters for the Dye Cycle Used in the Hypothetical Dyehouse

Cycle Step	NDC1	NDC2	NDC3	NDC4	NDC5	NDC6	NDC7	NDC8	NDC9	NDC10	NDC11	NDC12	NDC13	NDC14	NDC15	JBDR	L1	L2	L3
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
2	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	6	8	7	7
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	22	0	0
4	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	12	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
6	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	9	8	0
7	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	4	5	0	0
8	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	6	5	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	33	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0
11	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	36	36	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
13	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	5	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
16	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	9	8	0
17	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	4	5	0	0
18	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	6	5	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	33	0	0
20	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	15	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	8	0	0
25	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	4	3	0
26	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	5	4	0

The variable L1 specifies how long the cycle step takes, and the variables L2 and L3 specify when during the cycle step the need for a floor operator or a drug room operator respectively is expressed. When this need is expressed, one minute is allowed for the assignment to be made.

In Cycle Step 7, Cycle Step 13, and Cycle Step 17 JBDR has a value when NDC7 equals zero, which does not conform with the earlier discussion. In the mentioned cycle steps, the pH is checked and samples are taken. When the pH needs adjusting, a drug room operator must be assigned to prepare the chemicals. Likewise, to prepare an add a drug room operator is needed. In order to avoid any confusion, the seventh question should be restated in the following way. Does the drug room need signaling in this cycle step. If so, and if the assignment is to prepare chemicals or dyes for a pH adjustment or an add, NDC7 is set equal to zero and JBDR is given the appropriate value. If NDC7 were set equal to one, the drug room would be signaled even during the times when no pH adjustments or adds were required. In the above approach, the drug room is signaled only when a pH adjustment or an add is to be made.

One final exception is found in Cycle Step 27. The variable L2 is given a value one minute less than L1 so that the floor operator needed in the first cycle step of the next dye cycle can be assigned, if available, during the last minute of operation of the current dye cycle. If the drug

room needed to be signaled for the first cycle step of the next dye cycle, L3 would have a similar value. For this situation, NDC7 would equal 1 and JBDR would have the appropriate value.

Summary of User Requirements. The user must do the following to successfully use the computer model developed in this study:

1. Completely define the dyehouse to be simulated.
2. Specify the job accounting including the account number, time, lines, cards, and space.
3. Dimension variables to meet the requirements of the problem being studied.
4. Specify all variables to be supplied as input.

When the user has supplied the appropriate information, the model will generate output like that presented in Appendix E. The output of Appendix E corresponds to the simulation of the dyehouse described by the sample input of Appendix D.

Appendix CComputer Model of Batch Dyehouse

The computer program presented in this appendix was developed to simulate the activities found in typical batch dyehouses.

```
//STEP1 EXEC FTG1CLG
//C.SYSIN DD *
```

DYEHOUSE SIMULATION

THIS PROGRAM SIMULATES THE MINUTE TO MINUTE OPERATION IN A HYPOTHETICAL BATCH DYEHOUSE. BY MODELING THE ACTIVITIES TYPICALLY FOUND IN BATCH DYEHOUSES, INSIGHT INTO THE RELATIONSHIPS BETWEEN PRODUCTIVITY, MANPOWER UTILIZATION, WATER CONSUMPTION, AND ENERGY CONSUMPTION CAN BE GAINED. THIS INSIGHT SHOULD BE VERY USEFUL IN DETERMINING GUIDELINES FOR MORE ENERGY EFFICIENT AND MORE ECONOMICAL DYEHOUSE OPERATION.

DIMENSION VARIABLES AND DECLARE TYPE IF NECESSARY.

```
DIMENSION IA(25),IB(25),IC(25),IN(25),IX(25),NBT(25)
DIMENSION NBT1(25),IDT(25),NF2(25),IBF2(25),IBC2(25)
DIMENSION IFT(25),NF1(25),NF5(25),IBF1(25),IBC1(25)
DIMENSION NSCH(25),IMT(25),NDY(25),NF3(25),NF4(25)
DIMENSION K(25),KK(25),MF(25),NPH(25),NCPH(25)
DIMENSION IAD(25),NAD(25),NF6(25),IP(25),MWT(25)
DIMENSION ICSTP(25),INT(25),NA(25),NC(25),NPA(25)
DIMENSION NSLT(25),ICSTC(25),STM(25),CW(25),FW(25)
DIMENSION EN(25),RW(25),NTMP(25),MC(25),IHD(25)
DIMENSION ITM(25,2000),ITMP(25,2000)
DIMENSION ICSN(10),ID1(10),ID2(10),ID3(10),ID4(10)
DIMENSION JBPRP(25),IHN(25),IHDC(25,100)
DIMENSION IHTS(25,100),IHTE(25,100),IHADD(25,100)
DIMENSION ISCHD(25,100),IPRP(10,50),NDC1(10,50),
#NDC2(10,50)
DIMENSION NDC3(10,50),NDC4(10,50),NDC5(10,50),
#NDC6(10,50)
DIMENSION NDC7(10,50),NDC8(10,50),NDC9(10,50),
#NDC10(10,50)
```

```

DIMENSION NDC11(10,50),NDC12(10,50),NDC13(10,50),
#NDC14(10,50)
DIMENSION L1(10,50),L2(10,50),L3(10,50),S1(10,50),
#S2(10,50)
DIMENSION C1(10,50),F1(10,50),RN1(10,50),E1(10,50)
DIMENSION JBDR(10,50),ITS(10,50),ITE(10,50),
#ITH(10,50),NDC15(10,50)
DIMENSION SW(12000),SA(12000),CA(12000),DFW(12000)
DIMENSION X(12000),Y(12000),Z(4)
INTEGER*4 XH1(5),YH1(5),XH2(5),YH2(5),XH3(5),YH3(5)

```

ENTER DYEHOUSE DESCRIPTION

1. ND - NUMBER OF DRUG ROOM OPERATORS.
 2. NF - NUMBER OF FLOOR OPERATORS.
 3. NM - NUMBER OF DYE MACHINES.
 4. ITF - LENGTH OF SIMULATION, MIN.
-

```

READ(1,8001) ND,NF,NM,ITF

```

ENTER PH ADJUSTMENT FREQUENCIES AND ADD FREQUENCIES IN PERCENT.

```

READ(1,8002) PHF0,PHF1,PHF2
READ(1,8002) AFO,AF1,AF2,AF3,AF4,AF5

```

<----- CONVERT PERCENTAGES TO CORRESPONDING INTEGERS
IN SEQUENCE OF NUMBERS BETWEEN 0 AND 999.

```

R1 = 1000.0 - 10.0*PHF0
R2 = 1000.0 - 10.0*(PHF0 + PHF1)
A1 = 1000.0 - 10.0*AFO
A2 = 1000.0 - 10.0*(AFO + AF1)
A3 = A2 - 10.0*AF2
A4 = A3 - 10.0*AF3
A5 = A4 - 10.0*AF4
NR1 = R1
NR2 = R2

```

NA1 = A1
 NA2 = A2
 NA3 = A3
 NA4 = A4
 NA5 = A5

C
 C
 C-----
 C
 C
 C
 C
 C
 C
 C-----
 C
 C

ENTER CONSTANTS TO GENERATE RANDOM SEQUENCE OF NUMBERS
 THAT DETERMINE IF A PH ADJUSTMENT OR AN ADD NEEDS TO
 BE MADE.

DO 10 I = 1,2
 READ(1,8001) IA(I),IB(I),IC(I)
 READ(1,8001) IN(I),IX(I)
 10 CONTINUE

C
 C
 C

<----- SAVE THE INITIAL VALUES OF THESE CONSTANTS.

IA1 = IA(1)
 IA2 = IA(2)
 IBB1 = IB(1)
 IB2 = IB(2)
 IC1 = IC(1)
 IC2 = IC(2)
 IN1 = IN(1)
 IN2 = IN(2)
 IX1 = IX(1)
 IX2 = IX(2)

C
 C
 C-----
 C
 C
 C
 C
 C
 C
 C
 C
 C
 C
 C
 C

ENTER OPERATING VARIABLES TO SPECIFY PROCEDURES.

1. JBT1 = 1 OPERATORS GO ON BREAKS WHEN FREE
DURING EACH BREAK PERIOD.

JBT1 = 2 OPERATORS ARE GIVEN NO BREAKS.

2. JBT2 = 1 DOWN-THE-LINE ASSIGNMENTS OF MEN
AND MACHINES.

3. JBT3 = 1 PRINTOUT OF TABLES.

JBT3 = 2 PRINTOUT OF TABLES AND PLOTS.

4. NBT(I) - TIME WHEN BREAKS OCCUR DURING THE DAY.

NBTL(I) - LENGTH OF A BREAK PERIOD.

READ(1,8001) JBT1,JBT2,JBT3
 READ(1,8001) (NBT(I),I=1,9)
 READ(1,8001) (NBTL(I),I=1,9)

SPECIFY VARIABLES RELATED TO HEAT RECOVERY SYSTEM.

1. STL - MAXIMUM VOLUME OF STORAGE TANK, GAL.
2. SW(1) - INITIAL VOLUME OF HOT WATER IN STORAGE TANK, GAL.
3. SLEV - LEVEL OF STEAM CONSUMPTION ABOVE WHICH NO MACHINES MAY BEGIN A FILL-UP OR A HEAT-UP CYCLE, LB STEAM/HR.
4. FSLEV - LEVEL OF STEAM CONSUMPTION ABOVE WHICH NO MORE THAN NMT MACHINES MAY BEGIN A PART OF THE DYE CYCLE THAT REQUIRES A LARGE QUANTITY OF STEAM, LB STEAM/HR.
5. NMF - NUMBER OF MACHINES THAT MAY BEGIN FILLING DURING THE SAME MINUTE.
6. NMH - NUMBER OF MACHINES THAT MAY BEGIN A HEAT-UP CYCLE DURING THE SAME MINUTE.
7. NMT - NUMBER OF MACHINES THAT MAY BEGIN FILLING OR HEATING WHEN STEAM CONSUMPTION IS ABOVE FSLEV.
8. TMP1 - TEMPERATURE OF FRESH WATER, DEG. F.
 ENCDW - ENTHALPY OF FRESH WATER AT TMP1, BTU/LB.
9. TMP2 - TEMPERATURE OF WATER IN STORAGE TANK, DEG. F.
 ENSTW - ENTHALPY OF STORED WATER AT "TMP2", BTU/LB.

SVOL - CUBIC FEET PER POUND OF WATER AT
"TMP2".

10. TMPS - TEMPERATURE OF AVAILABLE STEAM,
DEG. F.

HVAP - HEAT OF VAPORIZATION AT TMPS, BTU/LB.

11. BCAP - BOILER CAPACITY, LB STEAM/HR.

READ(1,8003) STL,SW(1),SLEV,FSLEV
READ(1,8001) NMF,NMH,NMT
READ(1,8003) TMP1,ENCDW
READ(1,8003) TMP2,ENSTW,SVOL
READ(1,8003) TMPS,HVAP,STMPRS
READ(1,8003) BCAP

<----- CONVERT STL AND SW(1) FROM GALLONS TO POUNDS
AT "TMP2".

STL = (STL/7.48)/SVOL
SW(1) = (SW(1)/7.48)/SVOL

SPECIFY THE TIME DURING THE RUN WHEN NO MACHINES ARE
TO BEGIN A NEW DYE CYCLE. SPECIFY WHETHER MACHINE IS
TO BE HELD BEFORE OR AFTER IT HAS BEEN REFILLED AND
RELOADED.

IWE = ITF, CONTINUOUS OPERATION.

< ITF, NON-CONTINUOUS OPERATION, HOLD AT IWE.

IHF = 1, HOLD BEFORE REFILLING AND RELOADING.

= 2, HOLD AFTER REFILLING AND RELOADING.

READ(1,8001) IWE,IHF

C
C
C
C INPUT HEADINGS FOR PLOTS
C
C

C
C

```

      READ(1,8004) XH1
      READ(1,8004) YH1
      READ(1,8004) XH2
      READ(1,8004) YH2
      READ(1,8004) XH3
      READ(1,8004) YH3

```

C
C
C
C INPUT DYEING SCHEDULE
C
C

C
C

```

      READ(1,8005) NDSCH
      DO 20 I = 1,NM
      READ(1,8006) (ISCHD(I,I1),I1=1,NDSCH)
20  CONTINUE

```

C
C
C
C INPUT DYE CYCLE VARIABLES
C
C

C
C

```

      READ(1,8007) NDCU
      DO 40 I = 1,NDCU
      READ(1,8008) ICSN(I),(IPRP(I,I1),I1=1,6),ID1(I),
#ID2(I),ID3(I),ID4(I)
      NN = ICSN(I)
      DO 30 I1 = 1,NN
      READ(1,8009) NDC1(I,I1),NDC2(I,I1),NDC3(I,I1),
#NDC4(I,I1),NDC5(I,I1),NDC6(I,I1),NDC7(I,I1),
#NDC8(I,I1),NDC9(I,I1),
#NDC10(I,I1),NDC11(I,I1),NDC12(I,I1),NDC13(I,I1),
#NDC14(I,I1),NDC15(I,I1),JBDR(I,I1),L1(I,I1),L2(I,I1),
#L3(I,I1),S1(I,I1),S2(I,I1),C1(I,I1)
30  CONTINUE

```

```

      DO 35 I1 = 1,NN
      READ(1,8084) F1(I,I1),RN1(I,I1),E1(I,I1),ITS(I,I1),
#ITE(I,I1),ITH(I,I1)
8084  FORMAT(3F8.2,3I5)
      35  CONTINUE
      40  CONTINUE

```

C

C

C-----

C

C

```

8001  FORMAT(9I5)
8002  FORMAT(6F6.2)
8003  FORMAT(4F12.5)
8004  FORMAT(5A4)
8005  FORMAT(I2)
8006  FORMAT(25I2)
8007  FORMAT(I3)
8008  FORMAT(11I3)
8009  FORMAT(16I1,3I3,3F8.2)

```

C

C

C-----

C

C

C

ESTABLISH START-UP CONDITIONS.

