8

Some Scheduling Concepts and Functional Requirements for the CIM System

PRODUCTION SCHEDULING

There have been many scheduling schemes developed over the years to assist persons trying to produce desired products as requested.

For each plant a production scheduling system must be developed. The form and content of this schedule will vary depending on the type and design of the plant and the product mix produced. However, it is expected that the techniques used in determining the actual production schedule will be generic between plants in the same industry and even between industries.

It is not possible to thoroughly discuss each type of scheduling system. Three types of scheduling concepts are reviewed and the functional requirements developed. Hopefully these or combinations of these types will fit most of the production cases encountered.

1. *Typical Continuous Operation Plant Scheduling* is based on historical requirements, predicted sales forecasts modified by actual sales. Many chemical, paper and steel plants operate on this basis. Raw materials required for production runs are usually on hand. Inventory control and economic order quantity purchasing may be a part of this system.

2. *Just-In-Time Scheduling* is a newer technique and is being used for plants and processes that are designed to use this method. Since storage capacity is limited by design the initial plant costs may be reduced significantly. There are scheduling concerns to assure that all materials arrive at the proper time.

3. *Job Shop Scheduling* makes products to order. This varies from simple to complex depending on the products produced and the variety of products made within a facility. Examples might range from custom wood products to gear production to injection molding of parts.

With each of these example types of plants in turn the scheduling becomes more complicated with more interaction between plant facilities, space, materials and types of equipment required.

For any of the above cases the ability to develop a proposed schedule is usually straightforward. This calculation will remain a proposed schedule until plant feedback is provided. This will now indicate how well the plant is producing to meet the schedule. In some cases the schedule may not be met at all! Broken equipment or shortage of materials may require that other items be produced or even shutdown of the facility.

The hierarchical model through the four levels of scheduling and sequencing (Tables 3-VI to 3-X) defines the functional requirements for a typical plant schedule.

Just-in-time (JIT) scheduling adds another layer of complexity to the typical type schedule and the feedback required. A complete delivery schedule for each of the required materials must be created and constantly tracked. These must be compared against the production schedule to determine if usage is within limits to keep the plant in question at this rate. Since storage capacity is very limited each truck, car, etc., must arrive within a prescribed time window or changes must be made.

Make to order is a special case that is dependent on the number and types of products that are to be produced. In the previous examples of this type the complexity increases from an item made from wood to multitype gears to an unusual number of molded parts.

Gear production may sound easy but the molds, the metal composition, casting space, equipment availability and time required per unit make it more complex than first imagined.

Making molded parts uses all of the above but also requires special mold forms to be made, different operating conditions for each new mold and other complexities.

The hierarchical model indicates some of the following data that is required to meet production goals in a typical plant. Other data is added for other scheduling types indicating the amount of data to be handled to obtain the proper results:

1. Actual Production Rate
2. Quality of Production Product
3. Cost of Producing Product
4. Raw Material Usage
5. Energy Usage
6. Labor Required
7. Raw and Finished Goods Inventory
8. Equipment Availability
9. Storage Capacity for Raw Materials
10. Delivery Schedule for Raw Materials
11. Comparison of Rates of Consumption vs. Production Rate Required To Keep Plant Running Smoothly, Depending on Deliveries
12. Laboratory Data
13. Finished Goods Packaging (If Required)
14. Finished Goods Shipping
15. Interim Storage Availability

Figure 8-1 and Table 8-I present another way of showing the scheduling concepts involved [21]. In addition a potential production scheduling algorithm which has found acceptance in the steel industry [76, 90] is also described below.

A PRODUCTION SCHEDULING ALGORITHM

As stated in Table 3-VII, the Level 4A computer system (Figure 3-1) will be charged with maintaining the production schedule for the plant. In this part we will develop a proposal concerning the methods by which this production schedule can be initiated and maintained in this computer system.

Table 8-II presents the overall assumptions which govern the basic statement of this scheduling algorithm. With these assumptions, the procedures of Table 8-III are carried out to get the final schedule. Tables 8-IV and 8-V give the corresponding duties of associated personnel.

Figures 8-2 to 8-4 use a steel industry example to illustrate the scheduling technique outlined in the above tables and how this work interfaces with that done at the lower levels of the hierarchy.

