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THE TIMKEN COMPANY'S GAMBRINUS THERMAL TREATMENT FACILITY SCHEDULING SYSTEM

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ABSTRACT

The Gambrinus Thermal Treatment Facility (GTTF) is responsible for thermal treating The Timken Company's alloy steel products. At the GTTF, scheduling problems have resulted from both physical and operating constraints.

The Gambrinus Thermal Treatment Scheduling System (GSS) was developed to better manage GTTF order due-date and plant throughput performance. The system is composed of three components: the order data collection program, order manager, and the simulation scheduler. The components are fully integrated via the GSS interface program. The simulation scheduler automates the majority of routine scheduling decisions, and provides capabilities to recover from unplanned events such as furnace breakdowns. Additionally, the scheduler provides "what-if" capabilities to test scheduling alternatives and opportunities.

The simulation based scheduler is capable of forecasting very accurate schedules and can also be used as a continuous improvement analysis tool. Since the scheduling system has been released into production, substantial improvements have been made to GTTF's future order visibility and overall scheduling effectiveness. Consequently, GTTF is reporting increases in both order due-date and plant throughput performance.

1 INTRODUCTION

The Gambrinus Thermal Treatment Facility (GTTF) is a part of The Timken Company's Gambrinus Steel Plant (GSP) in Canton, Ohio. The GTTF is responsible for thermal treating Timken's alloy steel products. The alloy steel products include seamless tubing, solid bars, and wires. The GTTF consists of seven roller furnaces, nine car furnaces and one tunnel furnace. Thermal treating is a process that is used to produce a precise steel hardness and micro structure characteristics, and other mechanical properties.

Historically, the GTTF has been considered to be a difficult plant to schedule. Scheduling problems have resulted from furnace operation, size, temperature and speed limitations, and the sheer complexity of the thermal treatment process.

It should be noted that thermal treatment is one of many operations that must be performed before an order can be shipped to the customer. At the Timken Company, specifically, the Steel Business Unit (SBU), the overall order operation route is specified by the Standard Order Routing (SOR). There exist hundreds of SOR's, which may vary in total number of operations and actual performed operations. Shown below in Table 1 is an example of a typical SOR.

CODE	OPERATION
101	Pickle
901	HC Anneal
271	Scale Break
102	Pickle
201	Roll Str
941	Stress Relieve
301	Cut
103	Pickle
681	Final Inspect
991	Met Release & Ship

Table 1 - Standard Order Routing Example

In this example, the GTTF performs two operations on the order, 901, High Carbon Anneal, and, 941, Stress Relieve. The GTTF operations are highlighted in Table 1 by boxes.

When analyzing the GTTF's scheduling practice, two problems arose that directly reduced the plant's overall scheduling effectiveness and capability:

1. The GTTF had limited and incomplete future order visibility.
2. The GTTF had difficulty implementing a specific scheduling philosophy designed to manage furnace utilization and order due-date performance.

2 SCHEDULED OPERATIONS

There are eight thermal treatment operations that are scheduled at the GTTF. The GTTF operations include High Carbon Anneal, Low Carbon Anneal, Process Anneal, Temper, Stress Relief, Normalize, Quench, and Process Temper. A general description of the GTTF operations is given below (The Timken Company 1990).

Annealing is a treatment consisting of heating the steel uniformly to a temperature within or above the critical range and cooling at a controlled rate to a temperature under the critical range. This treatment is used to produce a definite microstructure, usually one designed for best machinability, or to remove stresses, induce softness, and alter ductility, toughness or other mechanical properties.

Tempering consists of heating the product uniformly to a temperature under the critical range, holding at that temperature for a designated period of time, and cooling in air. The treatment is used to produce one or more of the following end results:

1. The process temper treatment is used to soften the material for subsequent machining or cold working.
2. In addition, tempering is used to improve ductility and relieve stresses resulting from prior treatment of cold working.
3. Finally, the temper treatment is used to produce the desired mechanical properties or structure in the second step of a double treatment.

The stress relief process is used to denote a final thermal treatment when stress free material is desired. Its purpose is to restore elastic properties and minimize distortion on subsequent machining or hardening operations. This treatment is usually applied on material that has been heat treated (quenched and tempered). Normal practice would be to heat to a temperature 100 degrees F lower than the tempering temperature used to establish mechanical properties and hardness.