C

C

C-----

C

C

```

      DO 50 I = 1,ND
      IDT(I) = 0
      NF2(I) = 1
      NF6(I) = 0
      IBF2(I) = 0
      IBC2(I) = 0
50  CONTINUE
      DO 60 I = 1,NF
      IFT(I) = 0
      NF1(I) = 1
      NF5(I) = 0
      IBF1(I) = 0
      IBC1(I) = 0
60  CONTINUE
      DO 70 I = 1,NM
      IHD(I) = 0
      NSCH(I) = 1
      MWT(I) = 0
      NA(I) = 0
      NC(I) = 0
      NPA(I) = 0
      NSLT(I) = 0
      ICSTP(I) = 1

```

```

ICSTC(I) = 0
INT(I) = 0
IMT(I) = 0
NDY(I) = 0
NF3(I) = 1
NF4(I) = 0
K(I) = 0
KK(I) = 0
MF(I) = 0
NPH(I) = 0
NCPH(I) = 0
IAD(I) = 0
NAD(I) = 0
NTMP(I) = 1
ITM(I,1) = 0.0
ITMP(I,1) = 0.0
IHN(I) = 0
70  CONTINUE
    STW = SW(1)
    OFWT = 0.0
    IT = 0
    IPHO = 0
    IPH1 = 0
    IPH2 = 0
    IADO = 0
    IAD1 = 0
    IAD2 = 0
    IAD3 = 0
    IAD4 = 0
    IAD5 = 0
    IBT = 960
    NBF = 0
    NBD = 0
    IB1 = 0
    STTS = 0.0
    CTTS = 0.0
    NLDS = 0
    NCYS = 0
    IBCAP = 0

```

```

C
C
C-----
C
C
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C-----
C
C
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C
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C
C
C
C
C

```

```

EXECUTE ONE MINUTE OF SIMULATION.

```

```

C----- INCREMENT TIME COUNTERS.

```

```

80  IT = IT + 1
    IF (IBT.EQ.1440) IBT = 0

```

```

      IBT = IBT + 1
C
C <----- BREAK OPERATORS
C
      IF(JBT1.EQ.2) GO TO 2000
C
C CASE 1: ALL OPERATORS ARE GIVEN BREAKS ACCORDING TO
C THE FOLLOWING SCHEME:
C 1. BREAK PERIOD BEGINS.
C 2. OPERATOR GOES ON BREAK WHEN FREE.
C
      JB = 1
1010 IF(IBT.EQ.NBT(JB)) GO TO 1020
      IF(JB.EQ.9) GO TO 1030
      JB = JB + 1
      GO TO 1010
1020 IB1 = JB
1030 IF(IB1.EQ.0) GO TO 2000
      IF(NBF.EQ.NF) GO TO 1070
      NBF = 0
      DO 1060 I = 1,NF
      IF(NF1(I).NE.1) GO TO 1040
      IF(IBC1(I).EQ.1) GO TO 1050
      NF1(I) = 3
      IBC1(I) = 0
1040 IF(NF1(I).NE.3) GO TO 1050
      IBC1(I) = IBC1(I) + 1
      IF(IBC1(I).NE.NBTL(IB1)) GO TO 1050
      IBF1(I) = 1
      NF5(I) = 1
1050 IF(IBC1(I).EQ.1) NBF = NBF + 1
1060 CONTINUE
1070 IF(NBD.EQ.ND) GO TO 1110
      NBD = 0
      DO 1100 I = 1,ND
      IF(NF2(I).NE.1) GO TO 1080
      IF(IBC2(I).EQ.1) GO TO 1090
      NF2(I) = 3
      IBC2(I) = 0
1080 IF(NF2(I).NE.3) GO TO 1090
      IBC2(I) = IBC2(I) + 1
      IF(IBC2(I).NE.NBTL(IB1)) GO TO 1090
      IBF2(I) = 1
      NF6(I) = 1
1090 IF(IBC2(I).EQ.1) NBD = NBD + 1
1100 CONTINUE
1110 N1 = NBF + NBD
      N2 = NF + ND
      IF(N1.NE.N2) GO TO 2000
      IB1 = 0
      NBF = 0
      NBD = 0
      DO 1120 I = 1,NF
      IBF1(I) = 0

```

```

1120  CONTINUE
      DO 1130 I = 1,ND
      IBF2(I) = 0
1130  CONTINUE
2000  CONTINUE
C
C      <----- ASSIGN OPERATORS AND MACHINES.
C
      IF(JBT2.EQ.2) GO TO 3000
C
C      CASE 1:  DOWN-THE-LINE ASSIGNMENT WITH NO PRIORITY
C               GIVEN TO EITHER LOADING OR UNLOADING.
C
      JM = 0
2010  JM = JM + 1
      IF(JM.GT.NM) GO TO 2030
      IF(NF3(JM).EQ.0) GO TO 2010
      JF = 0
2020  JF = JF + 1
      IF(JF.GT.NF) GO TO 2030
      IF(NF1(JF).NE.1) GO TO 2020
      MF(JM) = JF
      NF1(JF) = 0
      NF3(JM) = 0
      GO TO 2010
2030  JM = 0
2040  JM = JM + 1
      IF(JM.GT.NM) GO TO 2100
      IF(NF4(JM).EQ.0) GO TO 2040
      IF(NF3(JM).EQ.1) GO TO 2040
      I1 = NSCH(JM)
      IDC = ISCHD(JM,I1)
      IF(IDC.EQ.0) GO TO 2040
      IF(KK(JM).EQ.0) GO TO 2080
      IP(JM) = IP(JM) + 1
      IF(NF4(JM).LT.6) GO TO 2050
      IF(IP(JM).EQ.IPRP(IDC,2)) GO TO 2060
      IF(IP(JM).EQ.IPRP(IDC,6)) GO TO 2070
2050  I1 = NF4(JM)
      IF(IP(JM).EQ.IPRP(IDC,I1)) JBPRP(JM) = NF4(JM)
      GO TO 2040
2060  JBPRP(JM) = 2
      GO TO 2040
2070  JBPRP(JM) = 3
      GO TO 2040
2080  JD = 0
2090  JD = JD + 1
      IF(JD.GT.ND) GO TO 2040
      IF(NF2(JD).NE.1) GO TO 2090
      KK(JM) = JD
      NF2(JD) = 0
      IP(JM) = 0
      GO TO 2040
2100  CONTINUE

```

```

3000 CONTINUE
C
C <----- CONTROL STEAM CONSUMPTION.
C
      FWRQ = 0.0
      DO 3001 I = 1,NM
      IF(INT(I).EQ.0) GO TO 3001
      I1 = NSCH(I)
      IDC = ISCHD(I,I1)
      ICS = ICSTP(I)
      IF(IDC.EQ.0) GO TO 3001
      LL = L1(IDC,ICS) - ICSTC(I)
      FWRQ = FWRQ + LL*F1(IDC,ICS)
3001 CONTINUE
      JMF = 0
      JMH = 0
      JMT = 0
      DO 3006 I = 1,NM
      IF(INT(I).EQ.1) GO TO 3006
      I1 = NSCH(I)
      IDC = ISCHD(I,I1)
      ICS = ICSTP(I)
      IF(IDC.EQ.0) GO TO 3006
      IF(NDC14(IDC,ICS).EQ.0) GO TO 3006
      IF(SA(IT).GE.SLEV) GO TO 3005
      IF(SA(IT).LT.FSLEV) GO TO 3002
      IF(JMT.GE.NMT) GO TO 3005
      JMT = JMT + 1
      GO TO 3006
3002 IF(F1(IDC,ICS).GT.0.0) GO TO 3003
      IF(JMH.GE.NMH) GO TO 3003
      JMH = JMH + 1
      GO TO 3006
3003 IF(STW.EQ.0.0) GO TO 3004
      IF(STW.GE.FWRQ) GO TO 3004
      GO TO 3005
3004 IF(JMF.GE.NMF) GO TO 3005
      JMF = JMF + 1
      GO TO 3006
3005 INT(I) = 2
3006 CONTINUE
C
C <----- TREATMENT OF DYE CYCLE.
C
      DO 3250 I = 1,NM
      I1 = NSCH(I)
      IDC = ISCHD(I,I1)
      IF(IDC.GT.0) GO TO 3010
      MWT(I) = 1
      IK = NTMP(I)
      IF(ITMP(I,IK-1).EQ.0) ITM(I,IK) = IT
      IF(ITMP(I,IK-1).EQ.0) GO TO 3250
      IK = IK + 1
      NTMP(I) = IK

```



```

      ITM(I,IK) = IT
      ITMP(I,IK) = 0
      IF(IT.GE.IWE) IHD(I) = 1
      GO TO 3250
3010  ICS = ICSTP(I)
      IF(IHD(I).EQ.1) GO TO 3240
      IF(INT(I).NE.0) GO TO 3080
      IF(NDC1(IDC,ICS).EQ.0) GO TO 3020
      IF(K(I).GT.0) GO TO 3020
      IF(MF(I).EQ.0) GO TO 3240
      K(I) = MF(I)
      GO TO 3240
3020  IF(NDC2(IDC,ICS).EQ.0) GO TO 3030
      IF(NA(I).EQ.0) GO TO 3240
      NA(I) = 0
3030  IF(NDC3(IDC,ICS).EQ.0) GO TO 3040
      IF(NC(I).EQ.0) GO TO 3240
      NC(I) = 0
3040  IF(NDC4(IDC,ICS).EQ.0) GO TO 3050
      IF(NDY(I).EQ.0) GO TO 3240
      NDY(I) = 0
3050  IF(NDC5(IDC,ICS).EQ.0) GO TO 3060
      IF(NPA(I).EQ.0) GO TO 3240
      NPA(I) = 0
3060  IF(NDC6(IDC,ICS).EQ.0) GO TO 3070
      IF(NSLT(I).EQ.0) GO TO 3240
      NSLT(I) = 0
3070  INT(I) = 1
      IF(ICS.GT.1) GO TO 3080
      J = IHN(I) + 1
      IHN(I) = J
      IHDC(I,J) = IDC
      IHTS(I,J) = IT
3080  IF(INT(I).NE.2) GO TO 3090
      INT(I) = 0
      GO TO 3240
3090  ICSTC(I) = ICSTC(I) + 1
      STM(I) = S1(IDC,ICS)
      CW(I) = C1(IDC,ICS)
      FW(I) = F1(IDC,ICS)
      EN(I) = E1(IDC,ICS)
      RW(I) = RN1(IDC,ICS)
      IF(ICSTC(I).GT.1) GO TO 3091
      IK = NTMP(I) + 1
      NTMP(I) = IK
      ITM(I,IK) = IT
      ITMP(I,IK) = ITS(IDC,ICS)
3091  MC(I) = 1
      IF(MF(I).GT.0) K(I) = MF(I)
      IF(NDC7(IDC,ICS).EQ.0) GO TO 3095
      IF(IHD(I).EQ.2) GO TO 3095
      IF(ICSTC(I).NE.L3(IDC,ICS)) GO TO 3095
      NF4(I) = JBDR(IDC,ICS)
3095  IF(NDC8(IDC,ICS).EQ.0) GO TO 3100

```

```

      IF(ICSTC(I).NE.L2(IDC,ICS)) GO TO 3100
      NF3(I) = 1
3100  IF(ICSTC(I).EQ.L1(IDC,ICS)) GO TO 3110
      IF(NDC13(IDC,ICS).EQ.0) GO TO 3250
      I1 = NSCH(I) + 1
      IDC = ISCHD(I,I1)
      IF(NDC1(IDC,I).EQ.0) GO TO 3250
      I1 = NSCH(I)
      IDC = ISCHD(I,I1)
      ICS = ICSTP(I)
      IF(ICSTC(I).EQ.L2(IDC,ICS)) NF3(I) = 1
      IF(IHF.EQ.2) GO TO 3250
      IF(IT.GT.IWE) NF3(I) = 0
      GO TO 3250
3110  IF(NDC9(IDC,ICS).EQ.0) GO TO 3150
      IF(NPH(I).GT.0) GO TO 3130
      CALL RDM(1,IA,IB,IC,IN,IX,IX3)
      NPH(I) = 0
      IF(IX3.LT.NR1) NPH(I) = 1
      IF(IX3.LT.NR2) NPH(I) = 2
      IF(NPH(I).EQ.0) IPHO = IPHO + 1
      IF(NPH(I).EQ.1) IPH1 = IPH1 + 1
      IF(NPH(I).EQ.2) IPH2 = IPH2 + 1
      IF(NPH(I).GT.0) GO TO 3120
      ICSTP(I) = ICSTP(I) + ID1(IDC)
      GO TO 3160
3120  NF4(I) = JBDR(IDC,ICS)
      GO TO 3160
3130  IF(NCPH(I).EQ.NPH(I)) GO TO 3140
      GO TO 3120
3140  ICSTP(I) = ICSTP(I) + ID1(IDC)
      GO TO 3160
3150  IF(NDC10(IDC,ICS).EQ.0) GO TO 3160
      NCPH(I) = NCPH(I) + 1
      ICSTP(I) = ICSTP(I) - ID2(IDC)
3160  IF(NDC11(IDC,ICS).EQ.0) GO TO 3200
      IF(NAD(I).GT.0) GO TO 3180
      CALL RDM(2,IA,IB,IC,IN,IX,IX3)
      NAD(I) = 0
      IF(IX3.LT.NA1) NAD(I) = 1
      IF(IX3.LT.NA2) NAD(I) = 2
      IF(IX3.LT.NA3) NAD(I) = 3
      IF(IX3.LT.NA4) NAD(I) = 4
      IF(IX3.LT.NA5) NAD(I) = 5
      IF(IT.LT.IWE) GO TO 3165
      J = IHN(I)
      IF(NAD(I).GT.0) IHADD(I,J) = 66
      NAD(I) = 0
3165  IF(NAD(I).EQ.0) IAD0 = IAD0 + 1
      IF(NAD(I).EQ.1) IAD1 = IAD1 + 1
      IF(NAD(I).EQ.2) IAD2 = IAD2 + 1
      IF(NAD(I).EQ.3) IAD3 = IAD3 + 1
      IF(NAD(I).EQ.4) IAD4 = IAD4 + 1
      IF(NAD(I).EQ.5) IAD5 = IAD5 + 1

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      IF(NAD(I).GT.0) GO TO 3170
      ICSTP(I) = ICSTP(I) + ID3(IDC)
      GO TO 3210
3170  NF4(I) = JBDR(IDC,ICS)
      GO TO 3210
3180  IF(IAD(I).EQ.NAD(I)) GO TO 3190
      GO TO 3170
3190  ICSTP(I) = ICSTP(I) + ID3(IDC)
      GO TO 3210
3200  IF(NDC12(IDC,ICS).EQ.0) GO TO 3210
      IAD(I) = IAD(I) + 1
      ICSTP(I) = ICSTP(I) - ID4(IDC)
3210  IF(NDC1(IDC,ICS).EQ.0) GO TO 3220
      IK = K(I)
      NF5(IK) = 1
      K(I) = 0
3220  INT(I) = 0
      ICSTC(I) = 0
      IF(NDC13(IDC,ICS).EQ.0) GO TO 3230
      ICSTP(I) = 1
      NLDS = NLDS + 1
      J = IHN(I)
      IHTE(I,J) = IT
      IF(IHADD(I,J).EQ.66) IAD(I) = 66
      IHADD(I,J) = IAD(I)
      NPH(I) = 0
      NCPH(I) = 0
      NAD(I) = 0
      IAD(I) = 0
      NSCH(I) = NSCH(I) + 1
      IK = NTMP(I) + 1
      NTMP(I) = IK
      ITM(I,IK) = IT
      ITMP(I,IK) = ITE(IDC,ICS)
      IF(IT.GE.IWE) IHD(I) = IHF
      GO TO 3250
3230  ICSTP(I) = ICSTP(I) + 1
      IK = NTMP(I) + 1
      NTMP(I) = IK
      ITM(I,IK) = IT
      ITMP(I,IK) = ITE(IDC,ICS)
      IF(NDC15(IDC,ICS).EQ.0) GO TO 3250
      IF(IHD(I).NE.2) GO TO 3250
      IHD(I) = 1
      ICSTP(I) = 1
      INT(I) = 0
      GO TO 3250
3240  IMT(I) = IMT(I) + 1
      STM(I) = S2(IDC,ICS)
      CW(I) = 0.0
      FW(I) = 0.0
      RW(I) = 0.0
      MC(I) = 0
      IK = NTMP(I)

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      IF(ITMP(I,IK-1).EQ.ITH(IDC,ICS)) ITM(I,IK) = IT
      IF(ITMP(I,IK-1).EQ.ITH(IDC,ICS)) GO TO 3250
      IK = NTMP(I) + 1
      NTMP(I) = IK
      ITM(I,IK) = IT
      ITMP(I,IK) = ITH(IDC,ICS)
3250  CONTINUE
C
C <----- COMPILE RESULTS FOR CURRENT MINUTE
C          AND RESET NECESSARY INDICATORS.
C
      DO 90 I = 1,ND
      IF(NF2(I).EQ.1) IDT(I) = IDT(I) + 1
      IF(NF6(I).EQ.1) NF2(I) = 1
      NF6(I) = 0
90    CONTINUE
      DO 100 I = 1,NF
      IF(NF1(I).EQ.1) IFT(I) = IFT(I) + 1
      IF(NF5(I).EQ.1) NF1(I) = 1
      NF5(I) = 0
100   CONTINUE
      DO 130 I = 1,NM
      IF(MC(I).EQ.1) NCYS = NCYS + 1
      MC(I) = 0
      MF(I) = 0
      IF(JBPRP(I).EQ.0) GO TO 130
      IF(NF4(I).GE.6) GO TO 110
      IF(JBPRP(I).EQ.1) NA(I) = 1
      IF(JBPRP(I).EQ.2) NC(I) = 1
      IF(JBPRP(I).EQ.3) NDY(I) = 1
      IF(JBPRP(I).EQ.4) NPA(I) = 1
      IF(JBPRP(I).EQ.5) NSLT(I) = 1
      JBPRP(I) = 0
      IK = KK(I)
      KK(I) = 0
      NF2(IK) = 1
      NF4(I) = 0
      GO TO 130
110   IF(JBPRP(I).NE.2) GO TO 120
      NC(I) = 1
      JBPRP(I) = 0
      GO TO 130
120   NDY(I) = 1
      JBPRP(I) = 0
      IK = KK(I)
      KK(I) = 0
      NF2(IK) = 1
      NF4(I) = 0
130   CONTINUE
      STMT = 0
      FWT = 0
      HRQ = 0
      CWT = 0
      RWT = 0

