Production Planning and Scheduling for Long Line Prestress Products

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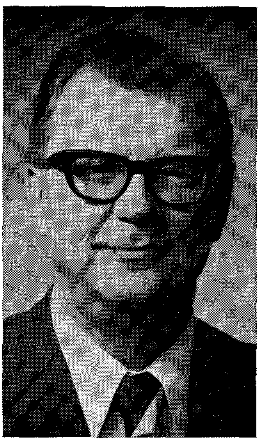

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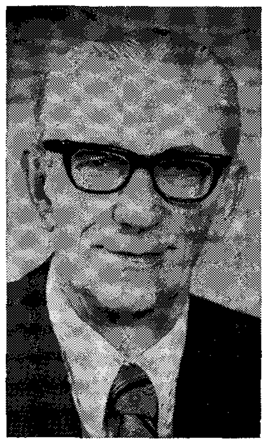

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This is a two-part paper.
Part 1 (published in the last issue) presented a state-of-the-art of scheduling and estimating techniques in the precast prestressed industry.
Part 2 (appearing in this issue) analyzes typical case studies in long-line prestress scheduling and provides an overall solution to the problems.

Synopsis

The precast concrete industry's problems in relation to production planning are discussed and the state-of-the-art of scheduling and estimating techniques are presented. The reasons for high strand losses and low labor productivity are analyzed and summarized.

A need for production sequence analysis is discussed and its use is illustrated. New theory and criteria for scheduling are established and their application in a step-by-step procedure demonstrated.

Computerized techniques are introduced as a scientific approach to decision making in the process of long line prestress production planning and scheduling.

Seventeen case studies describe the important problem areas in long line prestress scheduling. Conclusions and recommendations are presented after each case.

The method presented approaches full optimization in estimating labor, scheduling orders and controlling flow of raw materials. The application of the criteria recommended and the use of the new planning and scheduling method lead to substantial cumulative savings in production time, strand, labor and overhead.

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PART 1:

PART 2:

Looking for a Better Solution

In studying production planning problems we noted that in order to minimize production cost or, essentially, maximize profits, there are six major objectives that must be satisfied:

1. Maximize short-term profits.
2. Make deliveries on time.
3. Maximize utilization of casting equipment.
4. Avoid expanding production facilities.
5. Avoid expanding work force and shifts.
6. Maintain work quality.

The best solution to meet one objective may not be best for others. Thus, for a more realistic solution, the objectives should be weighed in terms of relative importance and, if possible, combined into a single criterion.

With these objectives in mind, it is proper to ask a question, namely, "what is scheduling?" In simple terms, it is a task to find and select daily production plans that yield minimum form space loss with the least number of setup changes.

Usually there may exist a large number of setups which will satisfy many constraints. However, the scheduler's problem is to choose such a set of successive setups for which the total form loss for the whole job is minimized.

If the minimization is achieved with the least possible number of setup changes, then this set constitutes an optimal solution which could represent the most efficient production path.

To select an efficient path means to choose such succession of setups that not only produces a high form space utilization but also, if possible, secures a high possible number of same setup repetitions.

Since the minimum form space losses may not be associated with the largest number of identical repetitions of the same setup, it is necessary to select several "best setups" to analyze them and to compare for economy.

To illustrate this process, let us consider a scheduling case that involves a 440-ft long form with 12-in. bulkheads and the following lengths and quantities of products:

Length, feet	Quantity, pieces
L1 = 50	Q1 = 27
L2 = 45	Q2 = 30
L3 = 40	Q3 = 34

Let us assume that after some effort, i.e., considering many possible setup arrangements (over 50), we have found an arrangement that produces "0" (zero) loss in five repetitive production cycles. Following the above procedure (see p. 69 of Part 1), the choice of other setups may be as follows:

	L1	L2	L3
Original quantities:	27	30	34
Setup No. 1: 5 cycles of 5,4,0	25	20	0
Remainder:	2	10	34
Setup No. 2: 2 cycles of 1,3,6	2	6	12
Remainder:	0	4	22
Setup No. 3: 2 cycles of 0,2,8	0	4	16
Remainder:	0	0	6
Setup No. 4: 1 cycle of 0,0,6	0	0	6
Remainder:	0	0	0

Total: 10 cycles

The succession of the specific setups (most of them repetitive in the example) is called a production path.

Specific production information can be derived from the above path:

Setup No. 1: 5 cycles
Form space loss: 0 ft
Form space utilization: 100.00%

Setup No. 2: 2 cycles
Form space loss: 4 ft
Form space utilization: 99.09%

Setup No. 3: 2 cycles
Form space loss: 19 ft
Form space utilization: 95.68%

Setup No. 4: 1 cycle, partial cast
Form space loss of 148 ft allows use of this portion of the form for casting some slabs from other jobs.

Quite often in evaluating several possible setups there might be some, usually one or two, that look just as good as the selected ones. Therefore, we should attempt to investigate these as well for possible ramifications into different branches to explore and compare the economy of other production paths.

For example, we have noted that in selecting the second setup arrangement, there was one that produced four repetitions with somewhat higher form loss. Thus, we could develop an alternate production path, as follows:

	L1	L2	L3
Original quantities:	27	30	34
Setup No. 1: 5 cycles of 5,4,0	25	20	0
Remainder:	2	10	34
Setup No. 2: 4 cycles of 0,2,8	0	8	32
Remainder:	2	2	2
Setup No. 3: 1 cycle of 2,2,2	2	2	2
Remainder:	0	0	0

Total: 10 cycles

The production information derived from this path is as follows:

Setup No. 1: 5 cycles
Form space loss: 0 ft
Form space utilization: 100.00%

Setup No. 2: 4 cycles
Form space loss: 19 ft
Form space utilization: 95.68%

Setup No. 3: 1 cycle, partial cast
Form space loss of 125 ft allows use of this portion of the form for casting slabs from other jobs.

The first production path produced a slightly higher form space utilization in the same number of production days (cycles). We just as well may choose the second production path, because the job can be completed with three setups instead of four.

For several reasons the lowest form space loss criteria may not be always desirable. For example, too many setup changes may be required, or the remainder of quantities is such that the successive setups have high form space losses. Therefore, a trade-off between the lowest form space loss and other criteria is recommended.

Elements of Scheduling

Knowledge of scheduling elements is important to understand the basics of planning and scheduling of long line prestress products. The most important elements are briefly illustrated and defined.

Fig. 8 shows an assortment of precast component quantities to be cast in a given form in one production cycle. All components must have the same nominal cross section, release strength, and strand pattern.

Some of the elements shown include form length, bulkhead space, end space, and the non-utilized form

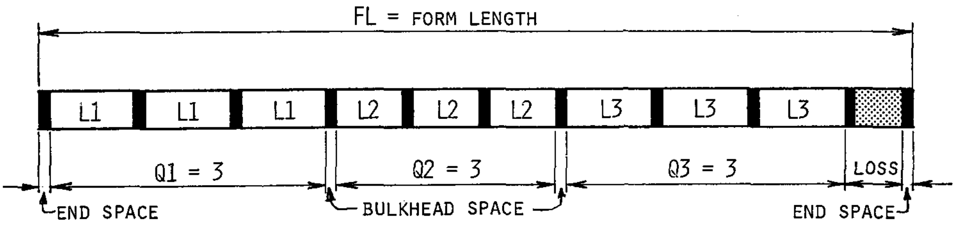


Fig. 8. Elements of scheduling.

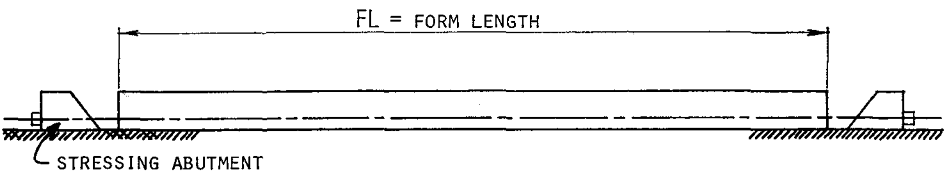


Fig. 9. Prestress bed with stressing abutments.

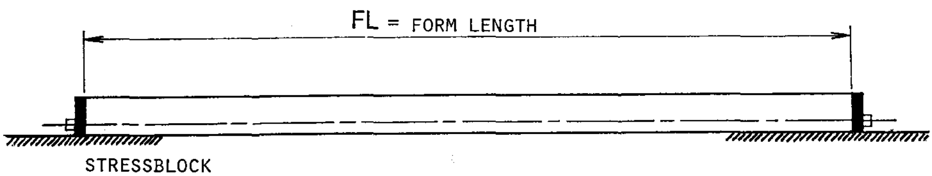


Fig. 10. Self-stressing form.

space or loss. The assortment of components can be written as "3, 3, 3," indicating that there are three components of each of three lengths placed within the form.