The normalizing process involves heating the product uniformly to a temperature at least 100 degree F above the critical range and cooling in air to room temperature. This treatment produces a re-crystallization and refinement of the grain structure and gives uniformity of structure and hardness to the product.

Quenching is a treatment consisting of heating the product uniformly to a temperature above the critical range and cooling rapidly in a liquid medium. GTTF can quench product in either oil and water.

For each GTTF order that is processed, a thermal treatment analyst must apply a thermal treatment. This consists of assigning both furnace temperature and process duration. The thermal treatment is determined by operation type, mill type, physical properties, and product size. The process duration can vary from 2 to 80 hours depending on the particular operation being performed.

3 SCHEDULED RESOURCES

There are three basic types of resources at the GTTF, roller, car, and tunnel furnaces. All furnace types are used to thermal treat steel.

3.1 Furnace Operation Capability

The GTTF furnaces have different operation capabilities. For most operations, a variety of furnaces may be selected, which provides some scheduling flexibility. It should also be noted that car furnaces have equivalent operational capabilities, and therefore are substantially more flexible than the roller or tunnel furnaces (Bouer 1990).

The roller and tunnel furnaces can be limited by the thermal treatment operation. For example, roller furnace number one is the only furnace that can process an atmospherically controlled thermal treatment. In addition, some of the furnaces may be restricted by size and speed limitations.

3.2 Furnace Charge Definition

All orders of steel are divided into charges regardless of furnace type. A charge is a load of steel that is processed in a furnace. A charge may consist of a single order or several orders, which is based on piece size and number.

In general, the charge size is determined by furnace height, width, length and physical order piece dimensions (outer diameter and length). For the roller furnaces, individual piece weight can limit the charge size due to roller weight capacity restrictions. The number of charges in an order is determined by the total number of pieces in the order and the charge size.

3.3 Roller Furnace Description

There are seven roller furnaces at the GTTF, roller furnace number one through number seven. All roller furnaces process orders in a continuous manner.

Fig. 1, shown below, illustrates how the roller furnace operates.

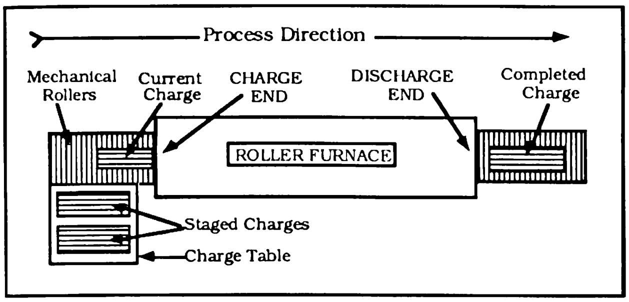


Figure 1: Roller Furnace

Orders are broken down into charges and placed on the mechanical rollers at the charge end of the furnace, via an overhead crane. Charges are constructed by placing the pieces along the width of the roller furnace. If more than one charge exists for an order, then consecutive charges are processed until all have been charged into the furnace. The charges are advanced through the furnace at the set roller speed and furnace temperature. A furnace can process more than one order simultaneously. However, those orders are restricted by the current thermal treatment. After a charge has completed processing, the overhead crane removes the charge from the discharge end of the furnace. All pieces are collected and baled, then released from the GTTF to the next work center given by the order's SOR.

3.4 4 Car Furnace Description

There are nine car furnaces at the GTTF. The car furnace is illustrated in Fig. 2. The cars, unlike the roller and tunnel furnaces, process product in a batch fashion.

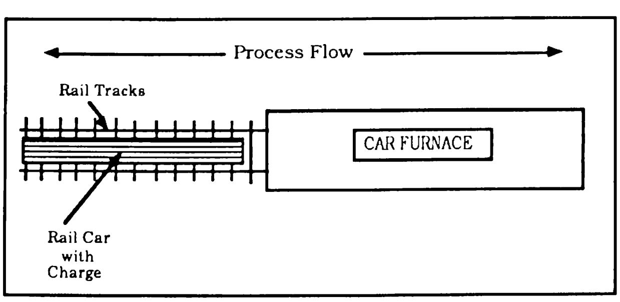


Figure 2: Car Furnace

All car furnaces have a single entry and exit point where the steel is charged and discharged from the furnace. Material is loaded onto a rail car, then moved into the furnace for processing. A charge is built to maximize the car's length, width and height capacity. After processing has been completed, the car is moved out of the furnace and unloaded by way of an overhead crane. Differences between the car furnaces exist in their physical size dimensions, but all are equivalent in operational capabilities.