OPTIMIZATION FROM THE MASTER SCHEDULING VIEWPOINT

The basic concept or driving force behind the installation of a master scheduling technique is the desire to obtain a coordinated flow through

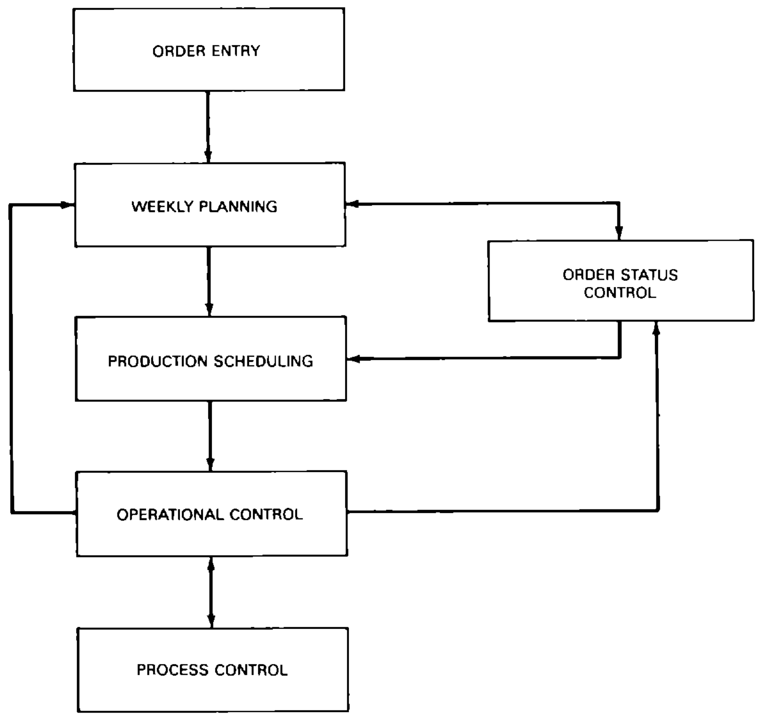

Figure 8-1 Production Management System- Functional Structure.

production in the plant. In general, master scheduling will attempt to optimize the conflicting objectives of: (1) Customer service, and, (2) Minimum inventory. It will do so in light of considerations required by equipment restrictions, handling requirements, maximum storage capabilities, general transportation operations, and overall capacity constraints.

As benefits of the master scheduling technique, the user can realistically expect to increase performance in due-date, reduce inventory and potentially increase production by utilizing a schedule that avoids production bottlenecks and/or equipment idleness. The master schedule provides a plan that can be used as an effective control to obtain these benefits.

The strategy suggested for the steel production system begins with the receipt of orders at the various sales offices. These orders are combined with forecasts to produce an order stream input to the master scheduling process. The actual orders are used for the close-in period and order history will be consulted for the long range prediction of requirements, i.e., the order stream. This stream is then ranked according to the due date accompanying each order. Since each order may have a different production time the order slack is calculated as:

$S_i = dd_i - p_i - t$

where:

S_i — slack time for order i

dd_i — due-date for order i

P_i — processing time for order i

t — current time

As long as the order slack is positive we have sufficient time to produce the item without any expediting. The problem occurs when the slack becomes negative which means that there is insufficient time to produce the order and meet the due-date required.

This order stream, now containing the characteristics of order, due-date and slack, represents a time phased requirement of finished product. The problem has then become one of somehow meeting the requirements of the stream in light of production restrictions, current inventories and other managerial objectives (i.e., smooth production level, minimize quantity of late orders, etc.)

At this point it is the function of the master scheduling system to weigh the various factors and alternatives and produce a schedule that satisfies the requirements of the order stream. The close-in schedule will be based on firm customer orders and will be used for actual production scheduling while the future schedule can be used for examinations of future resource requirements. This schedule will be optimal in the sense that a set of goal programming algorithms will have been utilized to minimize deviations from the multiple objectives of management. The master scheduling process can be viewed as Figure 8-5. The technique of goal programming appears to offer high promise in the development and solution of such a scheduling algorithm [63, 72, 76].

The concept of the job stream (Item A5, Table 8-III) can easily be input to this system. To utilize the job stream approach would require that the original order stream creation be modified by the job stream influence. The effect of the job stream would again be felt by the master schedule when it analyzed the current inventory (unapplied) mix. If a job stream approach was being utilized more matches would be anticipated and the master schedule would be adjusted accordingly. A report of the Purdue Laboratory for Applied Industrial Control (Report Number 112, *A Production Control Strategy for Hierarchical Multiobjective Scheduling with Specific Application to Steel Manufacture*, (May 1979), by Gerald T. Mackulak and Colin L. Moodie) [76] shows how many of these ideas may be implemented in the steel industry.