```

```

DO 140 I = 1,NM
  FWT = FWT + FW(I)
  HRQ = HRQ + EN(I)*FW(I)
  CWT = CWT + CW(I)
  RWT = RWT + RW(I)
  STMT = STMT + STM(I)
140 CONTINUE
  HWR = (HRQ-FWT*ENCDW)/(ENSTW-ENCDW)
  HWT = STW + CWT
  IF(STL.EQ.0) HWT = 0.0
  IF(STL.EQ.0.0) OFLW = CWT
  IF(HWT.GT.HWR) GO TO 150
  CWR = FWT - HWT
  STMR = (HRQ-HWT*ENSTW-CWR*ENCDW)/HVAP
  STW = 0.0
  GO TO 160
150 STMR = 0.0
  CWR = FWT - HWR
  STW = HWT - HWR
  OFLW = 0.0
  IF(STW.GT.STL) OFLW = STW - STL
  IF(STW.GT.STL) STW = STL
160 OFW(IT+1) = OFLW*60.0
  OFWT = OFWT + OFLW
  STT = STMR + STMT
  CTT = CWT + CWR + RWT
  STTS = STTS + STT
  CTTS = CTTS + CTT
  SA(IT+1) = STT*60.0
  CA(IT+1) = CTT*60.0
  SW(IT+1) = STW*7.48*SVOL
  STT = 0.0
  CTT = 0.0
  IF(SA(IT+1).GT.BCAP) IBCAP = IBCAP + 1
C
C <----- CHECK FOR END OF SIMULATION.
C
C   IF(IT.LT.ITF) GO TO 80
C
C
C-----
C
C
C   TOTAL RESULTS OF SIMULATION.
C
C-----
C
C
C   IDTT = 0
C   IFTT = 0
C   IMTT = 0
C   DO 170 I = 1,NM
C     IMTT = IMTT + IMT(I)

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170 CONTINUE
DO 180 I = 1,ND
IDTT = IDTT + IDT(I)
180 CONTINUE
DO 190 I = 1,NF
IFTT = IFTT + IFT(I)
190 CONTINUE
ISIT = IDTT + IFTT + IMTT
IPP = 0
NPK = 0
PEAK1 = 0.0
PEAKS = 0.0
DO 210 I = 1,ITF
IPP = IPP + 1
IF(SA(I+1).LE.PEAK1) GO TO 200
PEAK1 = SA(I+1)
200 IF(IPP.LT.480) GO TO 210
IPP = 0
NPK = NPK + 1
PEAKS = PEAKS + PEAK1
PEAK1 = 0.0
210 CONTINUE
PEAKS = (PEAKS/FLOAT(NPK))
SW2 = (SW(ITF+1)/7.48)/SVOL
DO 220 I = 1,NM
IF(INT(I).EQ.0) GO TO 220
I1 = NSCH(I)
IDC = ISCHD(I,I1)
ICS = ICSTP(I)
IK = NTMP(I) + 1
NTMP(I) = IK
ITM(I,IK) = IT
ITDIFF = (ITE(IDC,ICS) - ITS(IDC,ICS))*ICSTC(I)
ITMP(I,IK) = ITS(IDC,ICS)+(ITDIFF/L1(IDC,ICS))
220 CONTINUE

```

OUTPUT RESULTS OF SIMULATION.

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WRITE(3,8011)
8011 FORMAT(1H1,/ ,10X,'DYEHOUSE SIMULATION',/)
WRITE(3,8012)
8012 FORMAT(10X,'..... VARIABLES SPECIFIED .....',/)
WRITE(3,8013) ND
8013 FORMAT(17X,' ND - NUMBER OF DRUG ROOM OPERATORS .....,',
#,'..... ',I5)
WRITE(3,8014) NF

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8014  FORMAT(17X,' NF - NUMBER OF FLOOR OPERATORS .....',
      #'..... ',I5)
      WRITE(3,8015) NM
8015  FORMAT(17X,' NM - NUMBER OF DYE MACHINES .....',
      #'..... ',I5)
      WRITE(3,8016) ITF
8016  FORMAT(17X,' ITF - LENGTH OF SIMULATION, MIN. ....',
      #'..... ',I5,/)
      WRITE(3,8017)
8017  FORMAT(17X,' PH ADJUSTMENT AND ADD FREQUENCIES IN ',
      #'PERCENT',/)
      WRITE(3,8018)
8018  FORMAT(24X,' NO. OF PH ADJ.',3X,' FREQUENCY OF')
      WRITE(3,8019)
8019  FORMAT(26X,' TO BE MADE',6X,' OCCURANCE',/)
      WRITE(3,8020) PHF0
8020  FORMAT(17X,' PHF0 -           0           ',6X,F6.2)
      WRITE(3,8021) PHF1
8021  FORMAT(17X,' PHF1 -           1           ',6X,F6.2)
      WRITE(3,8022) PHF2
8022  FORMAT(17X,' PHF2 -           2           ',6X,F6.2,/)
      WRITE(3,8023)
8023  FORMAT(25X,' NO. OF ADDS',5X,' FREQUENCY OF')
      WRITE(3,8024)
8024  FORMAT(26X,' TO BE MADE',6X,' OCCURANCE',/)
      WRITE(3,8025) AFO
8025  FORMAT(17X,' AFO -           0           ',6X,F6.2)
      WRITE(3,8026) AF1
8026  FORMAT(17X,' AF1 -           1           ',6X,F6.2)
      WRITE(3,8027) AF2
8027  FORMAT(17X,' AF2 -           2           ',6X,F6.2)
      WRITE(3,8028) AF3
8028  FORMAT(17X,' AF3 -           3           ',6X,F6.2)
      WRITE(3,8029) AF4
8029  FORMAT(17X,' AF4 -           4           ',6X,F6.2)
      WRITE(3,8030) AF5
8030  FORMAT(17X,' AF5 -           5           ',6X,F6.2,/)
      WRITE(3,8031)
8031  FORMAT(17X,' CONSTANTS IN RANDOM NUMBER EQUATIONS',/)
      WRITE(3,8032) IA1,IA2
8032  FORMAT(17X,' IA(1) = ',I5,10X,' IA(2) = ',I5)
      WRITE(3,8033) IB1,IB2
8033  FORMAT(17X,' IB(1) = ',I5,10X,' IB(2) = ',I5)
      WRITE(3,8034) IC1,IC2
8034  FORMAT(17X,' IC(1) = ',I5,10X,' IC(2) = ',I5)
      WRITE(3,8035) IN1,IN2
8035  FORMAT(17X,' IN(1) = ',I5,10X,' IN(2) = ',I5)
      WRITE(3,8036) IX1,IX2
8036  FORMAT(17X,' IX(1) = ',I5,10X,' IX(2) = ',I5,/)
      WRITE(3,8037)
8037  FORMAT(///,10X,' .... OPERATING PRIORITIES ....',/)
      IF(JBT1.EQ.1) WRITE(3,8038)
8038  FORMAT(17X,' JBT1 = 1, BREAK OPERATORS WHEN FREE',/)
      IF(JBT1.EQ.2) WRITE(3,8039)

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8039  FORMAT(17X,'JBT1 = 2, NO BREAKS',/)
      WRITE(3,8040) (NBT(I),I=1,9)
8040  FORMAT(17X,' NBT(I), I = 1,9',9I6)
      WRITE(3,8041) (NBTL(I),I=1,9)
8041  FORMAT(17X,'NBTL(I), I = 1,9',9I6,/)
      WRITE(3,8042)
8042  FORMAT(17X,'JBT2 = 1, DOWN-THE-LINE',/)
      WRITE(3,8043) JBT3
8043  FORMAT(17X,'JBT3 = ',I1,/)
      IF(IWE.EQ.ITF) WRITE(3,8104)
8104  FORMAT(17X,'IWE = ITF, CONTINUOUS OPERATION',/)
      IF(IWE.LT.ITF) WRITE(3,8105) IWE
8105  FORMAT(17X,'IWE = ',I4,', HOLD MACHINES AT IWE',/)
      IF(IHF.EQ.1) WRITE(3,8106)
8106  FORMAT(17X,'IHF = 1, HOLD BEFORE REFILL',/)
      IF(IHF.EQ.2) WRITE(3,8107)
8107  FORMAT(17X,'IHF = 2, HOLD AFTER REFILL',/)
      WRITE(3,8044)
8044  FORMAT(1H1,////,10X,'.... HEAT RECOVERY SYSTEM ....',
#//)
      STL = STL*7.48*SVOL
      WRITE(3,8045) STL
8045  FORMAT(17X,' STL - ',F8.1,2X,'GAL.')
      SW1 = SW(1)*7.48*SVOL
      WRITE(3,8046) SW1
8046  FORMAT(17X,'SW(1) - ',F8.1,2X,'GAL.')
      WRITE(3,8047) SLEV
8047  FORMAT(17X,' SLEV - ',F8.1,2X,'LB STEAM PER HOUR')
      WRITE(3,8048) FSLEV
8048  FORMAT(17X,'FSLEV - ',F8.1,2X,'LB STEAM PER HOUR')
      WRITE(3,8049) NMF
8049  FORMAT(17X,' NMF - ',I6)
      WRITE(3,8050) NMH
8050  FORMAT(17X,' NMH - ',I6)
      WRITE(3,8051) NMT
8051  FORMAT(17X,' NMT - ',I6,/)
      WRITE(3,8052)
8052  FORMAT(17X,'WATER TEMPERATURE ENTHALPY')
      WRITE(3,8053)
8053  FORMAT(17X,' DEG F BTU/LB',/)
      WRITE(3,8054) TMP1,ENCDW
8054  FORMAT(17X,'FRESH',6X,F6.2,6X,F6.2)
      WRITE(3,8055) TMP2,ENSTW,SVOL
8055  FORMAT(17X,'STORED',5X,F6.2,6X,F6.2,3X,'SVOL = ',F6.4,
# ' FT3/LB')
      WRITE(3,8056) TMPS,STMPRS
8056  FORMAT(17X,'STEAM - ',F7.2,' DEG F, ',F6.2,' PSIA')
      WRITE(3,8057) HVAP
8057  FORMAT(17X,' ',F7.2,' BTU/LB - DHVAP',/)
      WRITE(3,8103) BCAP
8103  FORMAT(17X,'BOILER CAPACITY, LB/HR ',F8.1)
      WRITE(3,8086)
8086  FORMAT(1H1,////,10X,'.... DYEING SCHEDULE ....',/)
      WRITE(3,8087)