Form length

1. For wet-cast products (such as double-tees, stadium seats, beams), the form length is the out-to-out length of the form (not the bed) in feet.
   (a) Prestress beds with stressing abutments as in Fig. 9.
   (b) Self-stressing forms as in Fig. 10.
2. For extruded or slipformed products, the form length is the measured usable (uncut) portion of concrete as shown in Figs. 11 and 12.

End space is the space required to fasten the first bulkhead at end of the form in inches (also known as the end gate). Example: 4, 8, 12, 18, etc., or zero for extruded or slipformed products.

Bulkhead space is the space required to place and fasten a pair of bulkheads (joined or separate) to support the concrete and to provide an access for strand cutting. Depending on the depth of the product, the bulkhead space for wet-cast products may vary somewhere from 4 to 24 in. or more. For extruded or slipformed

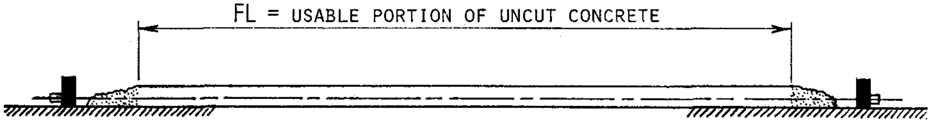


Fig. 11. Longitudinal section through extruded slab with one usable (uncut) portion of concrete.

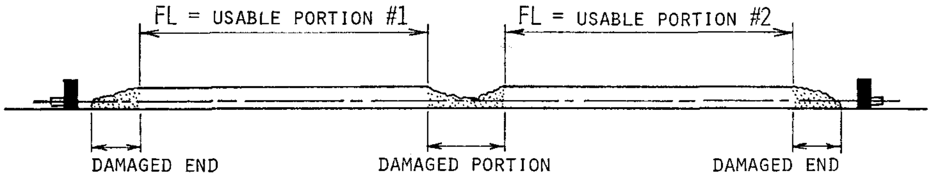


Fig. 12. Longitudinal section through extruded slab with two usable (uncut) portions of concrete.

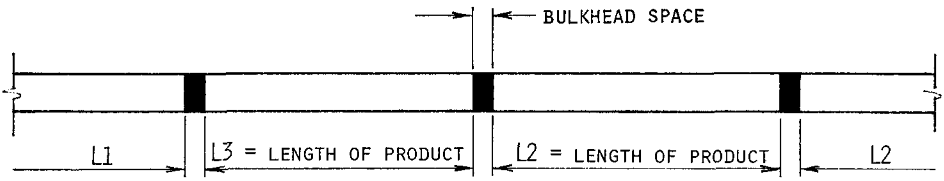


Fig. 13. Product length.

products, bulkhead space is the dimension that represents the thickness of the cut of the blade.

Product length is the total end-to-end length of the products in feet. The lengths are denoted by L1, L2, , . . . L7, as in Fig. 13.

Number of lengths is the number of different lengths of components within the same strand pattern under consideration.

Quantity is the total number of products of a given length. The quantities are denoted by Q1, Q2, ...Q7. Quantity Q1 corresponds with product length L1, etc.

Loss refers to the form space not utilized by product or bulkhead.

Setup arrangement is a set of numbers that specify how many pieces of product of each corresponding length are produced by the particular setup.

Setup is one or a series of identical setup arrangements that can be cast on succeeding days without repositioning bulkheads.

Form efficiency (or scheduling efficiency) is the gross length of products including bulkheads divided by the form length and expressed as a percentage.

Production path is a succession of setups that leads to the completion of a production plan.

In order to satisfy most of the planning and scheduling objectives, we have to establish some specific parameters for the scheduler. These parameters would assist him to determine the scope and limits of his task and measure the efficiency of the production plan.

For illustration, let us assume that we want to analyze a job consisting of 346 slabs that have to be scheduled for casting in a 238.00-ft long form and 12-in. bulkhead spacings with the following product lengths and their respective quantities:

L1, Q1 = 32.91, 108
L2, Q2 = 32.58, 132
L3, Q3 = 27.91, 63
L4, Q4 = 34.34, 19
L5, Q5 = 19.08, 24

This example has been selected from an actual project that can represent any of the stemmed products, hollow-cored slabs or wall panels.

Parameters for scheduling analysis

The following seven parameters must be established and used on every job. Without these, the planning and scheduling of prestressed production becomes simply juggling of numbers and therefore is useless.

1. The minimum limit for a total number of production cycles. This limit serves as a measuring unit or "yardstick" to compare the results and the effectiveness of each production path being developed. For the above example this limit is 46.707 or 47 production days.

2. The total number of all possible optimal setup arrangements for the available product lengths and their quantities. For the above example this total is 298.

3. The number of identical production cycles obtainable from the available quantities for each setup arrangement, as in Table 4.

4. Form space loss in feet for each setup arrangement, as in Table 5.

5. The setup arrangement that produces the smallest possible form space loss. In the example, the setup arrangement of 0, 5, 1, 0, 2 yields 0.03 ft form space loss in one production cycle.
(Note: the arrangement 0, 5, 1, 0, 2 means that this setup will produce five slabs of length L2, one slab of L3 and two slabs of L5. Slabs L1 and L4 are not represented in this setup arrangement.)

6. The setup arrangement that produces the largest possible number of identical production cycles. For the example, the setup arrangement of 3, 3, 1, 0, 0 yields 36 identical production cycles.

7. Consideration of shipping (or erection) order. There are four important conditions that may greatly influence the scheduler's decision:

(a) There is sufficient lead time between production and erection. Order of production sequence is not important.

(b) Erection schedule will influence production sequence to some degree. Scheduler has some latitude.

(c) Production sequence must fully comply with the shipping and erection order. Scheduler has no alternatives. Some jobs in this category may also be rated as rush orders.

(d) Production sequence suddenly must be modified or changed during the course of production to comply with the new requirements. These requirements may

Table 4. Some of setup arrangements that yield high number of identical cycles.

QUANTITIES OF L1	L2	L3	L4	L5	IDENTICAL CYCLES
3	3	1	0	0	36
3	4	0	0	0	33
4	1	2	0	0	27
1	5	1	0	0	26
3	3	0	0	1	24
1	4	1	0	1	24
1	6	0	0	0	22
0	4	3	0	0	21
5	0	1	1	0	19
1	3	1	1	1	19
0	7	0	0	0	18
1	2	4	0	1	15
0	5	1	0	2	12
1	2	2	1	2	12
1	1	5	0	1	12
0	0	6	1	1	10
1	1	2	2	2	9
1	0	7	0	0	9
3	0	0	2	3	8
2	1	0	1	4	6
0	2	2	3	0	6

Table 5. Some of setup arrangements that yield low form space losses.

QUANTITIES OF L1	L2	L3	L4	L5	FORM LOSS IN FEET
0	5	1	0	2	0.03
1	1	1	0	7	0.04
0	0	0	5	3	0.06
0	6	0	1	0	0.18
1	2	0	1	5	0.19
1	2	4	0	1	0.21
5	2	0	0	0	0.29
3	0	1	3	0	0.34
0	2	1	0	7	0.37
2	0	2	2	2	0.52
0	3	0	1	5	0.52
0	3	4	0	1	0.54
4	3	0	0	0	0.62
2	1	1	3	0	0.67
1	0	3	1	4	0.70
1	0	7	0	0	0.72
1	1	1	2	2	0.85
0	0	0	1	10	0.86
0	0	4	0	6	0.88
3	4	0	0	0	0.95
4	0	0	0	5	0.96
1	2	1	3	0	1.00

be dictated either by the customer (sudden change in erection schedule) or caused by the precaster (breakage, accident or other happening).

Considering factors that are inherent in the job-shop operation (such as short lead time, slow engineering, delay in shop drawings, slowness of getting shop drawings approved and unavailability of production materials), a full knowledge of the contractor's construction schedule is of the utmost importance.

Every job in the precaster's hands may time-wise fall under any of the above categories. Understanding all the conditions under which the precast industry caters to the construction industry, it is safe to say that the first category representing sufficient lead time occurs very seldom.

Criteria for Prestress Scheduling

Based on the established parameters for the analysis of prestress production planning and scheduling, the following three criteria are recommended. They apply equally to every job and are independent of its size, composition and delivery order.

Scheduling Criterion 1

Develop and select setup arrangements that secure maximum profit for the company.

This criterion can be satisfied in three ways (Tables 6 and 7) by:

1. Reducing form space loss (or maximizing form space utilization), as in Table 6.
2. Maximizing the repetition of identical setups to reduce changes, as in Table 7.
3. Combining the above two conditions into a single one to achieve the smallest overall form space loss with the least possible number of setup

Table 6. Some setup arrangements showing low form space losses in feet.