3.5 Tunnel Furnace Description

There is only one tunnel furnace at the GTTF. The tunnel is considered a hybrid car-roller furnace. The charges are constructed much like the car furnace. However, the tunnel operates in a continuous manner similar to a roller furnace. Fig. 3, below, illustrates how the tunnel functions.

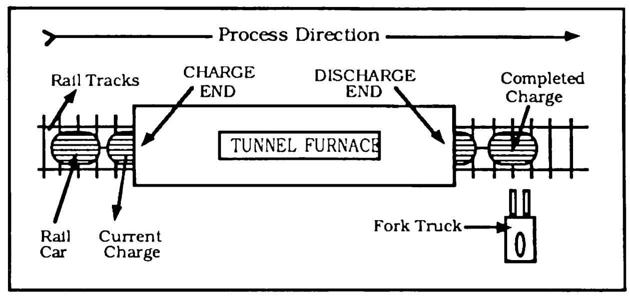


Figure 3: Tunnel Furnace

The product is loaded into the tunnel at the charge end and is removed at the discharge end. After the charge has finished processing, the rail car is unloaded and moved back to the charge end by a fork lift truck. Differences between the tunnel and roller furnaces exist in the mechanism in which the steel is physically advanced through the furnace. That is, the tunnel furnace moves the steel by way of rail cars, while the roller furnaces use mechanical rollers.

3.6 GTTF Scheduling Objectives

The GTTF scheduler employs the following scheduling objectives when creating the daily furnace schedules.

1. The scheduler attempts to schedule all orders on time. A GTTF due-date performance record is maintained to measure order timeliness.
2. Along with order timeliness, orders must be run within the predetermined operation queue time (lead time). Order lead times are determined by the operation type.
3. Furnace utilization is a measure of the proportion of time a machine is busy. The scheduler must operate the furnaces so that they are used efficiently.
4. Related to furnace utilization, the scheduler must be concerned with keeping energy costs down.

The objectives as a whole make scheduling the GTTF very complex. When maximizing furnace utilization, orders will be run that best match current furnace setups. Although this strategy will increase the overall plant throughput, typically order due-date performance will suffer. When the plant is run strictly by due-dates, furnace utilization falls off, energy costs increase, and the plant can become buried in work. As a result, a comprehensive scheduling methodology needs to be developed that best manages GTTF furnace utilization and order due-date performance.

3.7 Load on Plant

The load on GTTF is defined by the tonnage or number of bales of steel that are delivered to the plant daily. The plant load varies from day to day, which can be attributed to order mix of up stream production and economic factors. Typically, the GTTF receives approximately 5 to 500 orders per day with each order averaging four bales. An average bale of steel weighs about 3.5 tons or 7000 pounds.

3.8 Additional Plant Constraints.

There are a wide variety of GTTF scheduling constraints related to operation capabilities, and size limitations. These constraints include (Scott 1992):

- The length, width, and height of the furnaces.
- The temperature, and speed ranges of the furnaces.
- The length, diameter, and number of pieces in each order. Additionally, the type of product (bar stock or tubing) may be a constraint under certain circumstances.
- Order due-dates and rush orders can constrain GTTF operations.
- Thermal treatment processing complexities.
- Minimizing cost of operations while maintaining the highest level of quality.

3.9 Manual Scheduling Methodology

Orders arrive at the GTTF on a daily basis. Delivered orders are accompanied by a corresponding order card. The cards contain detailed size, customer, routing, and special processing information about the orders. The cards are reviewed by the GTTF analyst so that the proper thermal treatment may be assigned to each order.

In the manual scheduling system, the first level of scheduling is done by separating the orders into two groups, those for the cars, and those for the roller or tunnel orders. The furnaces are then scheduled separately. Taking into account current furnace setups, orders are first sorted by temperature, and then by due-date. The orders are assigned to each furnace accordingly.

Considering the high volume of orders received by the GTTF, scheduling the furnaces becomes a difficult and time consuming task. Thus, developing a more comprehensive furnace scheduling methodology is not practical under the manual system.

4 PROJECT MISSION

The mission of the GTTF Scheduling Project was to improve production throughput and due-date performance by using computer technology to provide order data visibility and to automate scheduling decisions for the roller and tunnel furnaces.