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8087  FORMAT(17X,'MACHINE NUMBER',/)
      WRITE(3,8088) (I,I=1,NM)
8088  FORMAT(17X,25I3,/)
      WRITE(3,8109)
8109  FORMAT(/)
      DO 230 J = 1,NDSCH
      WRITE(3,8089) (ISCHD(I,J),I=1,NM)
8089  FORMAT(17X,25I3)
      230  CONTINUE
      WRITE(3,8090)
8090  FORMAT(1H1,////,10X,'..... DYE CYCLE INFORMATION .....',
#//)
      DO 260 I = 1,NDCU
      WRITE(3,8091) I
8091  FORMAT(17X,'DYE CYCLE #',I3,/)
      WRITE(3,8092)
8092  FORMAT(17X,'CYCLE STEP NDC1-NDC15, JBDR  L1  L2  L3',
# '   S1      S2      C1      F1      RN1      ',
# 'E1      ITS      ITE      ITH',/)
      NN = ICSN(I)
      DO 240 J = 1,NN
      WRITE(3,8093) J,NDC1(I,J),NDC2(I,J),NDC3(I,J),
#NDC4(I,J),NDC5(I,J),NDC6(I,J),NDC7(I,J),NDC8(I,J),
#NDC9(I,J),NDC10(I,J),NDC11(I,J),NDC12(I,J),NDC13(I,J),
#NDC14(I,J),NDC15(I,J),JBDR(I,J),L1(I,J),L2(I,J),
#L3(I,J),S1(I,J),S2(I,J),C1(I,J),F1(I,J),RN1(I,J),
#E1(I,J),ITS(I,J),ITE(I,J),ITH(I,J)
8093  FORMAT(21X,I2,5X,I6I1,1X,I3,1X,I3,1X,I3,6F9.2,3I6)
      240  CONTINUE
      WRITE(3,8094)
8094  FORMAT(/,17X,'PREPARATION TIMES IN DRUG ROOM',/)
      DO 250 J = 1,6
      WRITE(3,8095) I,J,IPRP(I,J)
8095  FORMAT(17X,'IPRP(',I1,',',I1,',') = ',I3)
      250  CONTINUE
      WRITE(3,8096) ID1(I),ID2(I),ID3(I),ID4(I)
8096  FORMAT(/,17X,'ID1 =',I3,' ID2 =',I3,' ID3 =',I3,
# ' ID4 =',I3)
      WRITE(3,8097)
8097  FORMAT(1H1,////////)
      260  CONTINUE
      WRITE(3,8058)
8058  FORMAT(1H1,////,10X,'..... SUMMARY OF RESULTS COMPIL',
# 'ED DURING SIMULATION .....',/)
      WRITE(3,8059) NLDS
8059  FORMAT(17X,'NO. OF LOADS COMPLETED',16X,I10)
      WRITE(3,8085) NCYS
8085  FORMAT(17X,'NO. OF CYCLE STEPS EXECUTED',11X,I10)
      WRITE(3,8060) IMTT
8060  FORMAT(/,17X,'TOTAL MACHINE IDLE TIME',15X,I10)
      WRITE(3,8061) IFTT
8061  FORMAT(17X,'TOTAL FLOOR IDLE TIME',17X,I10)
      WRITE(3,8062) IDTT
8062  FORMAT(17X,'TOTAL DRUG ROOM IDLE TIME',13X,I10)

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      WRITE(3,8063) ISIT
8063  FORMAT(17X,'SUM OF ALL IDLE TIMES',17X,I10)
      WRITE(3,8064) STTS
8064  FORMAT(/,17X,'LBS. OF STEAM CONSUMED',16X,F10.1)
      WRITE(3,8065) CTTS
8065  FORMAT(17X,'LBS. OF WATER CONSUMED',16X,F10.1)
      WRITE(3,8066) OFWT
8066  FORMAT(17X,'LBS. OF STORAGE OVERFLOW(120 DEG F)',3X,
#F10.1)
      WRITE(3,8067) SW2
8067  FORMAT(17X,'LBS. OF FINAL STORAGE',17X,F10.1)
      ASTMCM = (STTS/FLOAT(ITF))*60.0
      WRITE(3,8068) ASTMCM
8068  FORMAT(/,17X,'AVE. STEAM CONSUMPTION, LB/HR',9X,F10.1)
      WRITE(3,8069) PEAKS
8069  FORMAT(17X,'AVE. PEAK STEAM CONSUMPTION, LB/HR',4X,
#F10.1)
      WRITE(3,8010) IBCAP
8010  FORMAT(17X,'NO. OF PEAKS ABOVE BOILER CAPACITY',4X,
#I10)
      NMHD = 0
      DO 270 I = 1,NM
      IF(IHD(I).EQ.1) NMHD = NMHD + 1
270  CONTINUE
      WRITE(3,8108) NMHD
8108  FORMAT(/,17X,'NO. OF MACHINES ON HOLD',15X,I2)
      TPH = FLOAT(IPH0 + IPH1 + IPH2)
      TADS = FLOAT(IAD0 + IAD1 + IAD2 + IAD3 + IAD4 + IAD5)
      APHF0 = (FLOAT(IPH0)/TPH)*100.0
      APHF1 = (FLOAT(IPH1)/TPH)*100.0
      APHF2 = (FLOAT(IPH2)/TPH)*100.0
      AAF0 = (FLOAT(IAD0)/TADS)*100.0
      AAF1 = (FLOAT(IAD1)/TADS)*100.0
      AAF2 = (FLOAT(IAD2)/TADS)*100.0
      AAF3 = (FLOAT(IAD3)/TADS)*100.0
      AAF4 = (FLOAT(IAD4)/TADS)*100.0
      AAF5 = (FLOAT(IAD5)/TADS)*100.0
      WRITE(3,8070)
8070  FORMAT(////)
      WRITE(3,8017)
      WRITE(3,8071)
8071  FORMAT(24X,'NO. OF PH ADJ.',3X,'EXPECTED',5X,'ACTUAL')
      WRITE(3,8072)
8072  FORMAT(26X,'TO BE MADE',5X,'OCCURANCE',3X,'OCCURANCE',
#/)
      WRITE(3,8073) PHF0,APHF0
8073  FORMAT(17X,'PHF0 -          0          ',6X,F6.2,6X,F6.2)
      WRITE(3,8074) PHF1,APHF1
8074  FORMAT(17X,'PHF1 -          1          ',6X,F6.2,6X,F6.2)
      WRITE(3,8075) PHF2,APHF2
8075  FORMAT(17X,'PHF2 -          2          ',6X,F6.2,6X,F6.2,/)
      WRITE(3,8076)
8076  FORMAT(25X,'NO. OF ADDS',5X,'EXPECTED',5X,'ACTUAL')
      WRITE(3,8077)

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8077  FORMAT(26X,'TO BE MADE',5X,'OCCURANCE',3X,'OCCURANCE',
      #/)
      WRITE(3,8078) AFO,AAFO
8078  FORMAT(17X,'AFO -           0           ',6X,F6.2,6X,F6.2)
      WRITE(3,8079) AF1,AAF1
8079  FORMAT(17X,'AF1 -           1           ',6X,F6.2,6X,F6.2)
      WRITE(3,8080) AF2,AAF2
8080  FORMAT(17X,'AF2 -           2           ',6X,F6.2,6X,F6.2)
      WRITE(3,8081) AF3,AAF3
8081  FORMAT(17X,'AF3 -           3           ',6X,F6.2,6X,F6.2)
      WRITE(3,8082) AF4,AAF4
8082  FORMAT(17X,'AF4 -           4           ',6X,F6.2,6X,F6.2)
      WRITE(3,8083) AF5,AAF5
8083  FORMAT(17X,'AF5 -           5           ',6X,F6.2,6X,F6.2)
      WRITE(3,8098)
8098  FORMAT(1H1,////,10X,'.... DYEING SUMMARIES ....',//)
      DO 290 I = 1,NM
      WRITE(3,8099) I
8099  FORMAT(17X,'MACHINE # ',I2,/)
      WRITE(3,8100)
8100  FORMAT(17X,'DYE CYCLE  STARTING TIME  STOPPING TIME',
      #' # OF ADDS',/)
      NN = IHN(I)
      DO 280 J = 1,NN
      WRITE(3,8101) J,IHDC(I,J),IHTS(I,J),IHTE(I,J),
      #IHADD(I,J)
8101  FORMAT(10X,I3,'.           ',I3,9X,I5,10X,I5,10X,I1)
      280  CONTINUE
      WRITE(3,8102)
8102  FORMAT(1H1,////)
      290  CONTINUE
      SA(1) = 0.0
      CA(1) = 0.0
      OFW(1) = 0.0
      SW(1) = SW(1)*7.48*SVOL
      IF(JBT3.EQ.1) GO TO 7020

C
C <----- PLOT STEAM CONSUMPTION.
C
      NPTS = ITF + 1
      DO 9010 I = 1,NPTS
      X(I) = (FLOAT(I) - 1.0)/60.0
      Y(I) = SA(I)
9010  CONTINUE
      Z(1) = (STTS/FLOAT(ITF))*60.0
      Z(2) = Z(1)
      Z(3) = 0.0
      Z(4) = 25000.0
      CALL PLOTS(IBUF,1000,6)
      XL = (FLOAT(NPTS) - 1.0)/720.0
      N1 = NPTS + 1
      N2 = NPTS + 2
      X(N1) = 0.0
      X(N2) = 12.0

```

```

Y(N1) = 0.0
Y(N2) = 25000.0
CALL FACTOR(0.6)
CALL PLOT(0.0,0.0,-3)
CALL PLOT(0.0,8.5,2)
CALL PLOT(6.0,6.0,-3)
CALL AXIS(0.0,0.0,XH1,-36,XL,0.0,X(N1),X(N2))
CALL AXIS(0.0,0.0,YH1,36,6.0,90.0,Y(N1),Y(N2))
CALL PLOT(0.0,6.0,3)
CALL PLOT(XL,6.0,2)
CALL PLOT(XL,0.0,2)
CALL PLOT(0.0,0.0,3)
CALL FLINE(X,Y,NPTS,1,0,2)
X(1) = 0.0
X(2) = ITF/60.0
X(3) = 0.0
X(4) = 12.0
CALL FLINE(X,Z,2,1,0,2)
Z(1) = BCAP
Z(2) = Z(1)
CALL NEWPEN(3)
CALL FLINE(X,Z,2,1,0,2)
CALL NEWPEN(1)
XL = XL + 6.0
CALL PLOT(XL,-6.0,3)
CALL PLOT(XL,7.5,2)
XL = XL + 4.0
CALL PLOT(XL,-6.0,-3)
9020  CONTINUE
      IF(JBT3.EQ.1) GO TO 9040
C
C <----- PLOT WATER CONSUMPTION.
C
      NPTS = ITF + 1
      DO 9030 I = 1,NPTS
X(I) = (FLOAT(I) - 1.0)/60.0
Y(I) = CA(I)
9030  CONTINUE
      Z(1) = (CTTS/FLOAT(ITF))*60.0
      Z(2) = Z(1)
      Z(3) = 0.0
      Z(4) = 400000.0
      XL = (FLOAT(NPTS) - 1.0)/720.0
      N1 = NPTS + 1
      N2 = NPTS + 2
      X(N1) = 0.0
      X(N2) = 12.0
      Y(N1) = 0.0
      Y(N2) = 400000.0
      CALL FACTOR(0.6)
      CALL PLOT(0.0,0.0,-3)
      CALL PLOT(0.0,8.5,2)
      CALL PLOT(6.0,6.0,-3)
      CALL AXIS(0.0,0.0,XH2,-36,XL,0.0,X(N1),X(N2))

```

```

CALL AXIS(0.0,0.0,YH2,36,6.0,90.0,Y(N1),Y(N2))
CALL PLOT(0.0,6.0,3)
CALL PLOT(XL,6.0,2)
CALL PLOT(XL,0.0,2)
CALL PLOT(0.0,0.0,3)
CALL FLINE(X,Y,NPTS,1,0,2)
X(1) = 0.0
X(2) = ITF/60.0
X(3) = 0.0
X(4) = 12.0
CALL FLINE(X,Z,2,1,0,2)
XL = XL + 6.0
CALL PLOT(XL,-6.0,3)
CALL PLOT(XL,7.5,2)
XL = XL + 4.0
CALL PLOT(XL,-6.0,-3)

```

C

```

9040  CONTINUE
      IF(JBT3.EQ.1) GO TO 9060

```

C

```

C <----- PLOT HEAT STORAGE CAPACITY.

```

C

```

NPTS = ITF + 1
N1 = NPTS + 1
N2 = NPTS + 2
XL = (FLOAT(NPTS)-1.0)/720.0
CALL FACTOR(0.6)
CALL PLOT(0.0,0.0,-3)
CALL PLOT(0.0,8.5,2)
CALL PLOT(6.0,6.0,-3)
X(N1) = 0.0
X(N2) = 12.0
Y(N1) = -5000.0
Y(N2) = 5000.0
CALL AXIS(0.0,0.0,XH3,-36,XL,0.0,X(N1),X(N2))
CALL AXIS(0.0,0.0,YH3,36,6.0,90.0,Y(N1),Y(N2))
CALL PLOT(0.0,6.0,3)
CALL PLOT(XL,6.0,2)
CALL PLOT(XL,0.0,2)
CALL PLOT(0.0,0.0,3)
X(1) = 0.0
X(2) = ITF/60.0
X(3) = 0.0
X(4) = 12.0
Z(1) = 0.0
Z(2) = 0.0
Z(3) = -5000.0
Z(4) = 5000.0
CALL NEWPEN(3)
CALL FLINE(X,Z,2,1,0,2)
Z(1) = STL
Z(2) = Z(1)
CALL FLINE(X,Z,2,1,0,2)
CALL NEWPEN(1)

```

```

DO 9050 I = 1,NPTS
X(I) = (FLOAT(I)-1.0)/60.0
Y(I) = SW(I)
9050 CONTINUE
CALL FLINE(X,Y,NPTS,1,0,2)
XL = XL + 6.0
CALL PLOT(XL,-6.0,3)
CALL PLOT(XL,7.5,2)
XL = XL + 6.0
CALL PLOT(XL,-6.0,-3)
CALL PLOT(0.0,0.0,999)

C
C <----- PLOT TEMPERATURE PROFILES
C
CALL PLOTS(IBUF,1000,6)
CALL PLOT(0.0,0.0,-3)
CALL PLOT(6.0,6.0,-3)
XX = 0.15
YY = (NM/3.0-2.8)/2.0
CALL SYMBOL(XX,YY,0.14,'TEMPERATURE PROFILES',90.0,20)
XX = 0.32
CALL SYMBOL(XX,YY,0.14,' (0-300 DEG. F) ',90.0,20)
CALL PLOT(0.62,0.0,-3)
XL = FLOAT(ITF)/720.0
CALL AXIS(0.0,0.0,XH1,-36,XL,0.0,0.0,12.0)
CALL PLOT(0.0,0.0,3)
YL = FLOAT(NM)/3.0
CALL PLOT(0.0,YL,2)
CALL PLOT(XL,YL,2)
CALL PLOT(XL,0.0,2)
CALL PLOT(0.0,0.0,3)
Z(3) = 0.0
Z(4) = 300.0
DO 9051 J = 1,NM
Z(1) = (FLOAT(NM) - FLOAT(J))*300.0/3.0
Z(2) = Z(1)
NPTS = NTMP(J)
N1 = NPTS + 1
N2 = NPTS + 2
X(N1) = 0.0
X(N2) = 12.0
Y(N1) = 0.0
Y(N2) = 300.0
DO 9052 I = 1,NPTS
X(I) = ITM(J,I)/60.0
Y(I) = ((FLOAT(NM) - FLOAT(J))*300.0 + ITMP(J,I))/3.0
9052 CONTINUE
CALL FLINE(X,Y,NPTS,1,0,2)
X(1) = 0.0
X(2) = FLOAT(ITF)/60.0
X(3) = 0.0
X(4) = 12.0
XX1 = -0.25
XX2 = -0.15

```