QUANTITIES OF L1	L2	L3	L4	L5	FORM LOSS IN FEET
0	5	1	0	2	0.03
1	1	1	0	7	0.04
0	0	0	5	3	0.06
0	6	0	1	0	0.18
1	2	0	1	5	0.19
1	2	4	0	1	0.21
5	2	0	0	0	0.29
3	0	1	3	0	0.34
0	2	1	0	7	0.37
2	0	2	2	2	0.52
0	3	0	1	5	0.52
0	3	4	0	1	0.54
4	3	0	0	0	0.62
2	1	1	3	0	0.67
1	0	3	1	4	0.70
1	0	7	0	0	0.72
1	1	2	2	2	0.85
0	0	0	1	10	0.86
0	0	4	0	6	0.88
3	4	0	0	0	0.95
4	0	0	0	5	0.96
1	2	1	3	0	1.00

Table 7. Some setup arrangements showing numbers of repetitions of identical production cycles.

QUANTITIES OF L1	L2	L3	L4	L5	IDENTICAL CYCLES
3	3	1	0	0	36
3	4	0	0	0	33
4	1	2	0	0	27
1	5	1	0	0	26
3	3	0	0	1	24
1	4	1	0	1	24
1	6	0	0	0	22
0	4	3	0	0	21
5	0	1	1	0	19
1	3	1	1	1	19
0	7	0	0	0	18
1	2	4	0	1	15
0	5	1	0	2	12
1	2	2	1	2	12
1	1	5	0	1	12
0	0	6	1	1	10
1	1	2	2	2	9
1	0	7	0	0	9
3	0	0	2	3	8
2	1	0	1	4	6
0	2	2	3	0	6
0	2	2	3	0	6

changes (see setup arrangement 3, 4, 0, 0, 0 in both tables).

Scheduling Criterion 2

Maintain good customer relationship with timely delivery, while keeping profit goal in mind.

There are no "ideal" jobs in scheduling. The customer will have his own preferences that will interfere with a smooth production flow.

For instance, in the previous example, the customer may require a specific shipping order which could be any one or more of the following:

1. L1 must go first (Table 8).
2. L2 must go first (Table 9).
3. L3, L4 and L5 must go first (Table 10).
4. L2 and L4 must go first (Table ll).
5. L5 must go first (Table 12).

Review of the above five cases (as follows) reveals that, in order to secure highest possible profit for the company, the scheduler must be able to develop and evaluate many setup arrangements to satisfy the customer's specific shipping or erection requirements.

A specific shipping or erection order (prescribed or promised) may change the setup arrangements in such a way as to drastically affect the economy of the production. For instance, it can be easily understood why Cases 3, 4, and 5 will unfavorably affect the job schedule compared to Cases 1 and 2.

Scheduling Criterion 3

The engineering and purchasing functions must be subordinated to the production schedule.

As soon as the contract is signed,

Table 8. Product Length L1 must go first.

L1, Q1 = 32.91, 108

L1	L2	L3	L4	L5	Form loss in feet
5	2	0	0	0	0.29
5	0	1	1	0	3.20
6	0	1	0	0	4.63
5	1	1	0	0	4.96
5	0	0	1	1	12.03
6	0	0	0	1	13.46
5	1	0	0	1	13.79
5	0	1	0	1	18.46

Table 9. Product Length L2 must go first.

L2, Q2 = 32.58, 32

L1	L2	L3	L4	L5	Form loss in feet
0	6	0	1	0	0.18
1	6	0	0	0	1.61
0	7	0	0	0	1.94
0	6	1	0	0	6.61
0	6	0	0	1	15.44

Table 10. Product Lengths L3, L4 and L5 must go first.

L3, Q3 = 27.91, 63
L4, Q4 = 34.34, 19
L5, Q5 = 19.08, 24

L1	L2	L3	L4	L5	Form loss in feet
2	0	2	2	2	0.52
0	0	1	3	5	1.67
0	0	5	2	1	1.69
0	0	2	1	7	3.28
0	0	3	3	2	4.09
0	0	4	1	4	5.70
0	0	1	4	3	6.49
0	0	2	2	5	8.10
0	0	6	1	1	8.12
0	0	4	2	2	10.52
0	0	1	5	1	11.31
0	0	1	1	8	12.11
0	0	2	3	3	12.92
0	0	3	1	5	14.53
0	0	5	1	2	16.95
0	0	2	4	1	17.74
0	0	3	2	3	19.35

Table 11. Product Lengths L2, L4 must go first.

L2, Q2 = 32.58, 132
L4, Q4 = 34.34, 19

L1	L2	L3	L4	L5	Form loss in feet
0	6	0	1	0	0.18
1	2	1	3	0	1.00
0	2	2	2	2	1.18
0	3	1	3	0	1.33
0	5	1	1	0	4.85
1	1	2	3	0	5.67
0	2	2	3	0	6.00
1	2	0	3	1	9.83
0	3	0	3	1	10.16
0	2	3	2	0	12.43
3	2	0	1	1	12.69
1	4	0	1	1	13.35
0	5	0	1	1	13.68

Table 12. Product Length L5 must go first.

L5, Q5 = 19.08, 24

L1	L2	L3	L4	L5	Form loss in feet
1	1	1	0	7	0.04
0	2	1	0	7	0.37
0	0	0	1	10	0.86
0	1	0	0	10	2.62
0	0	2	1	7	3.28
0	1	2	0	7	5.04
1	0	0	1	8	7.11
0	0	1	0	10	7.29
0	1	0	1	8	7.44
1	1	0	0	8	8.87
0	0	3	0	7	9.71
0	0	1	1	8	12.11
0	1	1	0	8	13.87
0	0	0	0	11	16.12
0	0	2	0	8	18.54

the sales and production departments (with the advice from the engineering department) must determine the most economical production schedule that complies with the customer's requirements for product delivery.

The production schedule will then establish the order in which the engineering department will design the product and prepare the shop drawings; the purchasing department will comply with the same schedule for ordering material accordingly (Table 13).

A good overall production schedule, if established at a very early stage of the contract, may lengthen the lead time for engineering, drafting and material purchasing. It establishes good work procedures in each department.

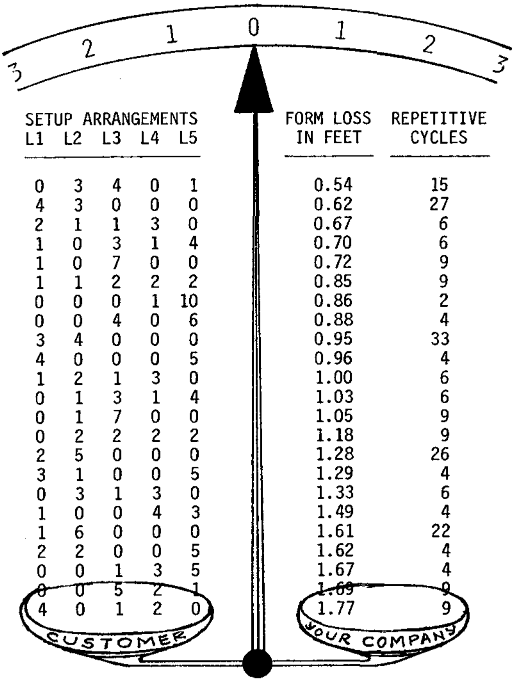
Table 13. Example sequence of product design and purchase of material.

Sequence of product design and purchasing of material:

L1	L2	L3	L4	L5	
0	3	4	0	1	
4	3	0	0	0	
2	1	1	3	0	
1	0	3	1	4	1
1	0	7	0	0	
1	1	2	2	2	
0	0	0	1	10	
0	0	4	0	6	
3	4	0	0	0	3
4	0	0	0	5	
1	2	1	3	0	
0	1	3	1	4	
0	1	7	0	0	
0	2	2	2	2	
2	5	0	0	0	
3	1	0	0	5	
0	3	1	3	0	
1	0	0	4	3	
1	6	0	0	0	
2	2	0	0	5	
0	0	1	3	5	
0	0	5	2	1	2
4	0	1	2	0	
0	1	0	4	3	

Final goal

The final goal of a good production schedule is to instill customer satisfaction and the desire for the highest possible profit in proper equilibrium (Fig. 14).