4.1 Project Scope

The GTTF scheduling system was designed to provide detailed short interval scheduling of the seven roller furnaces and the tunnel furnace. The system tackles the two major scheduling problems experienced at the GTTF: limited future order visibility, and difficulty in implementing a comprehensive scheduling philosophy.

The order visibility problem was resolved by developing an automated data base to manage the many GTTF orders. Order information can be viewed and setup electronically. The order manager includes all types of GTTF orders.

The furnace scheduling problems were addressed by developing an automatic scheduling system, designed to maintain both high furnace efficiency and throughput, and maximize order due-date performance.

It should be noted, that the GTTF scheduling system currently is limited to the roller and tunnel furnaces. The project was justified as a prototype to be used to evaluate FACTOR's scheduling capabilities. However, the system has been designed such that the car furnaces can be added at a later date if determined beneficial.

4.2 Project Objectives

The GTTF scheduling system project objectives are defined as (Branstrator et al. 1990):

- To provide an automated database to manage the many GTTF orders.
- To automate the majority of routine shop scheduling decisions consistent with GTTF operating constraints, rules, and objectives and to provide decision support capabilities relative to exceptions.
- To extend the scheduling horizon to several days so that a comprehensive strategy for all GTTF orders is generated.

- To provide information to anticipate scheduling problems and opportunities. Concurrently, to provide "what-if" capabilities to test scheduling alternatives.

4.3 Expected Benefits

If the GTTF scheduling project is successful, the following benefits are expected:

- Improved due-date attainment performance.
- Increased throughput, via increased furnace utilization and reduced furnace setup time.

The GTTF maintains operation statistics on order due-date performance and furnace utilization. After the GSS is released into production, the system will be evaluated against this historical data.

It has been concluded that if the project is successful, additional benefits may be realized. The additional benefits include reduced order lead-time, reduced inventory, reduced energy consumption, and increased product quality. However, it has been acknowledged that quantifying these benefits will be difficult.

5 SYSTEM OVERVIEW

The GTTF Scheduling System (GSS) is made up of four software components:

- Order data acquisition program.
- Order manager.
- FACTOR scheduler.
- Interface program.

The order data acquisition program collects and transfers all GTTF orders to the GSS. The order manager is an automated database that allows the user to review order information and to setup all GTTF orders. The FACTOR scheduler is a computer model that simulates the seven roller furnaces and tunnel furnace to generate the GTTF furnace schedules. Car and pit orders are included in the order manager, but are not scheduled by the FACTOR scheduler. The interface program sets up the GSS environment, and links the order manager with the FACTOR scheduler via a hierarchical menu structure.

5.1 Component Topology

The order data acquisition program resides on Timken's corporate IBM mainframe. Both the order manager and the FACTOR scheduler reside on the Timken Research VAX 6320. The order data acquisition program transfers raw order data to the order manager. The GSS interface provides the FACTOR scheduler with order data, furnace status data, model parameter data, and model setup data. The order manager has order report capabilities and the FACTOR schedule generates furnace schedules. Fig. 4 shows the component topology for the major GSS modules and interface program.

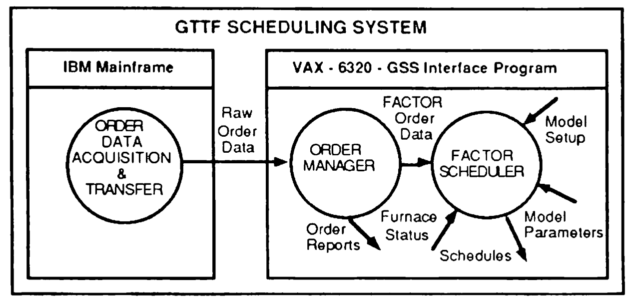
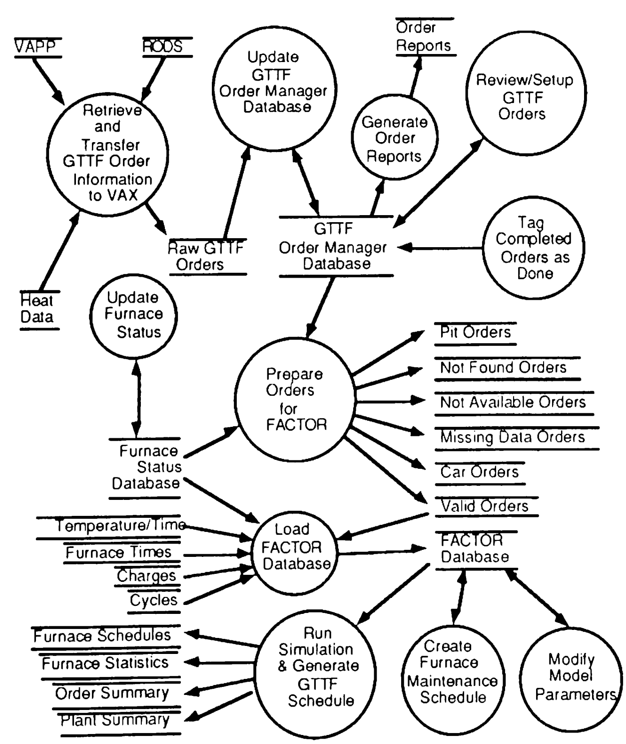


