Proceedings of the 1998 Winter Simulation Conference
D.J. Medeiros, E.F. Watson, J.S. Carson and M.S. Manivannan, eds.

MODELLING FURNACE OPERATIONS USING SIMULATION AND HEURISTICS

Bala Ram
Gunvant Patel

Department of Industrial Engineering
North Carolina Agricultural and Technical State University
Greensboro, NC 27411, U.S.A.

ABSTRACT

This work addresses the heat treatment operation in a manufacturing plant. The heat treatment operation is characterized by process times ranging from 7 hours to 112 hours. The immediate prior operation to heat treatment is turning. Currently, the batches loaded in heat treatment, often do not use furnace capacity adequately. This paper describes the use of heuristics and simulation to model *batch-loading* and *scheduling* in the furnace operation. The *batch-loading* operation is complex and involves issues relating to geometry, and heterogeneity in the parts and their processing requirements. Currently, the *batch-loading* is accomplished by operator ingenuity; however, parts available from turning for loading onto the furnaces, limit the operator. The limitation on parts available for *batch-loading* is due primarily to the use of a conventional "push" system used for scheduling. The model being proposed here has two facets to address the *batch-loading* and *scheduling* problems. A heuristic-based approach is proposed for the *batch-loading* task. This heuristic forms batches for heat treatment based on anticipated production from turning; in addition, the heuristic provides feedback to turning for adjustments to its production plan. Results from a solution to the batch-loading problem are integrated into a discrete-event simulation model for the heat treatment and turning operations.

1 INTRODUCTION

In this section we identify the context of the heat treatment operation, we provide details of the batch-loading task at the furnaces, and the current "push" system of production control. With this background we identify the issues we seek to model.

1.1 Heat Treatment Operations

The manufacturing company addressed here makes cylindrical parts. The outer diameter (OD), inner diameter (ID), and width characterize these parts. The process steps for these parts are briefly described here.

The first operation is ring rolling, in which a steel tube is cut based on final part size and then the ring is heated for a rolling operation to give a specified dimension to the ring. The turning operation follows ring rolling. At turning, a ring is converted into a specific part blank with a finishing tolerance. The next operation is heat treatment. At heat treatment a batch of part blanks is formed (*batch-loading* task) and the batch is processed in the furnace in order to give them a specified case depth. After heat treatment, finishing operations are performed on a part. Finishing operations include grinding, turning and assembly. A schematic for process flow is shown in Figure 1.

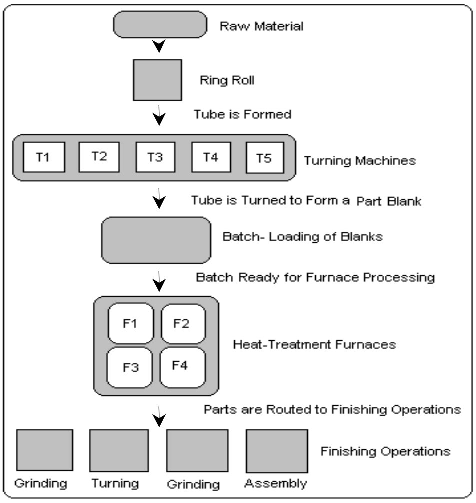

Figure 1: Process Flow

Furnaces are used for heat treatment processes. In the furnace a batch of parts is loaded and depending on the part specification, a case depth is applied to the part. The case depth is achieved through a combination of several factors including temperature, pressure, percent carbon injection, and cycle time.

1.2 Batch-Loading Task

There are five different types of products. These products are manufactured from two different types of material. Each product has different OD, ID, and width. Each product has different specifications for the heat treatment process. Consequently, there are about 500 type of parts that go through the heat treatment process.

Parts are loaded in a basket to form a batch and then the batch is processed in the furnace. A mix of part sizes is placed in a basket to form a layer. When a layer is complete, a perforated screen is placed on top of the parts, and the next layer is built on top of previously built layer. Several rules need to be followed in building a batch; considerations of part inner and outer diameters, height, and processing required in furnace (termed "recipe").