TABLE 8-I

PRODUCTION MANAGEMENT SYSTEM - SUBSYSTEMS

ORDER ENTRY

1. AFFECTS THE WHOLE COMPANY (IF MORE THAN ONE PLANT)
2. CHARACTERIZED BY INSTABILITY OF THE MARKET
3. CUSTOMER'S ORDERS EXPRESSED IN TECHNICAL TERMS TO ACCOUNT FOR:
   A) PLANT PRODUCTION CAPABILITY
   B) COST EFFECTIVE PRODUCTION CYCLE
   C) QUALITY/QUANTITY/DELIVERY

WEEKLY PLANNING

1. AFFECTS THE SPECIFIC PLANT
2. PERIODICALLY ISSUES ORDERS FOR PRODUCTION BASED ON:
   A) EQUIPMENT LOADING
   B) YIELD OPTIMIZATION
   C) COST OPTIMIZATION
   D) ORDERS ON FILE AND CUSTOMER'S SPECS
3. VIA MRP OR OTHER SUITABLE TECHNIQUES ASSURES AVAILABILITY OF NEEDED RAW MATERIALS ENERGY SOURCES, SPARE PARTS, ETC.

continued

Table 8-I continued

ORDER STATUS CONTROL

1. ANALYZES PRODUCTION COMPLETION DATA VERSUS ACTUAL SCHEDULES AND CUSTOMER'S ORDERS
2. RESCHEDULE IF NECESSARY

PRODUCTION SCHEDULING

1. GENERATE SHIFT/DAILY SCHEDULES BASED ON:
   A) WEEKLY PRODUCTION PLAN REQUIREMENTS
   B) MATERIAL AVAILABILITY
   C) EQUIPMENT STATUS
   D) ORDER STATUS

OPERATIONAL CONTROL (LEVEL 3)

1. EXECUTE THE PRODUCTION SCHEDULE
   A) EXPAND INTO WORK INSTRUCTIONS
   B) DISSEMINATE WORK INSTRUCTIONS
   C) COLLECT/COMPLEMENT COMPLETION DATA
   D) GENERATE AREA LEVEL REPORTS (MAINTENANCE/QUALITY/ PRODUCTION/COSTS)
   E) MAINTAIN MATERIAL INVENTORIES
   F) START FEEDBACK LOOP TO "ORDER STATUS CONTROL" SUBSYSTEM

PROCESS CONTROL (LEVELS 1 AND 2)

1. EXECUTE THE WORK INSTRUCTIONS
   A) INITIALIZE AND REGULATE THE EQUIPMENT TO MANUFACTURE THE UNIT PRODUCT(S)
      (1) CLOSED-LOOP (STAND-ALONE/ADVANCED CONTROL)
      (2) OPEN-LOOP OPERATOR GUIDE (ADVANCED CONTROL)
   B) REQUIRES SIMPLE/ENHANCED OPERATOR INTERFACE
   C) COLLECTS PRODUCTION DATA
   D) COLLECTS/ANALYZES PROCESS DATA
   E) GENERATES PRODUCTION REPORTS/ LOGS
2. FEEDBACK COMPLETION DATA

TABLE 8-II

OVERALL ASSUMPTIONS REGARDING PRODUCTION SCHEDULING

1. THERE IS NO UNIT OF THE PLANT WHOSE OPERATIONALLY IMPOSED PRODUCTION CYCLE IS AN APPRECIABLE FRACTION OF THE NORMAL PRODUCTION PERIOD OF THE PRODUCT INVOLVED IN A CUSTOMER'S ORDER.
2. THE PROBLEMS OF EQUIPMENT WEAR AND MAINTENANCE MAY DICTATE THE TIME SEQUENCES FOR PRODUCING PRODUCTS TO CUSTOMER SPECIFICATIONS OVER THE PERIOD OF AN EQUIPMENT'S USE CYCLE.
3. THERE WILL BE A STRICTLY ADHERED TO PRIORITY SYSTEM IN HANDLING CUSTOMER ORDERS AND JUDGING THEIR PLACE IN THE PLANT JOB STREAM.
4. PROVIDED BETWEEN-AREA INVENTORY LEVELS ARE MAINTAINED GREATER THAN ZERO AT ALL TIMES, EACH PRODUCTION AREA CAN BE OPTIMIZED INDEPENDENTLY OF THE OTHER AREAS PROVIDED THE PRODUCTION SCHEDULE ESTABLISHED BY THE CENTRAL PRODUCTION CONTROL SYSTEM IS CARRIED OUT.
5. TO HANDLE THE PROBLEM OF SMALL, SPECIAL ORDERS A RULE FOR ORDER ACCEPTANCE BE FORMULATED.