Figure 4: GSS Topology

5.2 Software High-Level Structured Analysis

The structure chart shown below in Fig. 5 illustrates the basic GSS functionality and data relationships. Yourdon's Structured Analysis notation is used where the bubbles represent system functions or actions, and horizontal bars represent data stores. The arrows indicate data flow between functions and data stores.



On a daily basis GTTF order data on the IBM mainframe is gathered from the VAPP, RODS, and Heat Chemistry databases, and is transferred to the Research VAX. The VAPP database is the Timken Company Steel Business Unit's MRP system. It supplies the GSS with order due-dates, and current order work center location. The RODS database contains detailed order information, such as product size and special processing data. The Heat Chemistry database provides the system with the heat chemistry analysis for each order.

Once the raw GTTF order data is received, the data is loaded into the order manager database. The load function insures that old orders are removed, new orders are added, and existing orders are maintained automatically. Orders that have been completed between VAPP updates are manually marked as completed orders by the user.

The order manager database maintains all types of GTTF furnace orders that include roller, tunnel, car, and pit orders. To setup an order, the user can review and edit order information via the order manager interface screens. Order setup involves assigning a furnace process temperature and time that are based on specific metallurgical requirements. For some thermal treatment classifications, the order manager will automatically setup orders by way of general cookbook-like setup rules. In addition, the order manager is capable of generating standard GTTF order reports.

The GSS provides the user with an interface screen used for updating the furnace status information. Furnace status information includes current furnace temperatures, roll speeds, and all staged furnace orders. Staged orders are those orders currently being charged into a furnace, or orders that have been loaded onto a charge table and are waiting to be loaded into a furnace.

Before the order data can be loaded, orders must be prepared for FACTOR. This task consists of sorting the orders by type, checking for data completeness and integrity, and assigning the necessary process plan needed to implement the correct thermal treatment. Valid orders that can be scheduled are segregated and loaded into the FACTOR database. Orders that cannot be scheduled are placed in separate data files, which include pit orders, car orders, orders with missing key data, orders that are not available to the GTTF, and referenced furnace status orders not found in the order manager database.

The model setup files are directly loaded into the FACTOR database before the simulator is executed. The files contain actual GTTF physical setup data used for model configuration.

The user directly accesses the FACTOR database to create maintenance schedules and to modify model parameters. Furnace maintenance schedules may be created to notify the FACTOR scheduler that a furnace is down due to general maintenance or a breakdown. Maintenance schedules are mapped to the simulation run time window and control when the furnace is available for scheduling. The model parameters can be modified by the user via the model parameter edit screens. Model parameters consist of software switches and limits used by GSS.

Once the FACTOR database has been completely updated, the simulation is executed and output reports are generated. The reports include furnace schedules, furnace statistics, order summary, and plant summary reports.

6 MODELING APPROACH

The most current order data is used by the FACTOR scheduler each time the simulation is executed. A simulation preprocessing program is run that sorts the orders and assigns a process plan to each order. The process plans are based on order operation. There are eight single furnace process plans and two double furnace process plans.

The FACTOR scheduler has been designed to automate the majority of "routine" scheduling decisions. However, the overall design philosophy gives the human scheduler the ability to override the system. For example, the user can select one of the following options:

1. Furnace type and number, and order sequence by making the order "Staged" on the Furnace Status Screen.
2. Furnace type and number, however lets the FACTOR scheduler to determine the optimum order sequence. This is accomplished by setting the furnace type and number on the Order Manager Setup Screen.
3. Furnace type, and lets the FACTOR scheduler determine the furnace number and optimum order sequence. This is accomplished by setting just the furnace type on the Order Manager Setup Screen.
4. Let the FACTOR scheduler have total flexibility to schedule the order.