```

YY = (NM-J)/3.0
NNP = 0
IF(J.GT.9) NNP = 113
IF(J.GT.19) NNP = 114
IF(NNP.GT.0) CALL SYMBOL(XX1,YY,0.1,NNP,0.0,0)
NNP = 112 + J
IF(J.GT.9) NNP = 112 + J - 10
IF(J.GT.19) NNP = 112 + J - 20
CALL SYMBOL(XX2,YY,0.1,NNP,0.0,0)
CALL FLINE(X,Z,2,1,0,2)
9051 CONTINUE
XL = XL + 6.0
YL = -6.0
CALL PLOT(XL,YL,*3)
CALL PLOT(0.0,0.0,999)

```

C

C-----

C

```

9060 CONTINUE
STOP
END
SUBROUTINE RDM(IY,I1,I2,I3,I4,I5,IX3)
DIMENSION I1(50),I2(50),I3(50),I4(50),I5(50)
I4(IY) = I4(IY) + 1
IF(I4(IY).EQ.I3(IY)) I1(IY) = I1(IY) + 20
IF(I4(IY).EQ.I3(IY)) I4(IY) = 0
IX1 = I1(IY)*I5(IY) + I2(IY)
IX2 = IX1/I3(IY)
IX3 = IX1 - IX2*I3(IY)
I5(IY) = IX3
RETURN
END

```

/*

//G.SYSIN DD *

(INPUT GOES HERE)

/*

//

0.00	0.00	0.00	150	150	150
0.00	0.00	0.00	90	90	150
0.00	0.00	0.00	90	90	90
2375.00	0.00	67.97	100	100	90
0.00	0.00	0.00	100	100	100
0.00	0.00	0.00	100	100	100
0.00	0.00	0.00	0	0	100
27 16 8 16 3 0 24 1 2 7 10					
10000000000000000000	5	0	0	0.00	0.00 0.00
00000011000000106	8	7	7	2.95	0.00 0.00
10000000000000000000	22	0	0	0.17	0.17 0.00
0010000000000000100	30	0	0	47.62	0.17 0.00
00000000000000000000	2	0	0	1.18	1.18 0.00
00010001000000000000	9	8	0	1.18	1.18 0.00
1000000001000000004	5	0	0	1.18	1.18 0.00
00001001010000000000	6	5	0	1.18	1.18 0.00
00000000000000000100	100	0	0	24.84	1.18 0.00
00000000000000000000	60	0	0	4.39	0.00 0.00
00000000100000000000	55	55	0	0.00	0.00 633.33
00000000000000000000	1	0	0	1.10	1.10 0.00
100000000001000001	5	0	0	1.10	1.10 0.00
00000000000000000100	5	0	0	47.62	1.10 0.00
00000000000000000000	2	0	0	1.18	1.18 0.00
01000001000000000000	9	8	0	1.18	1.18 0.00
1000000001000000004	5	0	0	1.18	1.18 0.00
00001001010000000000	6	5	0	1.18	1.18 0.00
00000000000000000100	100	0	0	24.84	1.18 0.00
000000000000010000	30	0	0	4.39	0.00 0.00
00000000000000000000	1	0	0	1.10	1.10 0.00
00000000000000000000	5	0	0	0.00	0.00 0.00
00000000000000000000	1	0	0	0.00	0.00 0.00
00000000000000000100	8	0	0	2.95	0.00 0.00
00000000100000000000	22	21	0	0.17	0.17 0.00
10000000000000000000	20	0	0	0.00	0.00 0.00
000000000000000001000	5	4	0	0.00	0.00 0.00
0.00	0.00	0.00	0	0	0
2375.00	0.00	67.97	100	100	0
0.00	0.00	0.00	100	100	100
0.00	0.00	0.00	100	160	100
0.00	0.00	0.00	160	160	160
0.00	0.00	0.00	160	160	160
0.00	0.00	0.00	160	160	160
0.00	0.00	0.00	160	160	160
0.00	0.00	0.00	160	160	160
0.00	0.00	0.00	160	260	160
0.00	0.00	0.00	260	260	260
0.00	0.00	0.00	260	150	260
0.00	0.00	0.00	150	150	150
0.00	0.00	0.00	150	150	150
0.00	0.00	0.00	150	160	150
0.00	0.00	0.00	160	160	160
0.00	0.00	0.00	160	160	160
0.00	0.00	0.00	160	160	160
0.00	0.00	0.00	160	160	160
0.00	0.00	0.00	160	260	160

0.00	0.00	0.00	260	260	260
0.00	0.00	0.00	150	150	150
0.00	0.00	0.00	90	90	150
0.00	0.00	0.00	90	90	90
2375.00	0.00	67.97	100	100	90
0.00	0.00	0.00	100	100	100
0.00	0.00	0.00	100	100	100
0.00	0.00	0.00	0	0	100

/*

//

Appendix ESample Output

In Appendix D an example set of input data is given in the proper format. When the dyehouse model developed in this study is supplied with this information, the program generates the results that follow. The figures generated by the execution of the computer model require the availability of Calcomp plotting capabilities.

DYEHOUSE SIMULATION

.... VARIABLES SPECIFIED

ND - NUMBER OF DRUG ROOM OPERATORS 3
 NF - NUMBER OF FLOOR OPERATORS 7
 NM - NUMBER OF DYE MACHINES 20
 ITF - LENGTH OF SIMULATION, MIN. 10080

PH ADJUSTMENT AND ADD FREQUENCIES IN PERCENT

	NO. OF PH ADJ. TO BE MADE	FREQUENCY OF OCCURANCE
PMF0 -	0	85.00
PMF1 -	1	10.00
PMF2 -	2	5.00

	NO. OF ADDS TO BE MADE	FREQUENCY OF OCCURANCE
AF0 -	0	85.00
AF1 -	1	10.00
AF2 -	2	5.00
AF3 -	3	0.0
AF4 -	4	0.0
AF5 -	5	0.0

CONSTANTS IN RANDOM NUMBER EQUATIONS

IA(1) =	21	IA(2) =	101
IB(1) =	7	IB(2) =	13
IC(1) =	1000	IC(2) =	1000
IN(1) =	0	IN(2) =	0
IX(1) =	499	IX(2) =	12

.... OPERATING PRIORITIES

JBT1 = 1, BREAK OPERATORS WHEN FREE

NBT(1), I = 1,9	90	210	300	570	690	810	1050	1170	1290
NBTL(1), I = 1,9	10	10	20	10	20	10	20	10	10

JBT2 = 1, DOWN-THE-LINE

JBT3 = 2

IME = ITF, CONTINUOUS OPERATION

.... HEAT RECOVERY SYSTEM

STL -	15000.0	GAL.
SW(1) -	0.0	GAL.
SLEV -	25000.0	LB STEAM PER HOUR
FSLEV -	25000.0	LB STEAM PER HOUR
NMF -	1	
NMH -	1	
NMT -	1	

WATER	TEMPERATURE DEG F	ENTHALPY BTU/LB	
FRESH	60.00	28.06	
STORED	120.00	87.92	SVOL = 0.0162 FT3/LB
STEAM -	327.81 DEG F, 100.00 PSIA		
	888.80 BTU/LB - DHVAP		

BOILER CAPACITY, LB/MR 40000.0

.... DYE CYCLE INFORMATION

DYE CYCLE # 1

CYCLE STEP	NDC1-NDC15, JBDR	L1	L2	L3	S1	S2	C1	F1	RN1	E1	ITS	ITE	ITH
1	1000000000000000	5	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
2	0000001100000106	8	7	7	2.95	0.0	0.0	2375.00	0.0	67.97	100	100	0
3	1000000000000000	22	0	0	0.17	0.17	0.0	0.0	0.0	0.0	100	100	100
4	0010000000000100	12	0	0	119.04	0.17	0.0	0.0	0.0	0.0	100	160	100
5	0000000000000000	2	0	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
6	0001000100000000	9	8	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
7	1000000100000004	5	0	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
8	0000100101000000	6	5	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
9	0000000000000100	33	0	0	75.28	1.18	0.0	0.0	0.0	0.0	160	260	160
10	0000000000000000	30	0	0	4.39	0.0	0.0	0.0	0.0	0.0	260	260	260
11	0000000100000000	36	36	0	0.0	0.0	967.59	0.0	0.0	0.0	260	150	260
12	0000000000000000	1	0	0	1.10	1.10	0.0	0.0	0.0	0.0	150	150	150
13	1000000000100001	5	0	0	1.10	1.10	0.0	0.0	0.0	0.0	150	150	150
14	0000000000000100	2	0	0	119.04	1.10	0.0	0.0	0.0	0.0	150	160	150
15	0000000000000000	2	0	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
16	0100000100000000	9	8	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
17	1000000010000004	5	0	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
18	0000100101000000	6	5	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
19	0000000000000100	33	0	0	75.28	1.18	0.0	0.0	0.0	0.0	160	260	160
20	0000000000010000	15	0	0	4.39	0.0	0.0	0.0	0.0	0.0	260	260	260
21	0000000000000000	1	0	0	1.10	1.10	0.0	0.0	0.0	0.0	150	150	150
22	0000000000000000	5	0	0	0.0	0.0	0.0	0.0	0.0	0.0	90	90	150
23	0000000000000000	1	0	0	0.0	0.0	0.0	0.0	0.0	0.0	90	90	90
24	0000000000000100	8	0	0	2.95	0.0	0.0	2375.00	0.0	67.97	100	100	90
25	0000000100000000	4	3	0	0.17	0.17	0.0	0.0	0.0	0.0	100	100	100
26	1000000000000000	20	0	0	0.0	0.0	0.0	0.0	0.0	0.0	100	100	100
27	0000000000000100	5	4	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	100

PREPARATION TIMES IN DRUG ROOM

[PRP(1,1) = 16
 [PRP(1,2) = 8
 [PRP(1,3) = 16
 [PRP(1,4) = 3
 [PRP(1,5) = 0
 [PRP(1,6) = 24

ID1 = 1 ID2 = 2 ID3 = 7 ID4 = 10

DYE CYCLE # 2

CYCLE	STEP	NDC1-NDC15, JBDR	L1	L2	L3	S1	S2	C1	F1	RM1	E1	ITS	ITE	ITM
1		1000000000000000	5	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0
2		00000001100000106	8	7	7	2.95	0.0	0.0	2375.00	0.0	67.97	100	100	0
3		1000000000000000	22	0	0	0.17	0.17	0.0	0.0	0.0	0.0	100	100	100
4		00100000000000100	30	0	0	47.62	0.17	0.0	0.0	0.0	0.0	100	160	100
5		00000000000000000	2	0	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
6		00010001000000000	9	8	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
7		10000000010000004	5	0	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
8		00001001010000000	6	5	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
9		00000000000000100	100	0	0	24.84	1.18	0.0	0.0	0.0	0.0	160	260	160
10		00000000000000000	60	0	0	4.39	0.0	0.0	0.0	0.0	0.0	260	260	260
11		00000000100000000	55	55	0	0.0	0.0	633.33	0.0	0.0	0.0	260	150	260
12		00000000000000000	1	0	0	1.10	1.10	0.0	0.0	0.0	0.0	150	150	150
13		10000000000100001	5	0	0	1.10	1.10	0.0	0.0	0.0	0.0	150	150	150
14		00000000000000100	5	0	0	47.62	1.10	0.0	0.0	0.0	0.0	150	160	150
15		00000000000000000	2	0	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
16		01000001000000000	9	8	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
17		10000000010000004	5	0	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
18		00001001010000000	6	5	0	1.18	1.18	0.0	0.0	0.0	0.0	160	160	160
19		00000000000000100	100	0	0	24.84	1.18	0.0	0.0	0.0	0.0	160	260	160
20		00000000000010000	30	0	0	4.39	0.0	0.0	0.0	0.0	0.0	260	260	260
21		00000000000000000	1	0	0	1.10	1.10	0.0	0.0	0.0	0.0	150	150	150
22		00000000000000000	5	0	0	0.0	0.0	0.0	0.0	0.0	0.0	90	90	150
23		00000000000000000	1	0	0	0.0	0.0	0.0	0.0	0.0	0.0	90	90	90
24		00000000000000100	8	0	0	2.95	0.0	0.0	2375.00	0.0	67.97	100	100	90
25		00000000100000000	22	21	0	0.17	0.17	0.0	0.0	0.0	0.0	100	100	100
26		10000000000000000	20	0	0	0.0	0.0	0.0	0.0	0.0	0.0	100	100	100
27		0000000000001000	5	4	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	100

PREPARATION TIMES IN DRUG ROOM

IPRP(2,1) = 16
 IPRP(2,2) = 8
 IPRP(2,3) = 16
 IPRP(2,4) = 3
 IPRP(2,5) = 0
 IPRP(2,6) = 24

ID1 = 1 ID2 = 2 ID3 = 7 ID4 = 10

.... SUMMARY OF RESULTS COMPILED DURING SIMULATION

NO. OF LOADS COMPLETED	621
NO. OF CYCLE STEPS EXECUTED	189922
TOTAL MACHINE IDLE TIME	11678
TOTAL FLOR IDLE TIME	23130
TOTAL DRUG ROOM IDLE TIME	9039
SUM OF ALL IDLE TIMES	43847
LBS. OF STEAM CONSUMED	3031267.0
LBS. OF WATER CONSUMED	34445120.0
LBS. OF STORAGE OVERFLOW(120 DEG F)	10400101.0
LBS. OF FINAL STORAGE	123786.8
AVE. STEAM CONSUMPTION, LB/HR	18043.2
AVE. PEAK STEAM CONSUMPTION, LB/HR	32225.7
NO. OF PEAKS ABOVE BOILER CAPACITY	0
NO. OF MACHINES ON HOLD	0

PH ADJUSTMENT AND ADD FREQUENCIES IN PERCENT

	NO. OF PH ADJ. TO BE MADE	EXPECTED OCCURANCE	ACTUAL OCCURANCE
PHF0 -	0	85.00	84.30
PHF1 -	1	10.00	9.74
PHF2 -	2	5.00	5.95

	NO. OF ACDS TO BE MADE	EXPECTED OCCURANCE	ACTUAL OCCURANCE
AFO -	0	85.00	85.26
AF1 -	1	10.00	9.78
AF2 -	2	5.00	4.97
AF3 -	3	0.0	0.0
AF4 -	4	0.0	0.0
AF5 -	5	0.0	0.0

.... DYEING SUMMARIES

MACHINE # 1

DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS	
1.	2	2	587	1
2.	2	588	951	0
3.	2	952	1325	0
4.	2	1326	1695	0
5.	2	1696	2529	2
6.	2	2530	2893	0
7.	2	2094	3287	0
8.	2	3288	3652	0
9.	2	3653	4036	0
10.	2	4037	4855	2
11.	2	4856	5219	0
12.	2	5220	5583	0
13.	2	5584	5947	0
14.	2	5948	6311	0
15.	2	6312	6680	0
16.	2	6681	7272	1
17.	2	7273	7639	0
18.	2	7642	8025	0
19.	2	8026	8415	0
20.	2	8416	9296	2
21.	2	9297	9660	0
22.	2	9661	10024	0
23.	2	10025	0	0

MACHINE # 2

DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS	
1.	2	2	371	0
2.	2	372	742	0
3.	2	743	1127	0
4.	2	1128	1718	1
5.	2	1719	2087	0
6.	2	2088	2451	0
7.	2	2452	2816	0
8.	2	2817	3403	1
9.	2	3404	3767	0
10.	2	3768	4162	0
11.	2	4163	4572	0
12.	2	4573	4936	0
13.	2	4937	5338	0
14.	2	5339	5706	0
15.	2	5707	6072	0
16.	2	6073	6700	1
17.	2	6701	7064	0
18.	2	7067	7926	2
19.	2	7927	8291	0
20.	2	8294	8890	1
21.	2	8891	9257	0
22.	2	9258	9629	0
23.	2	9630	9993	0
24.	2	9994	0	0

MACHINE # 3

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS
1.	2	2	374	0
2.	2	375	971	1
3.	2	972	1617	1
4.	2	1621	1984	0
5.	2	1985	2348	0
6.	2	2349	2938	1
7.	2	2939	3304	0
8.	2	3305	4137	2
9.	2	4138	4727	1
10.	2	4731	5097	0
11.	2	5098	5471	0
12.	2	5472	5835	0
13.	2	5836	6425	1
14.	2	6426	6789	0
15.	2	6790	7196	0
16.	2	7197	7565	0
17.	2	7566	7930	0
18.	2	7931	8546	1
19.	2	8547	9165	1
20.	2	9166	9533	0
21.	2	9534	9900	0
22.	2	9901	0	0

MACHINE # 4

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS
1.	2	2	428	0
2.	2	429	803	0