continued

Table 8-II continued

6. A LARGE PORTION OF THE ORDER BOOK WILL BE PREDICTABLE AT LEAST THROUGH INTERMEDIATE PRODUCTS INVENTORY. PRODUCTION OF GOODS NECESSARY TO MAINTAIN THIS INVENTORY MAY BE CARRIED OUT ON A SCHEDULE MADE OUT CONSIDERABLY IN ADVANCE. SUCH A PRODUCTION TO INVENTORY AND OPERATION FROM IT HAS BEEN CALLED THE "JOB STREAM" METHOD OF SCHEDULING.

TABLE 8-III

PRODUCTION SCHEDULING PROCEDURES

A. ITEMS CONSIDERED AT LEVEL 4A

1. EACH ORDER ITEM AS RECEIVED WILL BE ASSIGNED A PRIORITY AND AN ORDER SEQUENCE NUMBER OR PROMISED DELIVER DATE INDICATION.

2. UPON ASSIGNMENT OF THE PRIORITY AND ORDER SEQUENCE NUMBER TO THE ORDER, THE PRESENT JOB STREAM AND ALL IN-PROCESS INVENTORIES WILL BE SEARCHED TO FIND THE ITEM OF LOWEST PRIORITY WHICH CAN BE DIVERTED TO FILL THE ORDER.

3. IN MAKING THE SEARCH LISTED ABOVE, IT WILL BE CONFINED TO THOSE ITEMS IN WORKING INVENTORIES OR IN UNASSIGNED INVENTORIES. ITEMS ALREADY IN A PRODUCTION UNIT OR ALREADY LINED UP FOR SUBSEQUENT PASSAGE THROUGH SUCH A UNIT WILL NOT BE DIVERTED FROM ANOTHER ASSIGNMENT TO MEET A HIGHER PRIORITY ORDER. THIS IS NECESSARY TO AVOID A LAST MINUTE DISRUPTION TO THE OPERATION OF A UNIT TO CHANGE ITS OPERATING INSTRUCTIONS FOR A PARTICULAR ORDER.

4. AS AN ORDER MATURES, IT WILL BE ASSIGNED A CONTINUALLY HIGHER PRIORITY BASED UPON ITS PROMISE DATE TO ASSURE THAT EVEN THOSE ORDERS WHICH WERE ASSIGNED THE VERY LOWEST PRIORITY UPON RECEIPT WILL EVENTUALLY BE PRODUCED DESPITE THE ARRIVAL OF A LARGE NUMBER OF HIGHER PRIORITY ORDERS.

5. AS MUCH AS POSSIBLE A BASIC PRODUCTION STREAM, OR JOB STREAM, BASED UPON A STATISTICAL AVERAGING OF PAST ORDERS OVER A PERIOD RECOGNIZING MAJOR CYCLICAL EFFECTS, BIASED BY THE REQUIREMENTS OF PRODUCTION PROCESS EQUIPMENT, MAINTENANCE, ETC., WILL BE WORKED OUT FOR THE FORESEEABLE FUTURE. THIS SET OF DUMMY ORDERS (NOT YET CONTRACTED FOR) WILL BE USED TO ESTABLISH THE SEQUENCE OF ALL FUTURE PLANT PRODUCTION OPERATIONS AS FINALLY RECEIVED. THE STATISTICALLY ESTABLISHED PRODUCTION STREAM WILL BE DEVELOPED IN TERMS OF A SIGNIFICANTLY SIZED PRODUCTION LOT. THIS WILL BE DONE WITHOUT REFERENCE TO THE ACTUAL RATE OF PRODUCTION TO BE FINALLY SET BY CURRENT CONDITIONS. THE JOB STREAM, THUS ESTABLISHED, WOULD BE CARRIED THROUGH THE PLANT AS FAR AS THE STATISTICS SHOW THAT A REASONABLE NUMBER OF INVENTORIED ITEMS WILL SUFFICE.