Basket loading or the *batch-loading* task determines the throughput of furnace system. In the following, the rules that must be adhered to are stated in four categories

1. Part size and type:
   - parts in a layer have to have the same height;
   - if ID of outer part is x millimeters then the OD of inner part must be (x – 50) millimeters maximum, to keep 25 mm distance between the parts;
   - all parts in a basket must be made from the same material;
2. Recipe:
   - there are a total of 30 recipes (see Table 1), 15 for each material type; these recipes are characterized by a cycle time, a temperature profile, and a profile for the rate of carbon injection; Table 1 shows only the cycle times;
   - in a single basket, parts with recipe numbers within a three-number range are permissible, for example, parts with recipe numbers 3 thru' 5 are permitted to be loaded on the same basket;
3. Order Priority:
   - three different priorities exist: first "A" , next "B", and next "E".
4. Nesting:
   - parts can be nested in a layer; "nesting" implies putting parts within the ID of another part;

1.3 "Push" Scheduling System

The essential idea of a "push" system is illustrated in Figure 2. In a "push" scheduling system, parts (which constitute inventory) are built at all stages of processing in the production line based on projected demand. These inventories can become larger when there are imbalances in the production line.

Table 1: Recipes Used in Heat Treatment

Material 1		Material 2	
Recipe	Cycle Time (hr)	Recipe	Cycle Time (hr)
1	7.00	16	11.45
2	8.45	17	13.35
3	9.00	18	15.15
4	11.30	19	16.45
5	12.35	20	20.20
6	14.30	21	23.15
7	18.00	22	26.10
8	20.15	23	31.20
9	23.15	24	34.20
10	26.30	25	42.20
11	30.00	26	47.25
12	38.45	27	59.25
13	46.40	28	67.30
14	77.50	29	87.45
15	96.00	30	112.00

Figure 2: "Push" Manufacturing System

Currently, the planning department develops a production plan under this approach. The plan assigns priorities to different orders and sequences the orders for processing. Based on this plan the shopfloor picks up orders for processing. Such a plan does not take into account the rules to be adhered to in batching parts for the heat treatment operation. Consequently, the heat treatment department could become a bottleneck due to a low utilization of the baskets in the batch-loading task.

1.4 Problem and Modeling Need

Two problems are identified in the current operations. These center on heat treatment.

1. The batch-loading task is critical to effective utilization of the furnaces in heat treatment. This is currently done manually by the operator who is also responsible for monitoring the furnace processes.
2. The "push" system used for scheduling the turning operation prior to heat treatment often results in not having a "good" mix of parts ready for heat treatment'. A "good" mix has the potential to result in a high utilization of the baskets loaded into the furnaces.

2 RELEVANT LITERATURE

Here we present literature pertinent to the problem under consideration.

2.1 Loading Problem

Extensive research has been done on the loading problem. The previous efforts were directed towards the pallet loading and bin packing problems. The broad context and classification of 'cutting and packing' problems are presented in various books and research articles. Cutting problems or problems such as cutting stock, trim-loss problems, packing/loading problems such as vehicle, container, bin and pallet loading have a similar logical structure (Ram, 1992). These problems belong to the field of geometric combinatorics. Cutting and packing problems establish that improvement in the area of batch preparation for furnaces under multiple rules can benefit from research.

2.2 Push vs. Pull Scheduling

There are two basic types of scheduling systems, the push and the pull. The push system is associated with a fully integrated Manufacturing Resource Planning (MRPII) package that is designed to launch, realign, and cancel purchase and manufacturing orders predicted based upon projected demand (Louis, 1997). This is accomplished through the master production schedule, which encompasses customer orders and/or forecast, which in turn drive a material requirement planning (MRP) module. The MRP module determines what purchase and production orders needs to be launched, realigned, or canceled to support the master production schedule. Regardless of whether consumption is taking place or not, MRP will continue to demand that all items be procured or manufactured until a new explosion (computer calculation based upon a new master production schedule) is executed. This explosion will advise the user, by part number, what action to take.