SETUP ARRANGEMENTS L1	L2	L3	L4	L5	FORM LOSS IN FEET	REPETITIVE CYCLES
0	3	4	0	1	0.54	15
4	3	0	0	0	0.62	27
2	1	1	3	0	0.67	6
1	0	3	1	4	0.70	6
1	0	7	0	0	0.72	9
1	1	2	2	2	0.85	9
0	0	0	1	10	0.86	2
0	0	4	0	6	0.88	4
3	4	0	0	0	0.95	33
4	0	0	0	5	0.96	4
1	2	1	3	0	1.00	6
0	1	3	1	4	1.03	6
0	1	7	0	0	1.05	9
0	2	2	2	2	1.18	9
2	5	0	0	0	1.28	26
3	1	0	0	5	1.29	4
0	3	1	3	0	1.33	6
1	0	0	4	3	1.49	4
1	6	0	0	0	1.61	22
2	2	0	0	5	1.62	4
0	0	1	3	5	1.67	4
0	0	5	2	1	1.69	9
4	0	1	2	0	1.77	9

Fig. 14. Illustration of the required equilibrium of customer satisfaction and highest possible profit for the scheduler's company.

Computerization of Prestress Production Scheduling—Case Histories

Fortunately, long line prestress production scheduling is no longer the difficult and complex problem it used to be. As the next pages of this report show, the computerization has opened and solved a very wide range of planning and scheduling problems and has already achieved important results in prestress manufacturing efficiency.

Conclusions derived from the furnished case histories are based on numerous computer runs. Many scheduling projects have been documented for both manual and computer application, with the results compared and cost/benefit ratios developed.

CASE 1: "Batch" scheduling—breaking up large job in smaller packages by necessity

This condition illustrates one of the most typical cases in the scheduler's work: on a large project the total quantities of slabs are not released at one time.

Normally, because of slowness in design and shop drawing preparation and approval, the production data are released in "batches," i.e., smaller quantities, at irregular time intervals.

These are the cases when the production department is operating in the dark, because production cannot be maintained in accordance with the original plan and the planner loses control of his schedule.

The estimate prior to the submission of a bid on this project was based on 93 production days, using the "square foot area" estimating approach.

Eight months after the contract was signed, the production was started with 100 pieces of L2 slabs. On the 15th day of production, the engineering department released the balance of L2's and 100 pieces of L3's.

ELEMENTS OF CASE 1

```
Product            : T or TT
Number of slabs    : 637
Total area (sq ft) : 295,985
Number of lengths  : 3

    L1, Q1 = 58.50, 102
    L2, Q2 = 61.17, 322
    L3, Q3 = 53.80, 213

Length of form     : 420.00 ft
End bulkhead       :  12.00 in.
Intermed. bulkhead :  12.00 in.
```

Finally, after the shop drawings were approved (on the 16th day), the balance of L3's and all L2's were released for production. All the slabs were produced in 97 days, using 11 setups (one initial, plus ten changes).

After the project was completed, the results were compared with the computer run of what it would have done for the producer. The minimum limit for total number of production cycles (the "measuring gauge") was 90.12 or 91 days.

Seven production paths were developed to see what could have been achieved if all quantities would have been available to schedule the entire project (see Paths A, B and C in Fig. 15) and to simulate on the computer

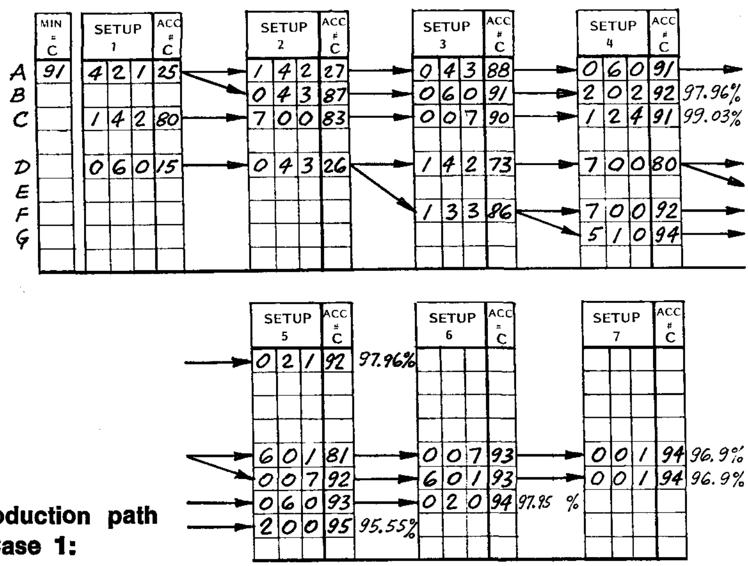


Fig. 15. Production path for Case 1:

the same conditions as on the actual production (Paths D, E, F, and G).

If all the quantities would have been available at the beginning of the project, production could have been accomplished in 91 days with four setups and 99.03 percent planning efficiency, as shown in Path A. Path F developed the most economical slab placement for the actual conditions (94 cycles with six setups).

Other paths required either one more production cycle or one more setup change. On the last production cycle, Path F produced 294.66 linear ft of form space loss that could have been utilized for another project if it would have been available.

The precaster lost money on this project, namely, 4 days of labor and strand compared to the original estimate.

Compared to the computer run, the scheduler lost out by 3 days of production or approximately $6800 (considering labor, strand, and overhead).

Conclusions

1. Use of a computer at the project bidding stage allows the estimator to evaluate all possible delivery conditions and to calculate the number of production days precisely.

2. If the difference in the total number of production days, as affected by the delivery schedule, is significant, the sales manager is in a position to either qualify his bid and/or submit full documentation to substantiate his statements and price differentials.

3. The scheduler is in a position to schedule the project with any number of quantities and immediately change the plans for higher productivity as more quantities become available.

4. Considered one of the worst aspects of the scheduler's work in the past, "batch" scheduling becomes a convenient way to economize even on those projects that develop problems from the first production day.

CASE 2: Effect of lumping several lengths in one

One of the most common scheduling habits is to take a short-cut by lumping several close length slabs in one. Schedulers do this for their own convenience, because it is easier and faster to schedule manually "one length" or "a few length" projects than with the greater number of slab length variation. The consequences of this approach are seldom known to the scheduler or his superiors.

ELEMENTS OF CASE 2

```
Product              : TT
Number of slabs      : 317
Total area (sq ft)   : 151,058
Number of lengths    : 3

    L1, Q1 = 59.50, 240
    L2, Q2 = 59.75,  68
    L3, Q3 = 59.92,   9

Length of form       : 304.00 ft
End bulkhead         :  12.00 in.
Intermed. bulkhead   :  12.00 in.
```

As the length difference between the longest and the shortest slabs was only 5 in., the scheduler assumed 59.92 ft as "one length" for the entire project and did the scheduling of the whole job in 3 minutes (see Path A in Fig. 16). Total result: 80 production days and two setups required with 79.74 percent form utilization factor.

Six production paths were developed on the computer to analyze the impact of the delivery schedule on the economy of the production. To everybody's surprise, the best path (see Path C) required only 64 production days, with 99.01 percent form utilization efficiency and three setups only.

Sixteen days saved on this project meant 16 additional lead-time days

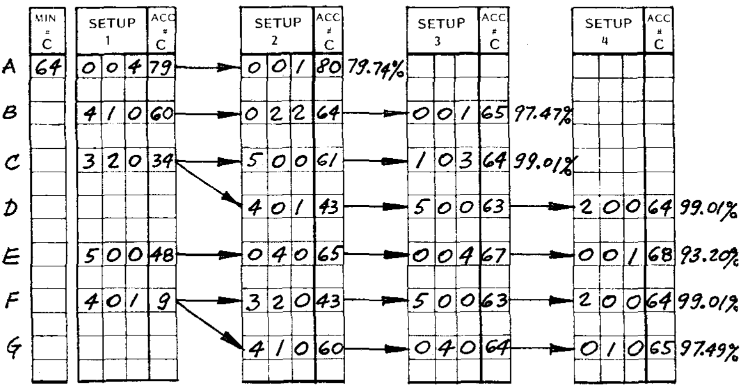


Fig. 16. Production path for Case 2.

that would have allowed the producer to rearrange engineering design work and delivery schedule to produce slabs in accordance with Path C.

The following savings would have been achieved:

Strand: 324 (form L) x 12 (strand) x 16 (days) x $0.18 .... $11,197
Labor: 304 (form L) x 0.98 (percent utilization) x 8 (ft) x 16 (days) x $0.17 .... $6,483
Overhead: 75 percent of direct labor (0.75 x 6483) $4,862

Total $22,542

Conclusions

1. In scheduling production either manually or with the aid of a computer, care must be taken even of the smallest dimensional differences in the lengths of slabs. Lumping together several lengths, where there are only three to five slab length variations, could be a bad practice.

2. The same applies to the form length. Each estimator and scheduler must know and use the exact length of each form in each plant. Careless lumping of lengths and inaccurate form lengths used in scheduling may cost the producer many lost production days and money.

3. With proper and prudent scheduling and attention to details, computerization may extend the leadtime for engineering and production preparation.

CASE 3: Effect of bulkhead spacing

Bulkhead space required to place and fasten a pair of bulkheads (joined or separate) to support the concrete and to provide an access for strand cutting varies from one extreme to another, depending on the producer's opinions.