6. BASED UPON THE RATE OF RECEIPT OF ORDERS AND THE CURRENT FORECAST OF MARKET CONDITIONS, THE ABOVE BASIC PRODUCTION STREAM WILL BE SCHEDULED FOR PLANT UNDERTAKING AT A RATE WHICH WILL MAINTAIN CONTINUOUS PLANT UNITS IN OPERATION AND WILL RESULT IN CUSTOMERS' ORDERS BEING PRODUCED WITHIN AN ACCEPTABLE TIME PERIOD. BASIC OBJECTIVES WILL BE TO SMOOTH OUT PLANT OPERATION WITHIN THE PRODUCTION RATE NECESSARY TO ACHIEVE MINIMUM COST OPERATION AT THAT RATE.

7. WHEN A PRODUCTION ERROR HAS BEEN MADE, A SEARCH WILL BE

continued

Table 8-III continued

MADE OF THE JOB STREAM TO DETERMINE THE NEXT ITEM WHICH THIS RESULTING PRODUCT MIGHT SATISFY. THE MISSED ITEM WILL BE IMMEDIATELY REORDERED. THE DIVERTED MATERIAL WILL THEN BE STORED IN THE APPROPRIATE UNAPPLIED INVENTORY AWAITING THE FULFILLMENT TIME. IT SHOULD BE NOTED THAT THE PRODUCTION SCHEDULE IS USUALLY INCREASED TO INCLUDE AN AMOUNT OF OVERPRODUCTION EQUIVALENT TO THE EXPECTED AMOUNT OF MATERIAL TO BE DIVERTED DOWNSTREAM.

8. THE FOLLOWING DECISIONS HAVE BEEN MADE CONCERNING THE OPERATION OF THE PRODUCTION PLANNING AND CONTROL SYSTEM TO BE IMPLEMENTED BY THE COMPUTER HIERARCHY DESCRIBED HEREIN.

   a. A SEARCH WILL BE MADE OF THE DIVERTED INVENTORY FIRST IN AN ATTEMPT TO FILL ORDERS FROM MATERIAL ON HAND.

   b. UNASSIGNED STOCK AT ALL INVENTORY POINTS MUST BE SEARCHED TO DETERMINE WHETHER EXISTING PRODUCT MAY BE USED TO FILL A GIVEN ORDER OR WHETHER NEW PRODUCT MUST BE MADE ESPECIALLY FOR IT.

   c. ALL MATERIAL IN PROGRESS ASSIGNED TO A PARTICULAR ORDER, WHICH IS OF A LOWER PRIORITY THAN THAT ASSIGNED TO THE CURRENT ORDER, WILL BE SEARCHED TO FILL THE PRESENT ORDER AND TO REWORK THE MATERIALS FOR THE DIVERTED ORDER.

9. INVENTORY TIME LIMIT FOR FINISHED STOCK MUST BE HONORED TO PREVENT DETERIORATION AND RESULTING QUALITY LOSS.

B ITEMS CONSIDERED AT LEVEL 3

1. STOCK INVENTORIES RESERVED TO COVER FLUCTUATIONS IN DEMAND WILL NORMALLY BE CONSIDERED AS ONE STANDARD DEVIATION OF THE ORDER RATE PER CATEGORY OVER THE REPETITIVE PERIOD OF THE ORDER BOOK PLUS A SAFETY STOCK FOR ACCIDENT.

2. ASSUME THAT TRANSPORTATION REQUIREMENTS BETWEEN AREAS DO NOT IMPOSE DELAYS IN PLANT OPERATION WHICH MUST BE CONSIDERED IN THE SCHEDULING PROCESS.

TABLE 8-IV

DUTIES ASSIGNED TO PERSONNEL AT THE OVERALL PRODUCTION CONTROL LEVEL (LEVEL 4A)

1. DETERMINATION OF, MAINTENANCE OF AND MODIFICATION OF CURRENT PRIORITY OBJECTIVES USED IN THE GOAL PROGRAMMING CALCULATION OF THE MASTER SCHEDULE.

2. OVERRIDE AND MODIFY THE PROPOSED MASTER SCHEDULE IN LIGHT OF ANY CONSIDERATIONS NOT APPARENT TO THE OPTIMAL SCHEDULING ALGORITHM.