The reorder point system and manual Kanban system are examples of a pull system. Basically, these pull systems employ a predetermined quantity on-hand for each part number, and consumption triggers replenishment. JIT sets up a pull system in contrast to the prevailing push system. By pulling rather than pushing orders through the plant, it sets up a series of internal customers that trigger movement of parts. If there is no demand, there is no activity (Stasey and McNair, 1997).

In practice, process planning and production scheduling activities are typically handled independently, and are carried out in a rigid, sequential manner with very little communication. Process alternatives are traded off strictly from the standpoint of engineering considerations and plans are developed without consideration of the current ability of the shop to implement them in a cost-effective manner. Production scheduling is performed under fixed process assumptions and without consideration of the opportunities that process alternatives can provide for acceleration of production flows. This lack of coordination leads to unnecessarily long order lead times and increased production costs and inefficiencies.

2.3 Heuristics

The field of heuristics within the area of optimization is extremely important to solve larger and more complex problems. Heuristics are methods, which seek good solutions (not necessarily an optimum). When the situation is very complex and traditional optimization methods are inadequate, heuristics are best suited to provide good solutions with the less effort.

There are a number of heuristic techniques that have contributed to the scheduling problem. They fall roughly into three category (a) Intensification/diversification method (b) Bottleneck method and (c) Expert systems, mixed AI/OR/DSS systems. Some heuristic methods are applicable to a wide classes of problem. Others are *ad hoc* 'rules of thumb' only applicable to the very specific class of problems for which they were designed (Morton and Pentico 1993).

2.4 Simulation

Simulation is a technique, wherein a model of a system, is run in compressed time, to perform experimentation for analyzing system performance (Harrell et al, 1996). Simulation has been used extensively in conjunction with optimization or heuristic methods; the role of simulation in such applications, is to study the effect of the decisions provided by the optimization or heuristic models. We have used QUEST (Queueing Event Simulation Tool) software in our work. The reason for the choice is primarily the capabilities in QUEST to interface with other languages in which the optimization or heuristic model may be implemented.

3 A MODEL

Two problems were identified in the existing manufacturing operation in the section 1.4. We present an

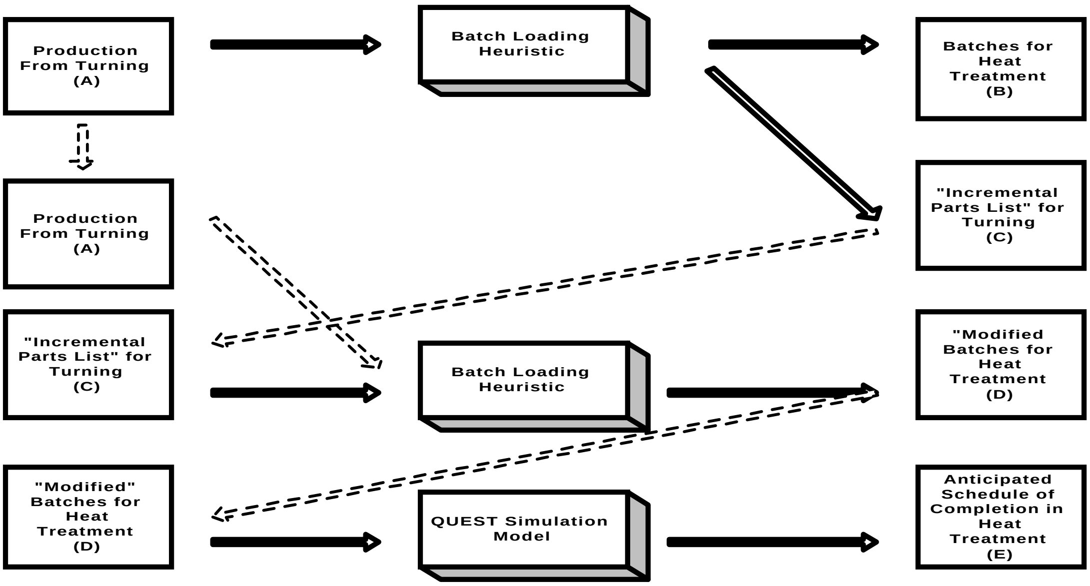

Figure 3: Overall Model

overall model, for this problem (shown in figure 3), which has the features listed below.