3.	2	804	1556	2
4.	2	1661	2471	2
5.	2	2472	2835	0
6.	2	2836	3217	0
7.	2	3221	3584	0
8.	2	3585	3971	0
9.	2	3972	4373	0
10.	2	4374	4740	0
11.	2	4741	5148	0
12.	2	5149	5535	0
13.	2	5536	5953	0
14.	2	5954	6767	2
15.	2	6768	7137	0
16.	2	7138	7510	0
17.	2	7511	7875	0
18.	2	7876	8251	0
19.	2	8261	8648	0
20.	2	8649	9013	0
21.	2	9014	9409	0
22.	2	9410	9794	0
23.	2	9795	0	0

MACHINE # 5

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS
1.	2	2	407	0
2.	2	408	771	0
3.	2	772	1156	0
4.	2	1157	1520	0
5.	2	1521	1908	0
6.	2	1909	2272	0
7.	2	2273	2655	0
8.	2	2656	3057	0
9.	2	3058	3437	0
10.	2	3438	3826	0
11.	2	3827	4205	0
12.	2	4206	4573	0
13.	2	4574	5190	1
14.	2	5191	5556	0
15.	2	5557	5937	0
16.	2	5938	6332	0
17.	2	6341	6708	0
18.	2	6709	7073	0
19.	2	7074	7445	0
20.	2	7446	7815	0
21.	2	7816	8426	1
22.	2	8427	8794	0
23.	2	8795	9166	0
24.	2	9167	9547	0
25.	2	9548	9911	0
26.	2	9912	0	0

MACHINE # 6

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS
1.	2	2	408	0
2.	2	409	777	0
3.	2	778	1158	0
4.	2	1159	1541	0
5.	2	1554	2145	1
6.	2	2146	2531	0
7.	2	2532	2896	0
8.	2	2897	3288	0
9.	2	3289	3653	0
10.	2	3654	4256	1
11.	2	4257	4643	0
12.	2	4644	5012	0
13.	2	5022	5387	0
14.	2	5389	5976	1
15.	2	5983	6585	1
16.	2	6586	7404	2
17.	2	7405	7771	0
18.	2	7781	8174	0
19.	2	8175	8548	0
20.	2	8549	8912	0
21.	2	8914	9289	0
22.	2	9290	9653	0
23.	2	9654	10017	0
24.	2	10018	0	0

MACHINE # 7

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS.
1.	2	2	412	0
2.	2	414	798	0
3.	2	809	1177	0
4.	2	1191	1588	0
5.	2	1591	1954	0
6.	2	1955	2322	0
7.	2	2323	3153	2
8.	2	3154	3527	0
9.	2	3528	4370	2
10.	2	4371	4734	0
11.	2	4737	5552	2
12.	2	5553	5938	0
13.	2	5939	6303	0
14.	2	6304	6668	0
15.	2	6669	7032	0
16.	2	7033	7622	1
17.	2	7623	8208	1
18.	2	8209	8574	0
19.	2	8576	8958	0
20.	2	8959	9332	0
21.	2	9341	9767	0
22.	2	9768	0	0

MACHINE # 8

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS
1.	2	8	429	0
2.	2	432	1266	2
3.	2	1267	1632	0
4.	2	1633	2000	0
5.	2	2001	2386	0
6.	2	2387	2751	0
7.	2	2752	3125	0
8.	2	3126	3489	0
9.	2	3490	3853	0
10.	2	3854	4228	0
11.	2	4229	4609	0
12.	2	4610	4982	0
13.	2	4983	5351	0
14.	2	5352	5718	0
15.	2	5719	6082	0
16.	2	6083	6470	0
17.	2	6472	6850	0
18.	2	6851	7214	0
19.	2	7215	7610	0
20.	2	7611	7975	0
21.	2	7976	8357	0
22.	2	8358	8968	1
23.	2	8969	9350	0
24.	2	9351	0	0

MACHINE # 9

DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS	
1.	2	8	432	0
2.	2	435	834	0
3.	2	843	1218	0
4.	2	1219	1593	0
5.	2	1595	2458	2
6.	2	2459	2824	0
7.	2	2825	3418	1
8.	2	3419	3782	0
9.	2	3783	4149	0
10.	2	4150	4988	2
11.	2	4989	5356	0
12.	2	5357	5727	0
13.	2	5728	6093	0
14.	2	6101	6468	0
15.	2	6473	6851	0
16.	2	6852	7215	0
17.	2	7221	7611	0
18.	2	7612	7977	0
19.	2	7978	8364	0
20.	2	8365	8817	0
21.	2	8818	9407	1
22.	2	9408	9795	0
23.	2	9801	0	0

MACHINE # 10

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS
1.	2	8	439	0
2.	2	441	1072	1
3.	2	1075	1438	0
4.	2	1439	1805	0
5.	2	1806	2409	1
6.	2	2410	2773	0
7.	2	2774	3137	0
8.	2	3138	3515	0
9.	2	3516	3879	0
10.	2	3880	4250	0
11.	2	4251	4614	0
12.	2	4615	5253	1
13.	2	5254	5619	0
14.	2	5621	6008	0
15.	2	6009	6375	0
16.	2	6376	6975	1
17.	2	6976	7348	0
18.	2	7349	7714	0
19.	2	7715	8086	0
20.	2	8087	8462	0
21.	2	8463	9105	1
22.	2	9106	9475	0
23.	2	9476	9877	0
24.	2	9878	0	0

MACHINE # 11

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS
1.	1	8	333	0
2.	1	347	568	0
3.	1	569	802	0
4.	1	815	1035	0
5.	1	1036	1247	0
6.	1	1248	1463	0
7.	1	1464	1687	0
8.	1	1688	1900	0
9.	1	1901	2115	0
10.	1	2116	2327	0
11.	1	2328	2549	0
12.	1	2550	2884	1
13.	1	2885	3275	1
14.	1	3276	3491	0
15.	1	3492	3706	0
16.	1	3707	3919	0
17.	1	3920	4139	0
18.	1	4141	4485	1
19.	1	4486	4698	0
20.	1	4699	4925	0
21.	1	4926	5148	0
22.	1	5149	5361	0
23.	1	5363	5590	0
24.	1	5591	5808	0
25.	1	5809	6033	0
26.	1	6036	6254	0
27.	1	6255	6466	0
28.	1	6467	6975	2
29.	1	6976	7188	0
30.	1	7189	7400	0
31.	1	7401	7619	0
32.	1	7620	7836	0
33.	1	7837	8055	0
34.	1	8056	8267	0
35.	1	8268	8483	0
36.	1	8486	8712	0
37.	1	8713	8936	0
38.	1	8937	9250	1
39.	1	9291	9516	0
40.	1	9517	9728	0
41.	1	9729	10076	1
42.	1	10077	0	0

MACHINE # 12

DYE CYCLE		STARTING TIME	STOPPING TIME	# OF ADDS
1.	1	8	309	0
2.	1	310	521	0
3.	1	522	749	0
4.	1	750	974	0
5.	1	975	1186	0
6.	1	1191	1409	0
7.	1	1410	1624	0
8.	1	1627	2093	2
9.	1	2094	2353	0
10.	1	2355	2570	0
11.	1	2571	2789	0
12.	1	2790	3016	0
13.	1	3017	3228	0
14.	1	3229	3441	0
15.	1	3442	3932	2
16.	1	3941	4152	0
17.	1	4153	4380	0
18.	1	4381	4717	1
19.	1	4719	4949	0
20.	1	4950	5173	0
21.	1	5174	5385	0
22.	1	5394	5605	0
23.	1	5609	5821	0
24.	1	5822	6039	0
25.	1	6040	6255	0
26.	1	6256	6472	0
27.	1	6473	5691	0
28.	1	6692	6903	0
29.	1	6904	7121	0
30.	1	7122	7339	0
31.	1	7340	7685	1
32.	1	7686	7904	0
33.	1	7907	8118	0
34.	1	8119	8350	0
35.	1	8351	8580	0
36.	1	8581	8802	0
37.	1	8803	9016	0
38.	1	9017	9245	0
39.	1	9246	9579	1
40.	1	9580	9806	0
41.	1	9807	0	0

MACHINE # 13

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS
1.	1	8	334	0
2.	1	352	573	0
3.	1	581	792	0
4.	1	821	1048	0
5.	1	1049	1290	0
6.	1	1307	1521	0
7.	1	1527	1755	0
8.	1	1756	1968	0
9.	1	1969	2190	0
10.	1	2191	2418	0
11.	1	2419	2632	0
12.	1	2634	2845	0
13.	1	2846	3067	0
14.	1	3068	3521	2
15.	1	3522	3878	1
16.	1	3879	4120	0
17.	1	4121	4346	0
18.	1	4347	4704	1
19.	1	4705	5048	1
20.	1	5049	5283	0
21.	1	5284	5512	0
22.	1	5516	5729	0
23.	1	5730	5971	0
24.	1	5989	6202	0
25.	1	6203	6416	0
26.	1	6417	6638	0
27.	1	6639	6861	0
28.	1	6862	7086	0
29.	1	7087	7335	0
30.	1	7336	7547	0
31.	1	7550	7761	0
32.	1	7762	7991	0
33.	1	8002	8214	0
34.	1	8215	8462	0
35.	1	8463	8803	1
36.	1	8804	9031	0
37.	1	9032	9368	1
38.	1	9369	9594	0
39.	1	9555	9807	0
40.	1	9808	10058	0
41.	1	10059	0	0

MACHINE # 14

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS
1.	1	8	343	0
2.	1	352	574	0
3.	1	581	851	0
4.	1	852	1103	0
5.	1	1104	1331	0
6.	1	1332	1543	0
7.	1	1557	1772	0
8.	1	1781	1992	0
9.	1	1993	2205	0
10.	1	2206	2441	0
11.	1	2442	2656	0
12.	1	2657	2876	0
13.	1	2877	3094	0
14.	1	3101	3453	1
15.	1	3461	3672	0
16.	1	3688	3901	0
17.	1	3902	4124	0
18.	1	4125	4353	0
19.	1	4354	4592	0
20.	1	4593	4842	0
21.	1	4843	5059	0
22.	1	5060	5299	0
23.	1	5300	5570	0
24.	1	5571	5784	0
25.	1	5785	6018	0
26.	1	6020	6487	2
27.	1	6488	6729	0
28.	1	6730	7067	1
29.	1	7077	7335	0
30.	1	7336	7548	0
31.	1	7550	7837	0
32.	1	7838	8056	0
33.	1	8057	8268	0
34.	1	8269	8501	0
35.	1	8509	8721	0
36.	1	8722	8958	0
37.	1	8959	9183	0
38.	1	9184	9408	0
39.	1	9409	9656	0
40.	1	9657	9879	0
41.	1	9880	0	0

MACHINE # 15

DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS	
1.	1	14	510	1
2.	1	511	750	0
3.	1	751	1010	0
4.	1	1011	1245	0
5.	1	1246	1464	0
6.	1	1465	1689	0
7.	1	1690	2022	1
8.	1	2025	2265	0
9.	1	2266	2479	0
10.	1	2480	2699	0
11.	1	2700	2925	0
12.	1	2926	3151	0
13.	1	3152	3374	0
14.	1	3375	3586	0
15.	1	3588	3842	0
16.	1	3843	4059	0
17.	1	4077	4288	0
18.	1	4289	4530	0
19.	1	4541	4761	0
20.	1	4762	4977	0
21.	1	4979	5192	0
22.	1	5193	5419	0
23.	1	5420	5823	1
24.	1	5824	6048	0
25.	1	6049	6290	0
26.	1	6291	6525	0
27.	1	6526	6776	0
28.	1	6777	7001	0
29.	1	7002	7232	0
30.	1	7233	7469	0
31.	1	7470	7681	0
32.	1	7682	7893	0
33.	1	7907	8140	0
34.	1	8141	8352	0
35.	1	8353	8569	0
36.	1	8570	8800	0
37.	1	8801	9017	0
38.	1	9018	9523	2
39.	1	9524	9735	0
40.	1	9736	9949	0
41.	1	9950	0	0

MACHINE # 16

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS
1.	1	14	380	0
2.	1	381	630	0
3.	1	631	875	0
4.	1	876	1095	0
5.	1	1096	1313	0
6.	1	1314	1531	0
7.	1	1558	1775	0
8.	1	1781	2002	0
9.	1	2005	2221	0
10.	1	2241	2695	2
11.	1	2696	2907	0
12.	1	2908	3375	2
13.	1	3376	3587	0
14.	1	3591	3802	0
15.	1	3803	4020	0
16.	1	4021	4252	0
17.	1	4253	4479	0
18.	1	4480	4706	0
19.	1	4707	4954	0
20.	1	4955	5300	1
21.	1	5301	5514	0
22.	1	5522	5854	1
23.	1	5874	5087	0
24.	1	6088	6322	0
25.	1	6323	6539	0
26.	1	6540	6764	0
27.	1	6767	6978	0
28.	1	6979	7193	0
29.	1	7194	7577	1
30.	1	7578	7805	0
31.	1	7806	8032	0
32.	1	8033	8252	0
33.	1	8261	8473	0
34.	1	8474	8713	0
35.	1	8714	8939	0
36.	1	8940	9155	0
37.	1	9156	9640	2
38.	1	9641	9862	0
39.	1	9863	10077	0
40.	1	10078	0	0

MACHINE # 17

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS
1.	1	14	401	0
2.	1	426	855	1
3.	1	856	1088	0
4.	1	1089	1300	0
5.	1	1313	1584	0
6.	1	1585	1806	0
7.	1	1807	2018	0
8.	1	2029	2294	0
9.	1	2295	2506	0
10.	1	2507	2744	0
11.	1	2747	2968	0
12.	1	2969	3194	0
13.	1	3195	3407	0
14.	1	3408	3630	0
15.	1	3631	3846	0
16.	1	3847	4071	0
17.	1	4077	4304	0
18.	1	4305	4543	0
19.	1	4547	4761	0
20.	1	4762	5018	0
21.	1	5025	5252	0
22.	1	5253	5464	0
23.	1	5465	5677	0
24.	1	5678	5901	0
25.	1	5902	6151	0
26.	1	6152	6367	0
27.	1	6368	6591	0
28.	1	6592	6811	0
29.	1	6823	7034	0
30.	1	7035	7246	0
31.	1	7247	7472	0
32.	1	7473	7707	0
33.	1	7708	8215	2
34.	1	8216	8452	0
35.	1	8453	8666	0
36.	1	8667	8910	0
37.	1	8911	9393	2
38.	1	9394	9608	0
39.	1	9609	9880	0
40.	1	9881	0	0

MACHINE # 18

DYE CYCLE		STARTING TIME	STOPPING TIME	# OF ADDS
1.	1	14	411	0
2.	1	436	855	1
3.	1	856	1089	0
4.	1	1090	1301	0
5.	1	1313	1670	1
6.	1	1673	1891	0
7.	1	1892	2109	0
8.	1	2110	2343	0
9.	1	2344	2558	0
10.	1	2559	2807	0
11.	1	2808	3045	0
12.	1	3047	3289	0
13.	1	3290	3510	0
14.	1	3512	3742	0
15.	1	3743	3971	0
16.	1	3972	4218	0
17.	1	4219	4431	0
18.	1	4432	4643	0
19.	1	4644	4864	0
20.	1	4865	5076	0
21.	1	5077	5289	0
22.	1	5290	5743	2
23.	1	5744	5955	0
24.	1	5956	6178	0
25.	1	6179	6395	0
26.	1	6396	6641	0
27.	1	6642	6862	0
28.	1	6863	7103	0
29.	1	7104	7341	0
30.	1	7342	7726	1
31.	1	7727	7939	0
32.	1	7940	8167	0
33.	1	8168	8387	0
34.	1	8410	8632	0
35.	1	8633	8847	0
35.	1	8848	9062	0
37.	1	9063	9279	0
38.	1	9280	9500	0
39.	1	9501	9725	0
40.	1	9726	9937	0
41.	1	9942	0	0

MACHINE # 19

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADDS
1.	1	14	411	0
2.	1	438	728	0
3.	1	729	1004	0
4.	1	1005	1251	0
5.	1	1252	1608	1
6.	1	1609	1835	0
7.	1	1836	2087	0
8.	1	2088	2333	0
9.	1	2334	2550	0
10.	1	2552	2790	0
11.	1	2791	3021	0
12.	1	3022	3251	0
13.	1	3252	3464	0
14.	1	3467	3678	0
15.	1	3695	3913	0
16.	1	3914	4181	0
17.	1	4195	4465	0
18.	1	4466	4689	0
19.	1	4690	4911	0
20.	1	4912	5157	0
21.	1	5158	5388	0
22.	1	5397	5616	0
23.	1	5625	5847	0
24.	1	5848	6326	2
25.	1	6327	6551	0
26.	1	6567	6780	0
27.	1	6781	7003	0
28.	1	7004	7233	0
29.	1	7234	7500	0
30.	1	7501	7712	0
31.	1	7713	8189	2
32.	1	8190	8465	0
33.	1	8466	8698	0
34.	1	8699	8911	0
35.	1	8912	9154	0
36.	1	9155	9376	0
37.	1	9377	9601	0
38.	1	9602	9814	0
39.	1	9837	10052	0
40.	1	10053	0	0

MACHINE # 20

	DYE CYCLE	STARTING TIME	STOPPING TIME	# OF ADCS
1.	1	14	468	0
2.	1	469	691	0
3.	1	701	914	0
4.	1	915	1143	0
5.	1	1144	1552	1
6.	1	1563	1782	0
7.	1	1787	2013	0
8.	1	2031	2319	0
9.	1	2320	2537	0
10.	1	2538	2752	0
11.	1	2753	2969	0
12.	1	2970	3316	1
13.	1	3317	3532	0
14.	1	3533	3747	0
15.	1	3748	3965	0
16.	1	3968	4220	0
17.	1	4221	4432	0
18.	1	4437	4649	0
19.	1	4650	5114	2
20.	1	5137	5348	0
21.	1	5349	5602	0
22.	1	5603	5951	1
23.	1	5952	6306	1
24.	1	6310	5532	0
25.	1	6533	6777	0
26.	1	6778	7015	0
27.	1	7016	7249	0
28.	1	7251	7605	1
29.	1	7606	7817	0
30.	1	7818	8081	0
31.	1	8082	8302	0
32.	1	8303	8570	0
33.	1	8571	8809	0
34.	1	8810	9034	0
35.	1	9035	9280	0
36.	1	9281	9526	0
37.	1	9527	9738	0