3. VERIFICATION AND AUTHORIZATION OF THE MASTER SCHEDULE BEFORE RELEASING IT TO THE LOWER LEVELS FOR DETAILED SCHEDULING.

4. MODIFICATION OF PRIORITIES FROM THOSE DETERMINED BY THE SYSTEM TO HANDLE ANY RUSH JOB CUSTOMER.

5. ALTERATION OF LOT SIZE RESTRICTIONS TO HANDLE ANY SPECIAL SMALL ORDERS.

6. CAUSE THE INITIATION OF AN UPDATED MASTER SCHEDULE AT ANY TIME DUE TO RECEIPT OF INFORMATION REGARDING PROBLEMS WHICH MAY EXIST ANYWHERE IN THE SYSTEM.

TABLE 8-V

PRODUCTION SCHEDULING DUTIES ASSIGNED TO PERSONNEL AT THE AREA SUPERVISORY LEVEL (LEVEL 3)

1. MANUAL OVERRIDE ON CUSTOMER PRIORITIES DEPENDING ON THE PRODUCTION SITUATION ENCOUNTERED.
2. DETAILED EXCEPTION PRODUCTION SMOOTHING NECESSARY TO ACHIEVE MINIMUM COST OPERATION.
3. DETERMINATION OF ADDITIONAL PRODUCTION ALLOWANCES TO COMPENSATE FOR PRODUCTION PROCESS BREAKDOWNS OR OTHER DIFFICULTIES.
4. INPUT ANY KNOWN TRANSPORTATION DELAYS RESULTING FROM SPECIAL ITEM HANDLING.
5. ALTERATION OF EXPECTED DIRECT PERCENTAGES FROM THOSE SELECTED AS INITIAL STANDARDS.
6. EXCEPTIONS TO INITIAL MANPOWER BALANCING RULES TO HANDLE UNFORESEEN PEAK LOADS, UNFORECASTED PROBLEMS, OR CHANGES IN UNION RULES, SICKNESS, ETC.