1. The batch-loading task will have automated decision support through modeling. An approach based on heuristics is proposed. This will improve the quality and consistency of the batch-loading task.
2. The heuristic will also create an "incremental list" of parts for the turning department. This list will improve the utilization of baskets being loaded into the furnace.
3. A third piece in the overall model is a discrete-event simulation of the heat treatment process, to generate anticipated schedule of production from heat treatment.

Table: 2, 3, 4 and 5 along with figure 4 explains the detail of overall model in figure 3.

A production plan and information received from turning forms a basis for input to the batch loading heuristic (A in Figure 3, details in Table 2). The output

Table 2: Details of Parts from Turning

Order #	Part #	Order Qty	Recipe #	OD (mm)	ID (mm)	Height (mm)	Turning Status
1021	A01	240	6	270.6	235.4	72.3	Completed
1022	A02	82	10	382.5	341.2	104.5	Completed
1023	B01	80	11	285.9	225.0	104.5	Not Started
1024	B02	225	7	175.3	145.8	72.3	Not Started
1025	C01	30	9	375.5	285.4	147.6	In Process
1026	D05	65	11	173.4	135.7	104.5	Completed

Table 3: Details of Potential Batches for Heat Treatment

Basket #	Order #	Part #	Order Qty	Recipe #	OD (mm)	ID (mm)	Height (mm)
1	1021	A01	120	6	270.6	235.4	72.3
2	1021	A01	120	6	270.6	235.4	72.3
3	1022	A02	42	10	382.5	341.2	104.5
	1026	D05	42	11	173.4	135.7	104.5
4	1022	A02	40	10	382.5	341.2	104.5
	1026	D05	23	11	173.4	135.7	104.5

Table 4: Details of Incremental Parts List for Turning

Basket #	Order #	Part #	Order Qty	Recipe #	OD (mm)	ID (mm)	Height (mm)
1	1024	B02	120	7	175.3	145.8	72.3
2	1024	B02	105	7	175.3	145.8	72.3
3	1023	B01	42	11	285.9	225.0	104.5
4	1023	B01	38	11	285.9	225.0	104.5
5	1025	C01	30	9	375.5	285.4	147.6

Table 5: Details of "Modified Batches" for Heat Treatment

Basket #	Order #	Part #	Order Qty	Recipe #	OD (mm)	ID (mm)	Height (mm)
1	1021	A01	120	6	270.6	235.4	72.3
	1024	B02	120	7	175.3	145.8	72.3
2	1021	A01	120	6	270.6	235.4	72.3
	1024	B02	105	7	175.3	145.8	72.3
3	1022	A02	42	10	382.5	341.2	104.5
	1023	B01	42	11	285.9	225.0	104.5
	1026	D05	42	11	173.4	135.7	104.5
4	1022	A02	40	10	382.5	341.2	104.5
	1023	B01	38	11	285.9	225.0	104.5
	1026	D05	23	11	173.4	135.7	104.5
5	1025	C01	30	9	375.5	285.4	147.6