6.1 Order Length

The GTTF scheduling system models orders by order length, not individual pieces. The order length is described as the combined length of the charges and the spaces between the charges. Furnace charge spacing is a metallurgical requirement. Fig. 6, shown below, diagrams this concept.

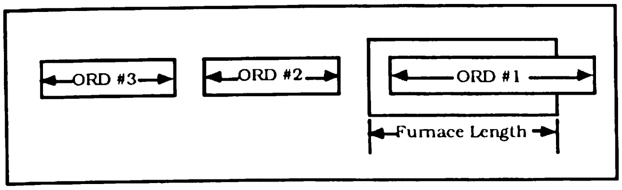


Figure 6: Order Length Concept

The charge size and number cannot be calculated until simulation run-time, when the order is selected by an available furnace. Charge size and number are then determined by the furnace and order dimensions, and number of pieces. Double stacking may also be included in calculated charge size and number.

Once charge size and number have been determined, order length may be calculated. This is done by summing the charge lengths and the spaces between the charges. In the simplest case, the order estimated process time can be calculated by using furnace speed. As a result, the order length approach maximizes the simulation run-time performance, because the system models an order as a single entity, not individual pieces.

6.2 Resources and Process Plans

The modeling approach implements four job steps (network nodes) (Pritsker Corporation 1989). This is shown below in Fig. 7.

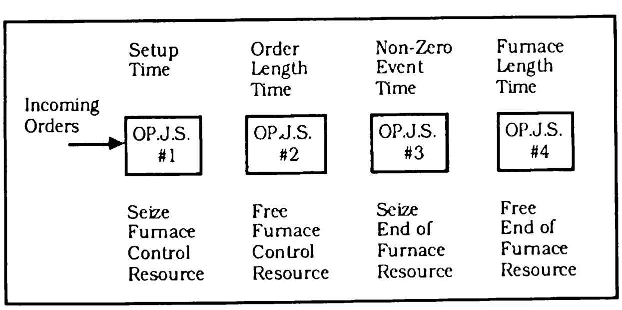


Figure 7: Roller and Tunnel Furnace Job Steps

Job step one determines furnace setup time and the next order to process. Furnace setup time is the time to adjust the furnace temperature and speed between adjacent orders.

Job step two models the time it takes for an order to enter the furnace. "Entering the Furnace" is defined as the time when the front end of the first charge of an order enters the furnace, until when the back end of the last charge of the order enters the furnace.

Job step three is a non-zero time node, used for simulation purposes. Since the furnace speed can be adjusted for the next order entering the furnace, the next order must be selected prior to calculating the previous order's remaining process time.

Finally, job step four models the total furnace length time. This involves calculating the time for the end of an order to travel from the entrance of the furnace to the furnace's exit.

Orders moving through the four node process plan will seize and free two simulation resources, which are the "Furnace Control" and "End of Furnace" Resources. This is done primarily for synchronization purposes, such that the order's total processing time can be correctly calculated. In addition, orders passing from job step to job step will invoke the custom 'C' modules defining the scheduling logic.

7 GTTF SCHEDULING METHODOLOGY

Scheduling logic for the GTTF was developed to better manage furnace utilization and order lateness. The remaining sections of this chapter will describe the developed scheduling methodology.

7.1 Order Lateness

On the basis of order lateness, all orders are sorted into two groups, critical orders, and non-critical orders. This concept is shown below in Fig. 8.

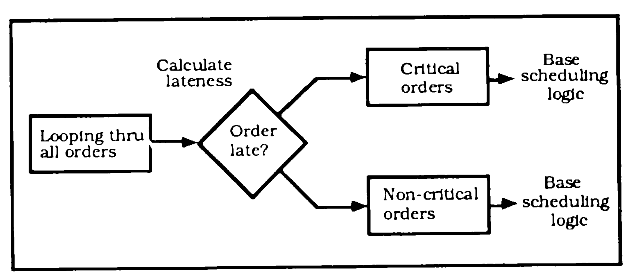


Figure 8: Critical Slack

For each available order, order lateness is calculated. Order lateness (or Critical Slack) is defined by:

$$\text{Critical\_Slack} = \text{Firm\_Plan\_Date} - \text{Current\_Time} - \text{Estimated\_Processing\_Time}$$

If the critical slack for an order is less than 30 hours then the order is considered critical, otherwise the order is non-critical. By sorting the orders by critical slack, potentially late orders are given a higher scheduling priority. Both critical and non-critical orders are scheduled by the base scheduling logic that maximizes furnace utilization. The compare value of 30 hours can be modified by the user.