38.	1	9739	9967	0
39.	1	9968	0	0

Figure E-1. Example Plot of Dyehouse Steam Demand for the Simulation Run Using the Sample Input of Appendix D

Figure E-2. Example Plot of Dyehouse Water Demand for the Simulation Run Using the Sample Input of Appendix D

Figure E-3. Example Plot of the Changes in the Volume of Hot Water in Storage for the Simulation Run Using the Sample Input of Appendix D

Figure E-4. Example Plot of the Temperature Profiles in Twenty Dye Becks in the Dyehouse of the Simulation Run Using the Sample Input of Appendix D

Appendix FDefinition of Program Variables

1. AAFO - the percentage of dyeings that required no adds.
2. AAF1 - the percentage of dyeings that required one add.
3. AAF2 - the percentage of dyeings that required two adds.
4. AAF3 - the percentage of dyeings that required three adds.
5. AAF4 - the percentage of dyeings that required four adds.
6. AAF5 - the percentage of dyeings that required five adds.
7. AF0 - the percentage of dyeings expected to require no adds.
8. AF1 - the percentage of dyeings expected to require one add.
9. AF2 - the percentage of dyeings expected to require two adds.
10. AF3 - the percentage of dyeings expected to require three adds.
11. AF4 - the percentage of dyeings expected to require four adds.
12. AF5 - the percentage of dyeings expected to require five adds.
13. APHF0 - the percentage of dyeings that required no pH adjustments.
14. APHF1 - the percentage of dyeings that required one pH adjustment.
15. APHF2 - the percentage of dyeings that required two pH adjustments.

16. ASTMC - the arithmetic average of steam consumption, lb/hr.
17. A1 - the lower limit of numbers between 0 and 999 that indicates no adds are to be made.
999>#>A1, no adds.
18. A2 - the lower limit of numbers between 0 and 999 that indicates one add is to be made.
A1>#>A2, one add.
19. A3 - the lower limit of numbers between 0 and 999 that indicates two adds are to be made.
A2>#>A3, two adds.
20. A4 - the lower limit of numbers between 0 and 999 that indicates three adds are to be made.
A3>#>A4, three adds.
21. A5 - the lower limit of numbers between 0 and 999 that indicates four adds are to be made.
A4>#>A5, four adds.
22. BCAP - the steam capacity of the boiler, lb/hr.
23. CA(I) - the quantity of water consumed during minute I, lb/hr.
24. CTT - the total quantity of water consumed during a minute of the simulation, lb.
25. CTTS - the total quantity of water consumed during the entire simulation, lb.
26. CW(I) - the quantity of cooling water used by dye beck I during the current minute, lb.
27. CWR - the quantity of fresh water required to supply fill water, lb.
28. CWT - the total cooling water requirements for the current minute, lb.
29. C1(I,J) - the amount of cooling water required during each minute of cycle step J in dye cycle I, lb.
30. EN(I) - the enthalpy of fill water filling dye beck I, Btu/lb.
31. ENCWD - the enthalpy of the available fresh water supply, Btu/lb.

- 32. ENSTW - the enthalpy of the hot water in storage, Btu/lb.
- 33. E1(I,J) - the enthalpy of the fill water to be used in cycle step J of dye cycle I, Btu/lb.
- 34. FSLEV - the level of steam consumption above which no more than NMT dye becks may begin filling up or heating up, lb steam/hr.
- 35. FW(I) - the quantity of fill water required by dye beck I during the current minute, lb.
- 36. FWRQ - the total quantity of water required to completely fill all dye becks currently in a filling cycle, lb.
- 37. FWT - the total quantity of fill water required by all dye becks during the current minute, lb.
- 38. F1(I,J) - the quantity of fill water required each minute during cycle step J of dye cycle I, lb.
- 39. HRQ - the total number of Btu's required to meet the fill water demand, Btu.
- 40. HVAP - the latent heat of vaporization of process steam, Btu/lb.
- 41. HWR - the quantity of water at the hot water storage temperature required to make up fill water, lb.
- 42. HWT - the quantity of hot water available in storage, lb.
- 43. I - the argument of do-loops.
- 44. IA(I) - a constant in the random number equation.
- 45. IAD(I) - the counter of adds made to a dyeing in dye beck I.
- 46. IADO - the number of dyeings that required no adds.
- 47. IAD1 - the number of dyeings that required one add.
- 48. IAD2 - the number of dyeings that required two adds.
- 49. IAD3 - the number of dyeings that required three adds.

- 50. IAD4 - the number of dyeings that required four adds.
- 51. IAD5 - the number of dyeings that required five adds.
- 52. IA1 - the initial value of IA(1).
- 53. IA2 - the initial value of IA(2).
- 54. IB(I) - a constant in the random number equation.
- 55. IBB1 - the initial value of IB(1).
- 56. IBCAP - the counter of the points in steam demand that exceed the maximum boiler capacity.
- 57. IBC1(I) - the counter for the time floor operator I has been on break.
- 58. IBC2(I) - the counter for the time drug room operator I has been on break.
- 59. IBF1(I) - the signal that floor operator I has been on break.
 - a. IBF1(I) = 1, operator I has been on break.
 - b. IBF1(I) = 0, operator I has not been on break.
- 60. IBF2(I) - the signal that drug room operator I has been on break.
 - a. IBF2(I) = 1, operator I has been on break.
 - b. IBF2(I) = 0, operator I has not been on break.
- 61. IBT - the counter that keeps track of the time of day.
- 62. IB1 - the break period that the simulation is currently in.
- 63. IB2 - the initial value of IB(2).
- 64. IC(I) - a constant in the random number equation.
- 65. ICS - the current cycle step number.

- 66. ICSN(I) - the number of cycle steps in dye cycle I.
- 67. ICSTC(I) - the counter of cycle step time for dye
beck I, min.
- 68. ICSTP(I) - the number of the cycle step that dye beck
I is currently executing.
- 69. IC1 - the initial value of IC(1).
- 70. IC2 - the initial value of IC(2).
- 71. IDC - the current dye cycle being used.
- 72. IDT(I) - the idle time of drug room operator I, min.
- 73. IDTT - the sum of the idle times of all drug room
operators, min.
- 74. ID1(I) - the number added to the current cycle step
number to skip the pH adjustment cycle
steps in dye cycle I.
- 75. ID2(I) - the number subtracted from the current cycle
step number to return dye cycle I to the
current step to test pH.
- 76. ID3(I) - the number added to the current cycle step
number to skip dye add cycle steps in dye
cycle I.
- 77. ID4(I) - the number subtracted from the current cycle
step number to return dye cycle I to the
cycle step where dyeing is sampled.
- 78. IFT(I) - the idle time of floor operator I, min.
- 79. IFTT - the sum of the idle times of all floor
operators, min.
- 80. IHADD(I,J) - the indicator that the final dyeing, J, in
beck I needed an add to be made. The add
was not made because IT was greater than
IWE when dyeing was sampled. A value
greater than five indicates that an add was
needed.
- 8. IHD(I) - indicates that dye beck I has been put on
hold at the end of the week.
 - a. $IHD(I) = 0$, dye beck I has not been put
on hold.

- b. $IHD(I) = 1$, dye beck I has been put on hold.
 - c. $IHD(I) = 2$, dye beck I is to be put on hold after being refilled and reloaded.
- 82. $IHDC(I,J)$ - the dye cycle used during dyeing number J in dye beck I.
- 83. IHF - the signal to put a dye beck on hold either before or after refilling and reloading.
 - a. $IHF = 1$, before.
 - b. $IHF = 2$, after.
- 84. $IHN(I)$ - the number of the dyeing currently in progress in dye beck I.
- 85. $IHTE(I,J)$ - the finishing time of dyeing number J in dye beck I.
- 86. $IHTS(I,J)$ - the starting time of dyeing number J in dye beck I.
- 87. IK - a variable used at times to represent other dimensioned variables.
- 88. $IMT(I)$ - the idle time of dye beck I.
- 89. $IMTT$ - the sum of the idle times of all the dye becks.
- 90. $IN(I)$ - a constant in the random number equation.
- 91. $INT(I)$ - the indicator of the cycle step initialization for beck I.
 - a. $INT(I) = 0$, step not initialized.
 - b. $INT(I) = 1$, step initialized.
 - c. $INT(I) = 2$, hold for one minute.
- 92. $IN1$ - the initial value of $IN(1)$.
- 93. $IN2$ - the initial value of $IN(2)$.
- 94. $IP(I)$ - the counter of the drug room job preparation time for dye beck I.

- 95. IPHO - the number of dye baths that required no pH adjustments.
- 96. IPH1 - the number of dye baths that required one pH adjustment.
- 97. IPH2 - the number of dye baths that required two pH adjustments.
- 98. IPP - the time counter used in averaging the peaks in steam consumption.
- 99. IPRP(I,J) - the preparation time required by the drug room to complete job J in dye cycle I, min.
- 100. ISCHD(I,J) - the number J dye cycle scheduled for dye beck I.
- 101. ISIT - the sum of operator and dye beck idle times, min.
- 102. IT - the time counter of the simulation, min.
- 103. ITE(I,J) - the ending temperature of cycle step J in dye cycle I, °F.
- 104. ITF - the final minute of the simulation.
- 105. ITH(I,J) - the holding temperature of cycle step J in dye cycle I, °F.
- 106. ITM(I,J) - the time during simulation when temperature reading J is made for dye beck I, min.
- 107. ITMP(I,J) - the temperature reading made at time ITM(I,J), °F.
- 108. ITS(I,J) - the starting temperature of cycle step J in dye cycle I, °F.
- 109. IWE - the time during simulation when dye becks will no longer be allowed to start up another dye cycle.
- 110. IX(I) - the seed number used to generate the next number in the sequence of random numbers.
- 111. IX1 - the initial value of IX(1).
- 112. IX2 - the initial value of IX(2).

- 113. IX3 - the random number generated.
- 114. IY - the case for which a random number is generated.
 - a. IY = 1, pH adjustment.
 - b. IY = 2, add.
- 115. I1 - a variable used to represent other variables.
- 116. I1(I) - the variable in subroutine RDM equivalent to IA(I).
- 117. I2(I) - the variable in subroutine RDM equivalent to IB(I).
- 118. I3(I) - the variable in subroutine RDM equivalent to IC(I).
- 119. I4(I) - the variable in subroutine RDM equivalent to IN(I).
- 120. I5(I) - the variable in subroutine RDM equivalent to IX(I).
- 121. J - a do-loop argument.
- 122. JB - a counting variable.
- 123. JBDR(I,J) - the indicator of drug room duty to be performed for dye cycle I when signaled at cycle step J.
 - a. JBDR(I,J) = 1, prepare dyes for add.
 - b. IBDR(I,J) = 2, prepare chemicals
 - c. JBDR(I,J) = 3, prepare dyes,
 - d. JBDR(I,J) = 4, prepare chemicals for pH adjustment.
 - e. JBDR(I,J) = 5, prepare salts.
 - f. JBDR(I,J) = 6, prepare dyes and chemicals.

- 124. JBPRP(I) - indicates that the drug room has completed the preparation needed for dye beck I.
- 125. JBT1 - selects scheme to give operators breaks.
- 126. JBT2 - selects scheme to assign operators to dye becks.
- 127. JBT3 - selects type of output to be generated.
- 128. JD - the counting variable for drug room operators.
- 129. JF - the counting variable for floor operators.
- 130. JM - the counting variable for dye becks.
- 131. JMF - the counting variable for the number of dye becks beginning fill cycles.