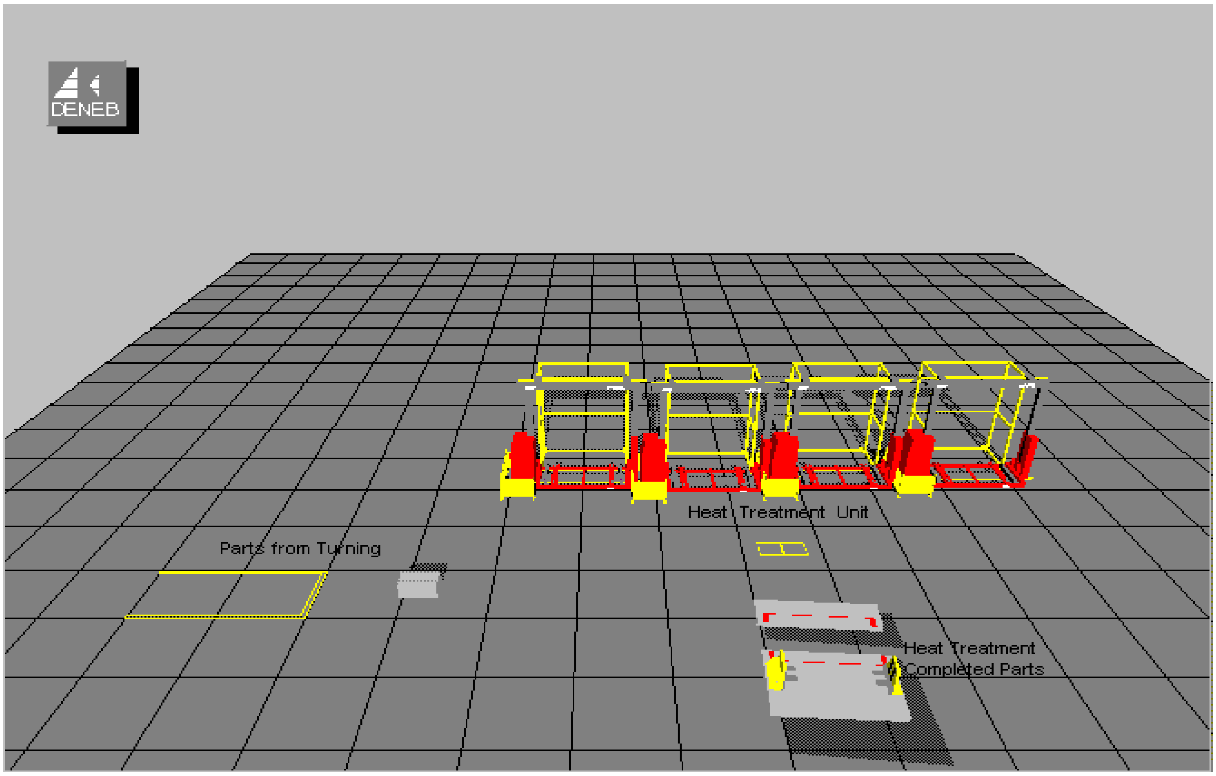

Figure 4: A Simulation Model for Anticipated Schedule of Completion of Batches in Heat Treatment

of heuristic explains the combination of orders that can be nested in a common basket and a specific basket in which those order(s) can go (B in Figure 3, details in Table 3). It also creates an incremental parts list (out-standing orders) which can also go along with other order(s) in a common basket (C in Figure 3, details in Table 4). For example if basket #1 has three candidate orders and turning status for individual order is completed, in-process and not started. The orders with turning status in-process and not started creates an incremental parts list. Using information from table 3 and 4, a new input is generated for batch loading heuristic. The output of heuristic now gives modified baskets ready for the heat treatment (D in Figure 3, details in Table 5).

A simulation model (refer to Figure 4) is developed using the output of above explained heuristic. Output of simulation gives an anticipated schedule of completion in heat treatment.

3.1 Heuristics for the Batch-Loading Problem

The general steps in the heuristic are as follows:

1. Create list of parts available for loading: A list of parts will be created from production plan database associated with turning. The following attributes of the individual parts will be retrieved from the database: order number, due date, part number, OD, ID, width, material, recipe number, order quantity and priority. We refer to this list as "P".
2. Sort parts list by material type: This step is necessary, as material types cannot be mixed in a basket. The resulting list will be called "P1" and "P2" for the two material types.
3. Sort P1 and P2 by recipe number: This step will help ensure that only a three number range of recipe is assigned to a single basket. The resulting list will be called "P1r" and "P2r" where "r" denotes the recipe number which could P2r range from 1 to 30 (see Table 1).
4. Create candidate list for baskets: Starting with "P1r" and "P2r" lists create groups of parts that can be in a single basket based on the "three-number range of recipes" criterion. There are several ways of doing this step; one way is chosen arbitrarily. The resulting lists will be called "CB_i" where i denotes a basket number. A "CB_i" list may have more parts than can be accommodated in a basket.
5. Check for nesting: For each list "CB_i", check if any parts satisfy the nesting criterion, i.e. the OD of the nested part is less than ID of any other part by 50 mm or more (see rules in "Batch-Loading task" section). Delete nested part from corresponding "CB_i" list, flag part that will nest this part, and add the nested part to "NP" list.
6. Create candidate list for each layer: For each list "CB_i", consider the part widths, to creat lists "Cb_iL_j" where j is a layer number. Parts with the same width are assigned to a layer.
7. List for each layer: Use an algorithm for the two-dimentional cutting stock/loading problem to create list of parts that can be accommodated in a layer while considering geometric constraints. The resulting lists are "RCb_iL_j" where j is a layer number. The number of layer lists created may increase when geometric constraints are imposed. Each layer list is assigned an identification number R.
8. Create layer list for each basket: Consider the revised list for each layer "RCb_iL_j". The layers that can be accommodated in a basket depends on the layer heights and the basket height. These two factors are considered to create lists "LB_i". Each LB_i consists of one or more layer identification numbers j. Lists "LB_i" and "RCb_iL_j" form a solution to the batch loading task problem.

3.2 Simulation for Heat Treatment

Figure 4 and 5 are two representations of the same simulation model. Table 5 provides the input for the simulation model. The heat treatment process has four identical furnaces, which can process one basket at a time. The largest recipe number represented in a basket determines the duration of heat treatment. Setup times for each batch are small and have been included in the cycle times for each recipe. The QUEST model for the heat treatment process has the basket as entities, and the four furnaces as the process. This simple model yields the anticipated schedule of completion of heat treated parts.

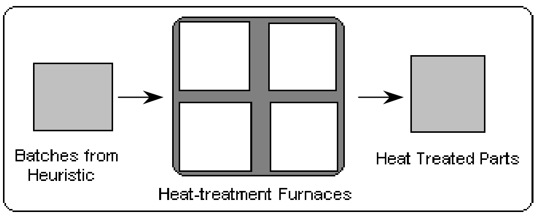

Figure 5: A Simulation Model for Heat Treatment

4 RESULTS

The heuristic part of this model will provide a decision support to the furnace operator to help decide which orders to load in a basket. It will also find a possible match of orders that can be nested together in a basket to increase furnace utilization. This decision support tool will help bring consistency and efficiency to the batch-loading task. The simple simulation model will help provide a projection of the completion of orders in heat treatment.

The heuristic is being developed in Visual Basic and the simulation model in QUEST.

REFERENCES

Morton T. E. and Pentico D. W. 1993. *Heuristic Scheduling Systems*, 26-33.

Louis R. S. 1997. *Integrating Kanban with MRPII,* 3-5.

Stasey R. and McNair C. J. 1990.*Crossroads, A JIT Success Story*, 15-21.

Ram B. 1992. The Pallet Loading Problem: A servey. *International Journal of Production Economics* 217-225.

Harrell C. R., Bateman R. E., Gogg T.J., and Mott J. R. A. 1996. *System Improvement Using Simulation,* 2-14.

AUTHOR BIOGRAPHIES

BALA RAM is a Professor in the Department of Industrial Engineering at North Carolina A&T State University in Greensboro, NC. His research interests include manufacturing systems discrete event simulation, operation research, and material handling. He holds a BSME and MSIE from the Indian Institute of Technology, Madras, India and a Ph.D. from the State University of New York at Buffalo.

GUNVANT PATEL is a MSIE candidate in the Department of Industrial Engineering at North Carolina A&T State University. He holds a BSIE degree from Saurashtra University in India.