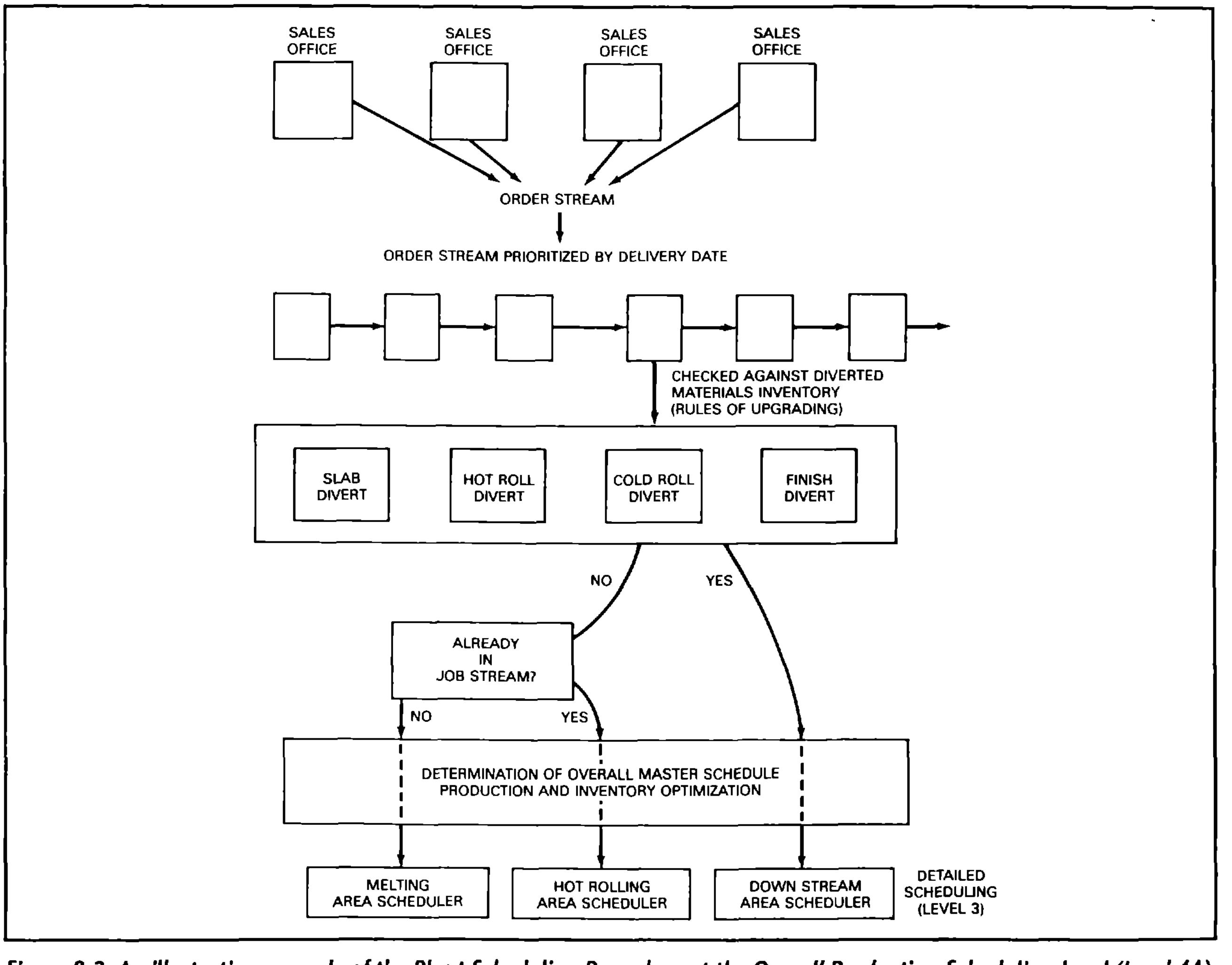

Figure 8-2 An Illustrative example of the Plant Scheduling Procedure at the Overall Production Scheduling Level (Level 4A).

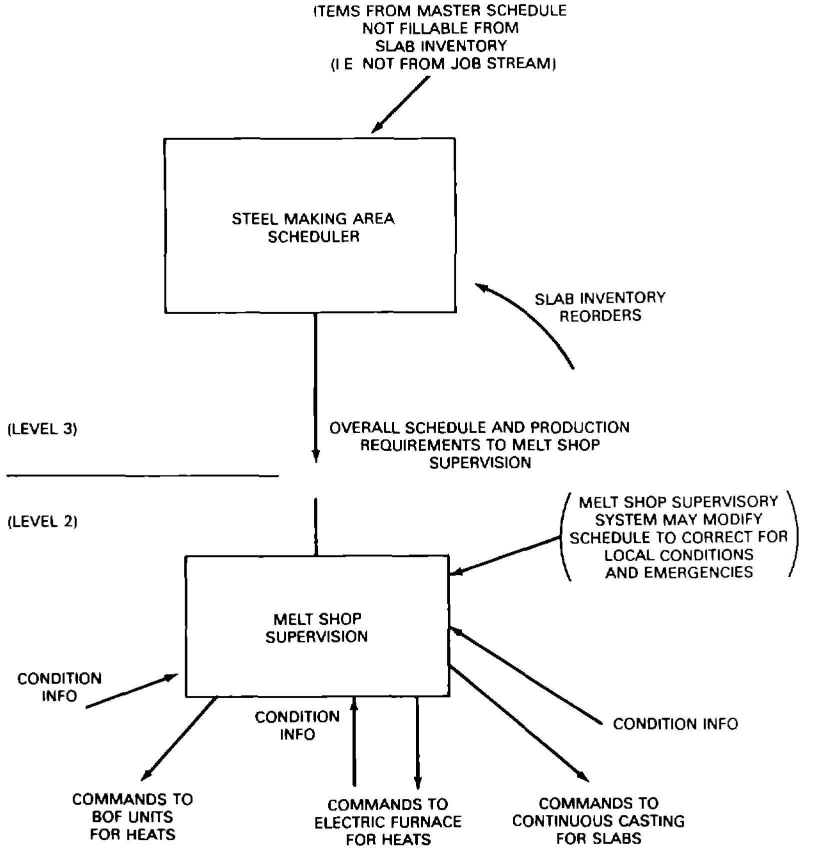

Figure 8-3 Intermediate Level Scheduling Functions as illustrated by the Steel Making Area System.