For instance, in 24-in. double-tee production the bulkhead space varies from as narrow as 4 in. (using collapsible bulkheads) to as wide as 24 in., with the majority of producers using about 12 in. of space.

Since the design and construction of bulkheads vary from a primitive to a well-engineered piece of accessory, other spacings also have been noted, from a popular 8 to 10 in., 14 in. and even 16 in.

Despite the steel form manufacturing industry's attempts to standardize the forming equipment, bulkhead

ELEMENTS OF CASE 3

```
Product             : TT
Number of slabs     : 140
Total area (sq ft): 66,046
Number of lengths : 3

    L1, Q1 = 58.17, 76
    L2, Q2 = 59.34, 32
    L3, Q3 = 60.50, 32

Length of form      : 420.00 ft
End bulkhead        :  12.00 in.
Intermed. bulkhead:  12.00 in.
```

spacing for some reason does not lend itself toward standardization.

A large bulkhead space causes an unnecessary form space and strand loss that could be saved if this space would be reduced to the practical minimum.

For example, one producer recently redesigned his bulkheads by reducing the space from 16 to 8 in. In a 500-ft long form he was casting an average of eight slabs of various lengths. The reduction of bulkhead space by 50 percent provided:

0.67 × 9 (spaces) × 8 (ft wide slab) = 48.24 sq ft form space saving daily or the increase of the production output by 48.24 × 250 (no. of work days) = 12,060 sq ft annually.

Likewise, the reduction of strand resulted in 0.67 × 9 (spaces) × 6 (strand average) = 36.18 linear ft saving daily and 36.18 × 250 (no. of work days) = 9045 linear ft annually.

The minimum limit for total number of production cycles was 19.91 or only 37.8 ft short of the full 20 cycles, whereas the production was scheduled manually in 22 cycles, as shown in Fig. 17.

Two production paths that were developed on the computer required 21 cycles. In an attempt to reduce one more production day, a quick decision was made to reduce the bulkhead space from 12 to 8 in.

As a result, Path C accomplished the job in 20 cycles with only two setups, saving the producer two setups and two important days of production (10 percent). The overall savings of strand, labor, setup changes and overhead totalled $3870.

In another case, the production manager of a large precast company that operates up to 16 prestress beds daily recently noticed that the accountant's books showed $3200 as the annual cost of bulkhead maintenance.

The "high" cost was attributed to the fact that 8-in. wide bulkheads, that were used throughout the plant, were damaged during double-tee stripping operations. In order to eliminate or at least minimize this maintenance cost, the manager ordered widening all bulkhead spaces from 8 to 12 in.

Naturally, the accountant's books no longer show considerable maintenance expense for the new 12-in. wide bulkheads. But, the books also

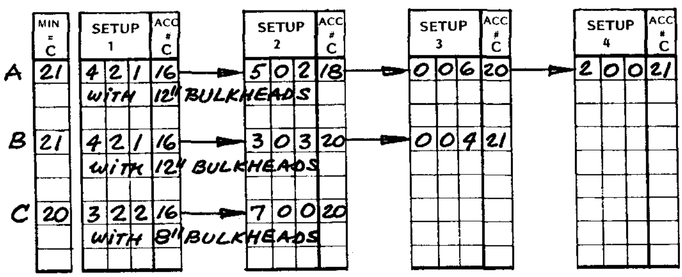


Fig. 17. Production path for Case 3.

do not show the following losses that have resulted from the above change:

1. Reduction of plant production capacity: 16 (lines) × 7 (bulkheads) × 0.34 (ft space loss) × 8 (ft width) = 305 sq ft daily, or 305 × 250 (production days) = 76,250 sq ft annually.
2. Loss of strand (attributed to the above reduction only): 16 (lines) × 7 (bulkheads) × 0.34 (ft loss) × 6 strands) = 229 linear ft of strand daily, or 229 × 250 (production days) = 57,250 linear ft annually.

Conclusions

1. Small dimensional changes and variations in bulkhead spacing may affect the profitability of the job.

2. There is no reason to maintain more than 12-in. bulkhead spacing for most of the products. If it can be further reduced, so much the better for the producer.

CASE 4: Effect of combining jobs with different strand patterns

This is a common practice in some prestress plants. The idea is to combine slabs from several jobs, including odds and ends, recasts, etc., with different patterns by using the "heaviest" strand pattern. The process may require double scheduling.

First, the scheduler has to lay out the production for each strand pattern separately. On the second trial he has to combine slabs of different patterns and calculate monetary gains or losses in order to make a decision. In addition, a check of stresses and cambers also has to be made in order to satisfy design requirements.

Originally, all three jobs were scheduled separately to be produced in 16 days with seven setups (Fig. 18). For the purposes of computer scheduling, all three jobs were combined into one, using a 10-strand pattern for all slabs (as it was approved by the design engineer).

ELEMENTS OF CASE 4

```
Product             : TT
Number of slabs     : 77
Total area (sq ft): 33,047
Number of lengths : 5

    Project A
    L1, Q1 = 59.33, 19
    L2, Q2 = 55.00, 20
    L3, Q3 = 55.33, 20
     all with 10 strands

    Project B
    L4, Q4 = 46.25, 14
         with 8 strands

    Project C
    L5, Q5 = 37.33,  4
         with 6 strands

Length of form     : 300.00 ft
End bulkhead       :   8.00 in.
Intermed. bulkhead:    8.00 in.
```

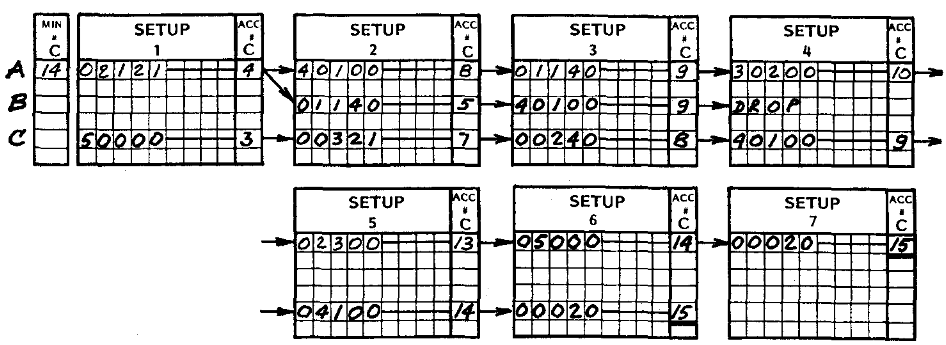


Fig. 18. Production path for Case 4.

Slabs were produced in 15 cycles and six setups. Production Path C indicated that by reducing end bulkhead space from 8 to 0.5 in. (fastening the bulkhead from the end of form), a saving of one additional setup can be achieved.

As a result, one production day and one setup were saved, with the following monetary savings achieved:

Gross savings of strand:

310 × 10 = 3100 linear ft

Strand wasted because of pattern differences:

L4: 46.92 × 2 × 14 = 1313 linear ft
L5: 38.00 × 4 × 2 = 307 linear ft

Total 1620 linear ft

Net strand saved:
3100 linear ft
− 1620 linear ft

1480 linear ft at $0.15 = $222.00

Labor savings: One production day at 95 percent capacity:
300 × 0.95 × 8 × $0.20 per sq ft = $456.00

One setup saved:
4 men × 1.5 hrs × $10 per hr = $60

One day's overhead saved at 75 percent of total direct labor:
$456 × 0.75 = $342

Total Saving: $1080.00

Conclusions

1. Combining products with different strand patterns requires an engineering check of stresses and cambers and therefore should be always approved by the engineering department.

2. Providing that the engineering requirements are satisfied, combining two or more projects with slabs of different strand patterns into one may produce substantial reductions in the number of production cycles and setup changes.

CASE 5: A very small job

One producer scheduled a 3-day production on a small order involving a slab length variation. His schedule resulted in a 66.64 percent form space utilization efficiency, as shown in production Path A (Fig. 19).

```
ELEMENTS OF CASE 5

Product              : TT
Number of slabs      : 17
Total area (sq ft)   : 6,565
Number of lengths    : 5

    L1, Q1 = 46.25, 6
    L2, Q2 = 42.10, 5
    L3, Q3 = 60.50, 4
    L4, Q4 = 43.20, 1
    L5, Q5 = 47.40, 1

Length of form       : 420.00 ft
End bulkhead         :  12.00 in.
Intermed. bulkhead   :  12.00 in.
```

The above numerical relation establishes the minimum limit for the total number of production cycles at 1.99905, or just 0.4 ft under two full cycles.

The project was rescheduled on a computer and produced in 2 days with 99.95 percent form space utilization efficiency as shown in production Path B.

This resulted in savings of one production day and one setup change, or $1777 for strand, labor and overhead.