- 132. JMH - the counting variable for the number of dye becks beginning heating cycles.
- 133. JMT - the counting variable for the number of dye becks beginning filling or heating cycles.
- 134. K(I) - the floor operator assigned to dye beck I.
- 135. KK(I) - the drug room operator assigned to dye beck I.
- 136. LL - time remaining before cycle step if finished, min.
- 137. L1(I,J) - the length of cycle step J in dye cycle I, min.
- 138. L2(I,J) - the time in cycle step J of dye cycle I to signal that dye beck needs a floor operator, min.
- 139. L3(I,J) - the time in cycle step J of dye cycle I to signal that dye beck needs a drug room operator, min.
- 140. MC(I) - indicates that a cycle step was executing in dye beck I during current minute.
 - a. MC(I) = 1, executing.
 - b. MC(I) = 0, idling.

- 141. MF(I) - the floor operator being assigned to dye beck I.
- 142. MWT(I) - the indicator that dye machine I is idle during current minute because there was no dyeing scheduled.
- 143. NA(I) - indicator of add preparation.
 - a. NA(I) = 1, preparation completed.
 - b. NA(I) = 0, preparation not completed.
- 144. NAD(I) - the number of adds to be made to the dyeing in dye beck I.
- 145. NA1 - the integer value of A1.
- 146. NA2 - the integer value of A2.
- 147. NA3 - the integer value of A3.
- 148. NA4 - the integer value of A4.
- 149. NA5 - the integer value of A5.
- 150. NBD - the number of drug room operators that have finished breaks.
- 151. NBF - the number of floor operators that have finished breaks.
- 152. NBT(I) - the time during the day when break time I is to be given, min.
- 153. NBTL(I) - the length of break I, min.
- 154. NC(I) - indicator of chemical preparation.
 - a. NC(I) = 1, preparation completed.
 - b. NC(I) = 0, preparation not completed.
- 155. NCPH(I) - the number of times that the dye bath pH has been adjusted in dye beck I.
- 156. NCYS - the total number of minutes of machine time spent executing dye cycles.
- 157. ND - the number of drug room operators.

158. NDCU - the number of dye cycles used.
159. NDC1(I,J) - indicates if cycle step J of dye cycle I needs a floor operator.
- a. NDC1(I,J) = 1, floor operator needed.
 - b. NDC1(I,J) = 0, floor operator not needed.
160. NDC2(I,J) - indicates if cycle step J of dye cycle I needs dyes and chemicals for an add.
- a. NDC2(I,J) = 1, dyes and chemicals needed.
 - b. NDC2(I,J) = 0, dyes and chemicals not needed.
161. NDC3(I,J) - indicates if cycle step J of dye cycle I needs chemicals.
- a. NDC3(I,J) = 1, chemicals needed.
 - b. NDC3(I,J) = 0, chemicals not needed.
162. NDC4(I,J) - indicates if cycle step J of dye cycle I needs dyes.
- a. NDC4(I,J) = 1, dyes needed.
 - b. NDC4(I,J) = 0, dyes not needed.
163. NDC5(I,J) - indicates if cycle step J of dye cycle I needs chemicals for a pH adjustment.
- a. NDC5(I,J) = 1, chemicals needed.
 - b. NDC5(I,J) = 0, chemicals not needed.
164. NDC6(I,J) - indicates if cycle step J of dye cycle I needs salts.
- a. NDC6(I,J) = 1, salts needed.
 - b. NDC6(I,J) = 0, salts not needed.
165. NDC7(I,J) - indicates if drug room needs signaling during cycle step J of dye cycle I.
- a. NDC7(I,J) = 1, signal drug room.
 - b. NDC7(I,J) = 0, do not signal drug room.

166. NDC8(I,J) - indicates if next cycle step needs a floor operator during cycle step J of dye cycle I.
- a. NDC8(I,J) = 1, signal floor operators.
 - b. NDC8(I,J) = 0, do not signal floor operators.
167. NDC9(I,J) - indicates if pH adjustment is to be made during next cycle step while executing cycle step J of dye cycle I.
- a. NDC9(I,J) = 1, pH adjustment is made in next cycle step.
 - b. NDC9(I,J) = 0, pH adjustment is not made in next cycle step.
168. NDC10(I,J) - indicates if pH adjustment is completed in cycle step J of dye cycle I.
- a. NDC10(I,J) = 1, pH adjustment completed.
 - b. NDC10(I,J) = 0, pH adjustment not completed.
169. NDC11(I,J) - indicates in cycle step J of dye cycle I if add is to be made in next cycle step.
- a. NDC11(I,J) = 1, add will be made.
 - b. NDC11(I,J) = 0, add will not be made.
170. NDC12(I,J) - indicates if add is completed in cycle step J of dye cycle I.
- a. NDC12(I,J) = 1, add completed.
 - b. NDC12(I,J) = 0, add not completed.
171. NDC13(I,J) - indicates if cycle step J is the last cycle step in dye cycle I.
- a. NDC13(I,J) = 1, last cycle step.
 - b. NDC13(I,J) = 0, not the last cycle step.
172. NDC14(I,J) - indicates if it is allowable to hold dye cycle I at beginning of cycle step J.
- a. NDC14(I,J) = 1, allowable.
 - b. NDC14(I,J) = 0, not allowable.

173. NDC15(I,J) - indicates if machine is loaded and filled at end of cycle step J of dye cycle I.
- a. NDC15(I,J) = 1, loaded and filled.
 - b. NDC15(I,J) = 0, not loaded and filled.
174. NDSCH - the number of dyeings scheduled for each dye beck.
175. NDY(I) - the indicator of dye preparation for dye beck I.
- a. NDY(I) = 1, dye prepared.
 - b. NDY(I) = 0, dye not prepared.
176. NF - the number of floor operators.
177. NF1(I) - indicates the status of floor operator I.
- a. NF1(I) = 0, operator busy.
 - b. NF1(I) = 1, operator free.
 - c. NF1(I) = 3, operator on break.
178. NF2(I) - indicates the status of drug room operator I.
- a. NF2(I) = 0, operator busy.
 - b. NF2(I) = 1, operator free.
 - c. NF2(I) = 3, operator on break.
179. NF3(I) - indicates if dye beck I needs or does not need a floor operator.
- a. NF3(I) = 0, no operator needed.
 - b. NF3(I) = 1, operator needed.
180. NF4(I) - indicates if dye beck I needs or does not need a drug room operator.
- a. NF4(I) = 0, no operator needed.
 - b. NF4(I) = 1, operator needed to prepare add.
 - c. NF4(I) = 2, operator needed to prepare chemicals.

- d. NF4(I) = 3, operator needed to prepare dyes.
 - e. NF4(I) = 4, operator needed to adjust pH.
 - f. NF4(I) = 5, operator needed to prepare salts.
 - g. NF4(I) = 6, operator needed to prepare dyes and chemicals.
- 181. ND5(I) - indicates whether or not to free floor operator I for reassignment.
 - a. NF5(I) = 1, free floor operator.
 - b. NF5(I) = 0, do not free floor operator.
- 182. NF6(I) - indicates whether or not to free drug room operator I for reassignment.
 - a. NF6(I) = 1, free drug room operator.
 - b. NF6(I) = 0, do not free drug room operator.
- 183. NLDS - the total number of unloads during the simulation.
- 184. NM - the number of dye becks.
- 185. NMF - the maximum number of dye becks allowed to begin filling at the same time.
- 186. NMH - the maximum number of dye becks allowed to begin heating at the same time.
- 187. NMHD - the number of dye becks on hold at the end of the simulation.
- 188. NMT - the maximum number of dye becks allowed to heat-up or fill-up when steam consumption is above FSLEV.
- 189. NN - replaces IHN(I) in do-loop.
- 190. NNP - call number of symbol to be plotted in temperature profile plot.

- 191. NPA(I) - indicates the completion of pH adjustment for dye beck I.
 - a. NPA(I) = 1, pH adjustment completed.
 - b. NPA(I) = 0, pH adjustment not completed.
- 192. NPH(I) - the number of pH adjustments that must be made to the dye bath in dye beck I.
- 193. NPK - the number of peaks in steam consumption to be averaged.
- 194. NPTS - the number of points to be plotted.
- 195. NR1 - the integer value of R1.
- 196. NR2 - the integer value of R2.
- 197. NSCH(I) - current position in dye cycle schedule for dye beck I.
- 198. NSLT(I) - indicates the completion of salt preparation.
 - a. NSLT(I) = 1, salts prepared.
 - b. NSLT(I) = 0, salts not prepared.
- 199. NTMP(I) - the number of temperature readings made for dye beck I.
- 200. N1 - NPTS + 1, used in plots.
- 201. N2 - NPTS + 2, used in plots.
- 202. OFLW - the pounds of water overflowing the hot water storage tank during current minute.
- 203. OFW(I) - the overflow of hot water storage during minute I, lb/hr.
- 204. OFWT - the total overflow of hot water tank during simulation, lb.
- 205. PEAKS - the sum of the peaks in steam consumption.
- 206. PEAK1 - the peak in steam consumption over a prescribed time interval, lb. steam/hr.

- 207. PHFO - the percentage of dye baths expected to require no pH adjustments.
- 208. PHF1 - the percentage of dye baths expected to require one pH adjustment.
- 209. PHF2 - the percentage of dye baths expected to require two pH adjustments.
- 210. RN1(I,J) - the overflow rinse water used each minute in cycle step J of dye cycle I.
- 211. RW(I) - rinse water to overflow required by dye beck I, lb.
- 212. RWT - total rinse water required during a minute, lb.
- 213. R1 - the lower limit of numbers between 0 and 999 that indicates no pH adjustments.
R1>#>R2, 1 pH adjustment.
R2>#>0, 2 pH adjustments.
- 214. R2 - the lower limit of numbers between 0 and 999 that indicates one pH adjustment.
R1>#>R2, 1 pH adjustment,
R2>#>0, 2 pH adjustments.
- 215. SA(I) - the steam consumption during minute I, lb/hr.
- 216. SLEV - the level of steam consumption above which no dye beck may begin filling up or heating up, lb. steam/hr.
- 217. STL - the capacity of the hot water storage tank, gal.
- 218. STM(I) - the steam consumed by dye beck I, lb.
- 219. STMPRS - the pressure of the process steam, psia.
- 220. STMR - steam required to heat fill water, lb.
- 221. STMT - the total steam required by dye cycles during current minute, lb.
- 222. STT - the total steam used during current minute, lb.
- 223. STTS - the total steam consumption for simulation, lb.

- 224. STW - the quantity of hot water currently in storage, lb.
- 225. SVOL - specific volume of water at storage temperature, ft^3/lb .
- 226. SW(I) - hot water in storage during minute I, lb.
- 227. SW1 - the initial value of SW(I), lb.
- 228. SW2 - the final value of SW(I), lb.
- 229. S1(I,J) - the steam consumed each minute when executing cycle step J of dye cycle I, lb.
- 230. S2(I,J) - the steam consumed each minute when holding at beginning of cycle step J of dye cycle I, lb.
- 231. TADS - the total number of adds made.
- 232. TMP1 - the temperature of fresh water, $^{\circ}\text{F}$.
- 233. TMP2 - the temperature of stored water, $^{\circ}\text{F}$.
- 234. TMPS - the temperature of steam, $^{\circ}\text{F}$.
- 235. TPH - the total number of pH adjustments made.
- 236. X(I) - the array of X-coordinates to be plotted.
- 237. XH1(I) - the X-axis label for steam plot.
- 238. XH2(I) - the X-axis label for water plot.
- 239. XH3(I) - the X-axis label for storage plot.
- 240. XL - the length of the X-axis, in.
- 241. XX - a distance in X-direction relative to origin, in.
- 242. XX1 - a distance in X-direction relative to origin, in.
- 243. XX2 - a distance in X-direction relative to origin, in.
- 244. Y(I) - the array of Y-coordinates to be plotted.
- 245. YH1(I) - the Y-axis label for steam plot.

- 246. YH2(I) - the Y-axis label for water plot.
- 247. YH3(I) - the Y-axis label for storage plot.
- 248. YL - the length of the Y-axis, in.
- 249. YY - a distance in the Y-direction from origin,
 in.
- 250. Z(I) - the array of Z-coordinates to be plotted.

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