7.2 Order Priority Levels

Fig. 9 illustrates the order scheduling priority levels. Listed below are the various levels and their definitions. Priority level classifications are listed from highest to lowest priority, respectively.

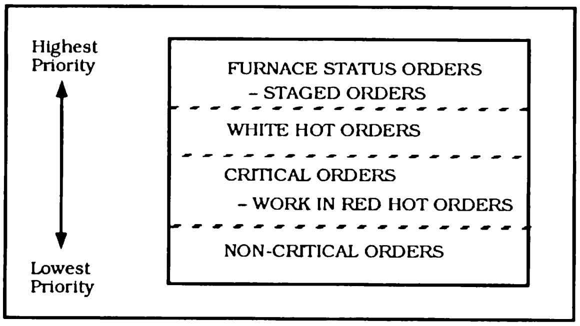


Figure 9: Order Scheduling Priority Levels

1. Charge Order - The order that is currently being loaded into the furnace. This order is referenced on the furnace status screen.
2. Staged Order - Orders that have been placed on a furnace charge table and are ready to be charged into a furnace. Staged orders are referenced on the Furnace Status Screen.
3. White Hot Order - An order that will be processed on the next available furnace regardless of setup time considerations. White hot orders are set in the order manager.
4. Critical Order - Orders that the system considers late or potentially late based on the critical slack calculation.
5. Red Hot Order - An order that will be scheduled as a critical order, regardless of the due date. Red hot orders will be worked into the group of critical orders and are also set in the order manager.
6. Non-Critical Order - Orders considered to have sufficient time to be processed after critical orders based on the critical slack calculation.

7.3 Base Scheduling Logic

The base scheduling logic is designed to maximize furnace utilization, whereas critical slack is designed to minimize order lateness. When a furnace is ready to process the next order, the FACTOR scheduler will attempt to find an order that matches the current furnace setup, such as:

- Same Temperature,
- Same Speed,
- Earliest Due Date.

If such an order does not exist, then the FACTOR scheduler will attempt to find the next best order, such as one having the:

- Same Temperature,
- Closest Speed,
- Earliest Due-Date.

Again, if such an order cannot be found, then the FACTOR scheduler defaults to the order that best satisfies the following:

- Closest Temperature not within +/- 20 degrees of another furnace,
- Closest Speed,
- Earliest Due Date.

In some cases because of product quality and operational considerations, there can exist exceptions to the base scheduling logic.

8 CONCLUSION

The Gambrinus Thermal Treatment Facility is part of the Timken Company's Gambrinus Steel Plant. The GTTF is responsible for thermal treating Timken steel products. The GTTF is composed of several thermal treatment furnaces that include the car, roller, and tunnel furnaces.

Historically, the GTTF has been a difficult plant to schedule. Scheduling difficulties have resulted from both physical and operating constraints that include:

- The height, width, length, and weight capacities of the furnaces.
- The temperature and process speed ranges of the furnaces.
- The due-dates and optional rush order priorities of each order.
- The metallurgical complexity of the thermal treatment process.

The Gambrinus Thermal Treatment Scheduling System was developed to better manage GTTF order due-date and plant throughput performance. The system is composed of three components, the order data collection program, order data manager, and the FACTOR scheduler. The components are fully integrated via the GSS interface program. The order data acquisition program automatically gathers current and future GTTF order information, and the order manager is used by the GTTF scheduler to manage, review and setup orders. The FACTOR scheduler automates the majority of routine scheduling decisions, and provides capabilities to recover from unplanned events such as furnace breakdowns.

Additionally, the scheduler provides "what-if" capabilities to test scheduling alternatives and opportunities.

The GTTF Scheduling System has been used by GTTF personnel on a daily basis since September 1991. Since released into production, improvements have been made to the GTTF's order due-date and throughput performance. As a result, a more comprehensive scheduling practice is now possible.

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