Conclusions

1. Substantial savings in planning and scheduling production can be especially achieved on small jobs. One production cycle on a 25-day job results in 4 percent savings. But the same day that is saved on a 3-day job yields 33 percent savings.

2. It is very difficult to schedule small jobs, because they are more "rigid" and provide less latitude than the large ones. Therefore, just as much attention, time and patience should be afforded for scheduling small jobs.

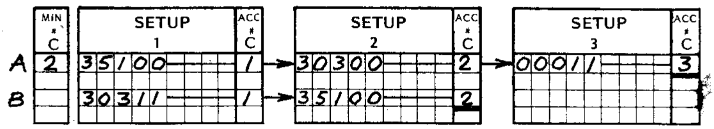


Fig. 19. Production path for Case 5.

Another fact should be remembered: Statistically as well as traditionally, the small contracts form the bulk of each precaster's business.

CASE 6: Very short form length

A considerable number of prestress producers still use very short forms (120 to 290 ft long). Production at such plants or on such prestress beds continuously results in large form space, labor and strand losses, because efficient scheduling is either extremely difficult or, in most cases, impossible.

ELEMENTS OF CASE 6

Product	: TT
Number of slabs	: 82
Total area (sq ft)	: 27,134
Number of lengths	: 4
L1, Q1	= 37.42, 62
L2, Q2	= 60.00, 12
L3, Q3	= 42.70, 6
L4, Q4	= 47.75, 2
Length of form	: 155.00 ft
End bulkhead	: 0 in.
Intermed. bulkhead	: 12.00 in.

One producer scheduled the above job in 26 days with nine setups. The project was rescheduled on the computer. The minimum limit for total number of production cycles was 22.27.

The new schedule required 23.49 cycles and five setups. As a result, two production days and four setups were saved, and 94.64 percent form space utilization efficiency achieved (See Fig. 20).

Conclusions

1. The only way to economize production in short forms is to allow for as many setup changes as necessary to take the advantage of minimum form space losses.

2. The variety of slab lengths and quantities helps the scheduler to explore more combinations and find those that utilize the form length more efficiently. Mixing jobs with different strand patterns (as in Case 4) should always be considered.

CASE 7: Jobs with a long list of "specials"

In addition to so-called "standard lengths," many jobs also include a

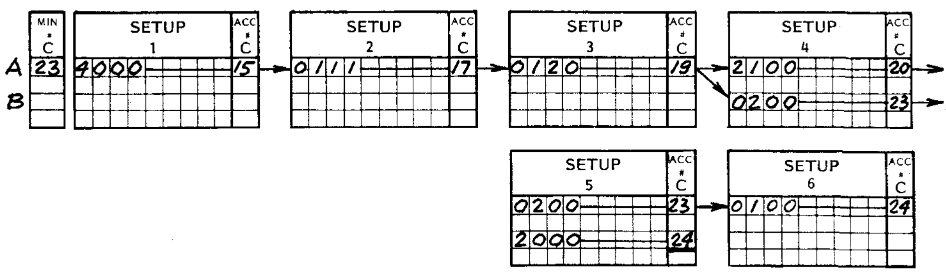


Fig. 20. Production path for Case 6.

high number of "specials," i.e., slabs of great variety of lengths, all required in small quantities.

Scheduling of such jobs is difficult, time-consuming and, if done quickly or haphazardly, results in high form space and strand losses. In case of tight delivery condition, the situation becomes even worse and profitable scheduling impossible.

We do not intend to demonstrate this lengthy case because of space limitations here. Instead, we can describe superficially a simple case that represents this condition.

ELEMENTS OF CASE 7

```
The project involved 158 TT-
slabs to produced in a 400 ft
long form with 8 in. end  and
intermediate bulkhead spacing.

The complexity of the job was
increased by  two  strand
patterns:

Pattern "A" had 91 slabs with
17 length variations (L1 thr.
L17).  Slab lengths  within
this pattern varied between 9
and 60 ft.

Pattern "B" had 67 slabs with
6 length variations (L18 thr.
L23). Slab lengths involved
in this pattern were more uni-
form - from 53 to 60 ft.
```

The original manual scheduling performed by a highly qualified scheduler required 25 production days. The schedule was re-analyzed on the computer and two production days were saved, reducing the total to 23 days. The rescheduling of the project saved the producer $2650.

Conclusion

Computerized scheduling provides the means to handle even the most complicated jobs with a lot of specials. In order to achieve the highest efficiency in scheduling, these cases require extra time and patience. A combination of computer runs and manual calculations is also advisable.

CASE 8: Combined unfavorable conditions that complicate scheduling

Most jobs involve some complications that make scheduling difficult. For instance, contrasting length and/or quantity variations, short length of form, high number of specials, and unfavorable shipping order are a few examples. There are many cases where several of these conditions are combined.

This case describes a scheduling condition that involves two overpowering quantities of slabs, one-third of the slabs are specials, and a short bed.

ELEMENTS OF CASE 8

```
Product          : TT
Number of slabs  : 346
Total area (sq ft): 85,787
Number of lengths : 5

    L1, Q1 = 32.91, 108
    L2, Q2 = 32.58, 132
    L3, Q3 = 27.91,  63
    L4, Q4 = 34.34,  19
    L5, Q5 = 19.08,  24

Length of form    : 238.00 ft
End bulkhead      :  12.00 in.
Intermed. bulkhead:  12.00 in.
```

The minimum limit for total number of production cycles was 46.707, yielding a "borderline" case, allowing a latitude of 69.7 ft for the whole job or averaging 1.48 ft per cycle.

Six production paths were developed on the computer of which the two best ones are shown in Fig. 21. Compared to the manual schedule, the producer saved two setups and two production cycles in the amount of $1734 for labor and strand.

The job was produced in accordance with Path A in 47 days, using five setups, with the overall form utilization efficiency of 99.38 percent.

Conclusion

In complicated cases, it is vital to develop many production paths for better choice and comparison.

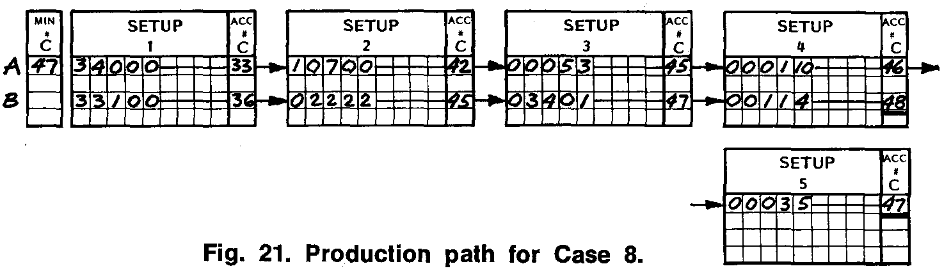


Fig. 21. Production path for Case 8.

CASE 9: "Sensitivity" of two length variations

Regardless of the number of length variations, the importance of a careful selection of the right setup arrangement either from the form utilization or repetition standpoint is the same.

Although the number of arrangements for two length variations may not be as high as for 4, 6 or 8 lengths, it is sufficiently high to be of the estimator's and scheduler's concern.

The following two examples (Cases 9A and 9B) illustrate this condition.

The slab-to-form-length relation yields eight possible setup arrangements shown in Table 14. If the arrangements are not carefully selected, high form space losses could be expected.

The slab-to-form-length relation develops 14 possible arrangements as shown in Table 15.

Conclusion

The importance of carefully scheduling two product length variations must not be overlooked under any conditions.

ELEMENTS OF CASE 9A

Product	: TT
Number of slabs	: 108
Total area (sq ft)	: 46,592
Number of lengths	: 2
L1, Q1 = 52.00, 56	
L2, Q2 = 56.00, 52	
Length of form	: 500.00 ft
End bulkhead	: 8.00 in.
Intermed. bulkhead	: 8.00 in.

ELEMENTS OF CASE 9B

Product	: H.C.
Number of slabs	: 106
Total area (sq ft)	: 20,608
Number of lengths	: 2
L1, Q1 = 28.00, 50	
L2, Q2 = 21.00, 56	
Length of form	: 365.00 ft
Blade thickness	: 0.30 in.

Table 14. Setup arrangements yielding wide variation in form space losses.

Quantities for L1	L2	Form loss in feet
3	6	1.33
4	5	5.33
5	4	9.33
6	3	13.33
7	2	17.33
8	1	21.33
0	8	46.00
1	7	50.00

Table 15. Setup arrangements yielding wide variation in form space losses.