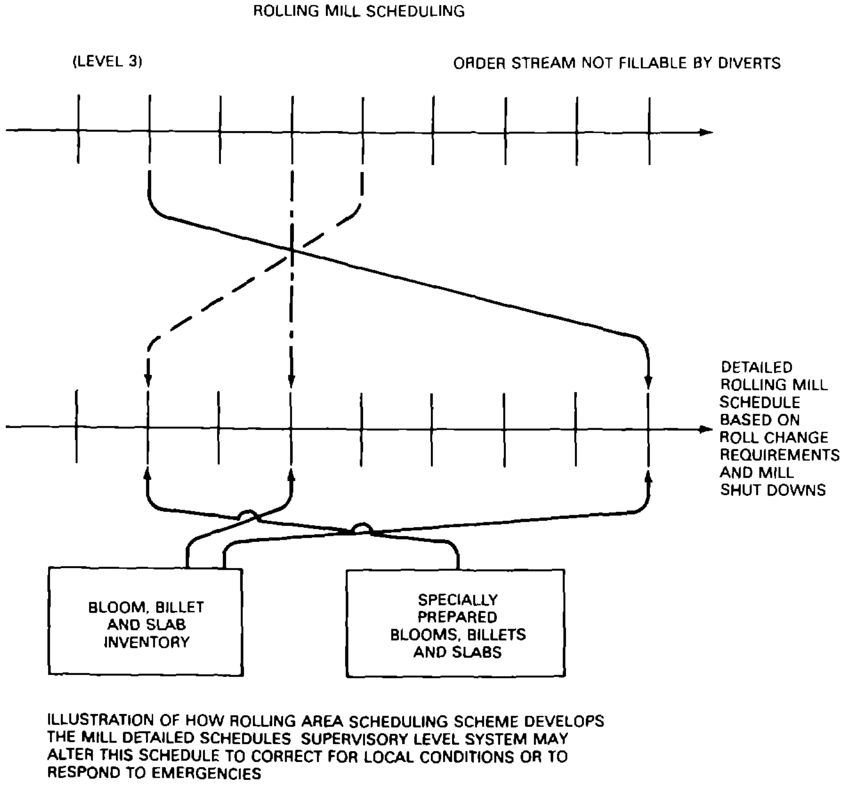

Figure 8-4 Intermediate Level Scheduling Functions as Illustrated by the Hot Rolling Area System.

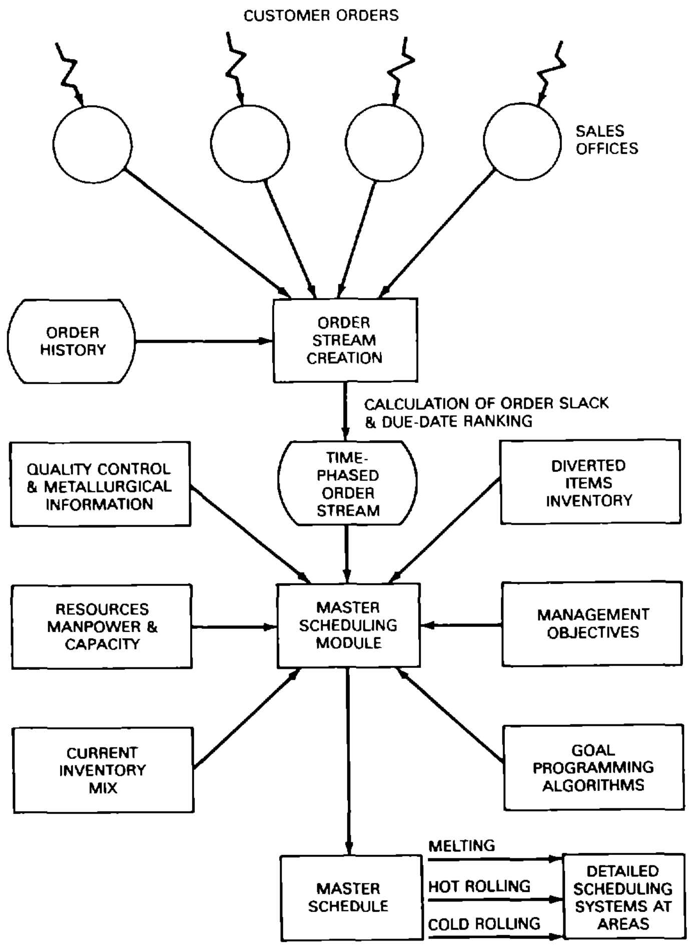

Figure 8-5 Master Scheduling Process at Overall Production Scheduling (Level 4A).