Quantities for L1	L2	Form loss in feet
1	16	0.60
4	12	0.63
4	8	0.65
10	4	0.68
13	0	0.70
0	17	7.60
3	13	7.62
6	9	7.65
9	5	7.68
12	1	7.70
2	14	14.63
5	10	14.65
8	6	14.68
11	2	14.70

CASE 10: How to get the most from hollow-cored slab scheduling

Many hollow-cored slab producers violate the elementary rules of scheduling. As a result, they discard thousands of square feet of good product that could have been sold at a full sales price (see Fig. 7 and comments in Part 1).

The following study was especially made to prove that scheduling hollow-cored products in medium length or long forms can be accomplished with negligible losses.

In order to emphasize this case and to make it more difficult, we have selected the form length in the range from 356 to 365 ft.

ELEMENTS OF CASE 10

```
Product             : H.C.
Number of slabs     : 114
Total area (sq ft): 9,705
Number of lengths : 3

    L1, Q1 = 22.00, 41
    L2, Q2 = 26.00, 41
    L3, Q3 = 14.32, 32

Length of form (bed):
from 356' to 365' at 1 ft
increments.
Blade thickness    :  0.30 in.
```

To observe and study the interplay of the scheduling elements, we made ten computer runs, extending the length of the form by 1 ft each time, but keeping the same original slab lengths and quantities for the entire experiment. The results are summarized and tabulated in Table 16.

Conclusion

With careful selection of proper arrangements, the scheduler can almost always develop a slab cutting pattern that will result in near zero losses.

Computerized scheduling provides the means to reduce the losses to such a degree that they can nearly be eliminated, rather than lifted from the bed as it frequently happens today.

CASE 11: Daily scheduling of hollow-cored slab production

Capitalizing on the experience gained with cases similar to Case 10, the principles were applied on an actual project with the following details as shown at the top of the next page.

Table 16. Summary of results of Case 10.

L.F. of extruded slab	No. of setup arrangements	Arrangements producing smallest loss L1	L2	L3	Loss in feet per cycle	Percent of form efficiency	Number of arrangements w/ loss less than 1 inch	Min. limit for total number of cycles
356	125	7	5	5	0.00	100	1	6.8228
357	127	0	6	14	0.05	99.986	1	6.8037
358	127	0	11	5	0.03	99.99	2	6.7847
359	128	2	11	2	0.01	99.99	2	6.7658
360	128	6	6	5	0.00	100	1	6.7470
361	130	1	2	20	0.05	99.986	1	6.7283
362	130	1	7	11	0.03	99.99	2	6.7097
363	131	1	12	1	0.01	99.99	3	6.6912
364	131	5	7	5	0.00	100	2	6.6729
365	133	0	3	20	0.05	99.986	1	6.6546

ELEMENTS OF CASE 11

Product	: H.C.
Number of slabs	: 612
Total area (sq ft)	: 49,970
Number of lengths	: 3
L1, Q1 = 20.16, 288	
L2, Q2 = 17.33, 108	
L3, Q3 = 22.29, 216	
Length of bed	: 501.00 ft
Blade thickness	: 0.30 in.

The usual method of assuming the "average" or "minimum" length of the extruded total length of slab was not used in this case. Instead, the increase in product yield was achieved by measuring the "usable" extruded length of slab and scheduling the cutting order daily.

The project was started with 49 percent of the quantities, and the balance was added on the fifth day of production. On the seventh day, the slipforming machine failed to produce a full cross section for 6.75 ft. Thus, the scheduler ended up with scheduling two partial lengths of bed that day.

The general arrangement of the form is shown in Fig. 22. Production record of the first 9 days of the job is shown in Table 17.

The usable length of the slipformed uncut slab, as it was measured every day, is shown in the second column. The job was finished in 25.5 production cycles with 99.9 percent utilization of the usable length of uncut slab.

Table 17. Record of first 9 days of production.

Quantities of L1	L2	L3	L4	L5	L6	Form loss in feet
5	0	0	0	0	0	36.53
4	0	2	0	0	0	38.21
5	0	0	1	0	0	38.49
3	0	3	0	0	0	39.05
4	0	1	1	0	0	39.33
2	0	4	0	0	0	39.89
4	1	1	0	0	0	39.90
5	0	0	0	1	0	39.96
3	0	2	1	0	0	40.17
4	0	0	2	0	0	40.45
3	1	2	0	0	0	40.74
4	0	1	0	1	0	40.80

Due to uncertainties in normal scheduling, the producer was losing 6 to 12 linear ft of product per line daily. In contrast with computerized scheduling, the losses average less than 4 in., achieving a production scheduling efficiency of 99.9 percent.

Conclusions

1. It is well known that the total length of the usable portion of the extruded or slipformed uncut slab is different every day.

2. It is bad practice to schedule the entire job basing the cutting patterns on the assumed "safe length" of the uncut slab.

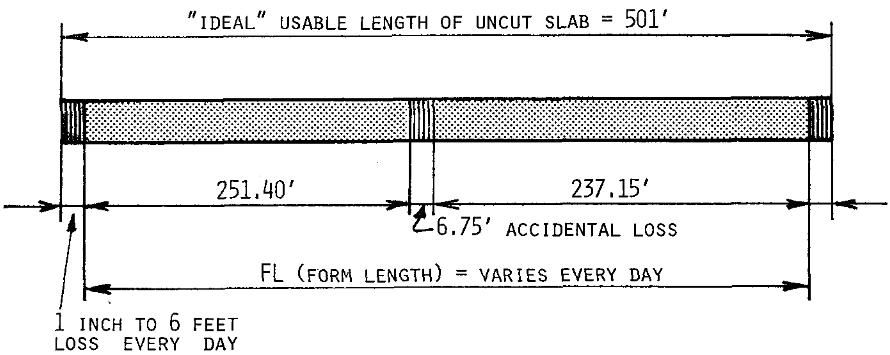


Fig. 22. General arrangement of a 501-ft long extrusion bed.

3. In order to achieve the highest possible production yield, and at the same time reduce waste of the product, the cutting pattern must be established after measuring the usable total length of the uncut slab daily.

CASE 12: Use of extended "dead" strand with coupler to reduce losses

This case describes a method that helps achieve nearly 100 percent utilization of the form space and reduce strand loss to the minimum using extended "dead" strands with couplers. It can be used under several conditions (see Fig. 23).

(a) The remainder of the quantities that have to be cast on the last production day fill the form only partially. On small jobs this condition can destroy any hope for profit.

(b) Only a portion of the form is utilized for the duration of the job.

In many cases producers use long (roof slab) forms for wall panel production, but, because of the complexity of the wall panel design (numerous inserts, cutouts, plates, frames, etc.), the labor crew can finish only a portion of the form length in a normal 8-hour working day.

ELEMENTS OF CASE 12

Product	: TT panels
Number of slabs	: 102
Total area (sq ft)	: 17,319
Number of lengths	: 4
L1, Q1 =	25.00, 15
L2, Q2 =	14.96, 9
L3, Q3 =	9.00, 3
L4, Q4 =	21.71, 75
Length of form	
original	: 370.00 ft
reduced to	: 254.10 ft
End bulkhead	: 6.00 in.
Intermed. bulkhead	: 12.00 in.

The original length of the form was 370 ft, but the crew cast either 11 slabs or two-thirds, i.e., approximately 250 to 260 ft of the form length daily.

Independent computer runs were performed for several setup arrange-

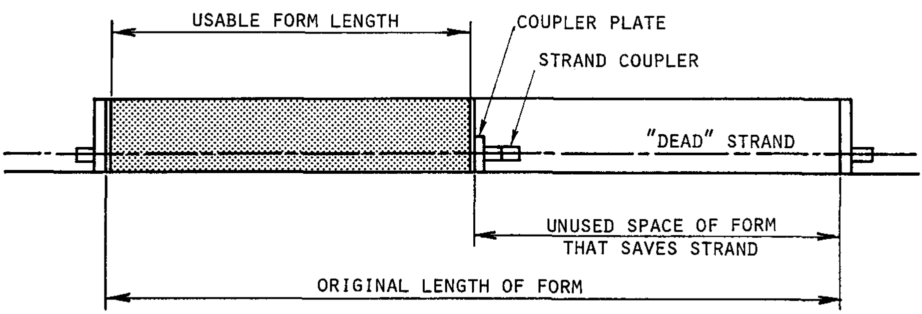


Fig. 23. Method of shortening form with "dead" strand.

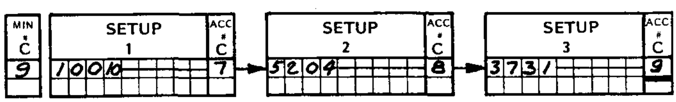


Fig. 24. Production path for Case 12.

ments. Subsequently, the job was scheduled in 9 days, having three setups, with overall form utilization efficiency of 99.52 percent (practically no strand loss). (See Fig. 24.)

Conclusions

1. Extended "dead" strand with the coupler implemented with computerized scheduling is an effective way to save strand and increase productivity.

2. Computerization allows a quick evaluation of all obtainable form lengths for selecting the best solution.

CASE 13: Removable form section—New method in scheduling

This is a completely new and unique way to save strand. It is based on the principle that one or several sections of the form can be removed from a self-stressing form in order to shorten it.

Fig. 25 illustrates the concept. For example, the original length of the form is 260 ft, consisting of thirteen 20-ft sections. The last two sections are removable in order to shorten the form.

Thus, the producer is in a position to utilize 220, 240 or 260-ft long forms, whichever is needed. The end of each removable section is reinforced to resist the prestressing force and carries a special attachment to fasten or remove the jacking plate, which is also removable.

ELEMENTS OF CASE 13

Product	: TT panels
Number of slabs	: 38
Total area (sq ft)	: 9,538
Number of lengths	: 4
L1, Q1 = 30.30, 12	
L2, Q2 = 31.63, 7	
L3, Q3 = 31.88, 17	
L4, Q4 = 32.63, 2	
Length of form	
original	: 400.00 ft
reduced to	: 260.00 "
	240.00 "
	220.00 "
End bulkhead	: 12.00 in.
Intermed. bulkhead	: 24.00 in.

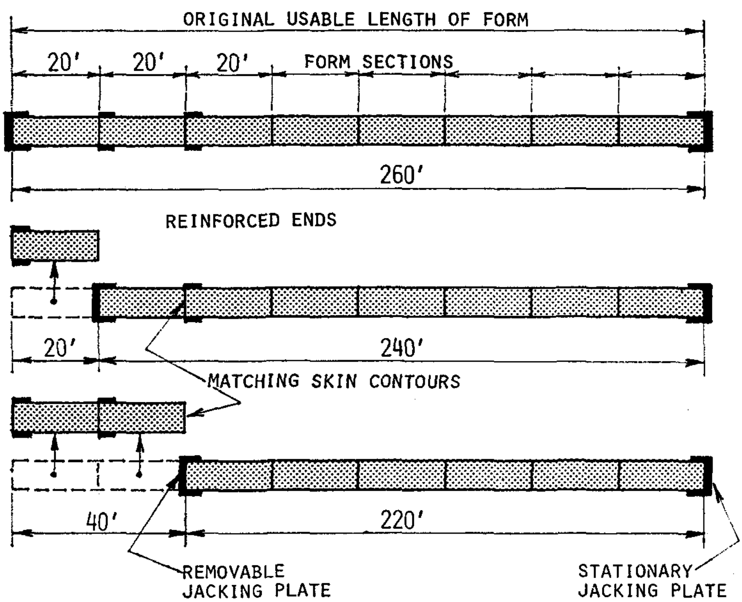


Fig. 25. Method of shortening form by removing one or two form sections.

Two production paths were developed for each of 260, 240 and 220-ft long forms, and 240 ft was chosen as the most economical length. (Only three selected production paths are shown in Fig. 26, thus achieving a form space utilization of near 100 percent).

Conclusion

Removing sections to shorten the form can be an effective way to save strand. Computerization allows a quick evaluation of all obtainable form lengths for selecting the best solution.

CASE 14: All slabs of the same length

There are many jobs that require one length of the product only. It may seem that the scheduling of such jobs is simple; but in reality, they do present problems.

Fig. 27 shows utilization percentages for 300 and 500-ft long forms in

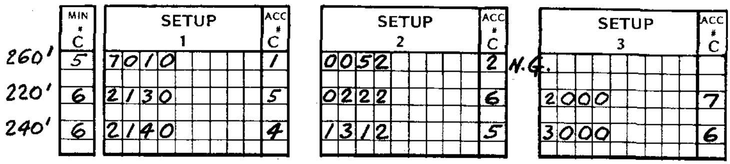


Fig. 26. Production path for Case 13.

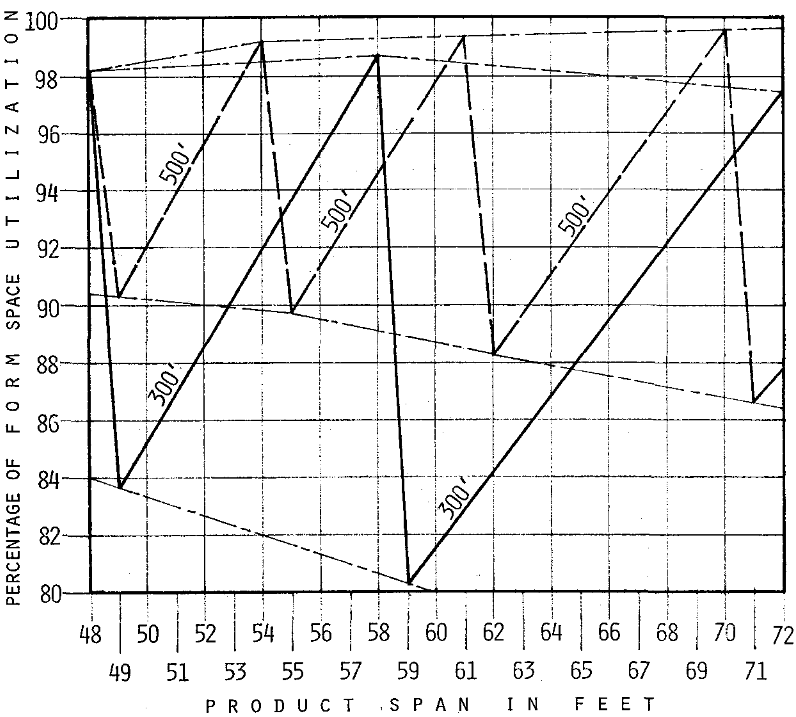


Fig. 27. Utilization of space percentages in 300- and 500-ft long forms.

relation to the product length in the range from 48 to 72 ft. For instance if the product is 54 to 58 ft long, high form space utilization can be expected in forms that are 300 ft. But if the product is 58 to 65 ft long, the opposite is true.

In general, the spread between high and low form space loss can vary from 0.5 to 13 percent for 500 ft and from 1 to 20 percent for the 300-ft long form.

When the scheduler confronts a job with the products of one length only, several alternatives are possible:

1. If there is a choice of available beds, select such form length that produces the highest utilization percentage.
2. Combine with slabs of similar patterns from another job as described in Case 4.
3. Shorten the form as described in Case 14.
4. If the form space loss exceeds 5 percent or more, use the extended "dead" strand technique as described in Case 12.

Conclusions

1. The precast producer with a good form length mix is in a more advantageous position than his competitor whose forms are all of the same length.

2. A graph (similar to that shown in Fig. 27), if properly prepared and provided at each plant, could become an invaluable marketing tool.

CASE 15: Difficult scheduling cases

There is a small percentage of cases where the product and form length is such that high form space losses are unavoidable. The following case illustrates this condition.

ELEMENTS OF CASE 15

```
Product             : TT
Number of slabs     : 67
Total area (sq ft)  : 31,218
Number of lengths   : 6

    L1, Q1 = 59.80, 12
    L2, Q2 = 57.27, 11
    L3, Q3 = 58.96, 18
    L4, Q4 = 57.84, 21
    L5, Q5 = 56.37,  4
    L6, Q6 = 53.27,  1

Length of form      : 400.00 ft
End bulkhead        :   8.00 in.
Intermed. bulkhead  :   8.00 in.
```

The minimum limit for total number of production cycles is 9.884. The total number of possible setup arrangements is 324 of which 1, 1, 2, 2, 0, 0 yields the maximum of nine identical cycles with 44.66-ft form space loss.

Table 18 shows some of the best setup arrangements where form space losses are nevertheless high. It is a difficult situation for the sched-

Table 18. Setup arrangements with high form space losses (Case 15).

Quantities of L1	L2	L3	L4	L5	L6	Form loss in feet
5	0	0	0	0	0	36.53
4	0	2	0	0	0	38.21
5	0	0	1	0	0	38.49
3	0	3	0	0	0	39.05
4	0	1	1	0	0	39.33
2	0	4	0	0	0	39.89
4	1	1	0	0	0	39.90
5	0	0	0	1	0	39.96
3	0	2	1	0	0	40.17
4	0	0	2	0	0	40.45
3	1	2	0	0	0	40.74
4	0	1	0	1	0	40.80

uler. If there are not other jobs available that can be combined with this one, there is no choice. But at least the scheduler knows and can justify his action with proper documentation.

Conclusions

1. Utilize variety of bed lengths to find the most economical one.

2. Shorten the form.

3. Use extended "dead" strand with a coupler.

4. Combine with other jobs of similar patterns, if possible.

CASE 16: Importance of reducing setup changes

Our experience shows that jobs with a high number of different product lengths require many setup changes. The following typical job illustrates this situation.

ELEMENTS OF CASE 16

Product	: TT panels
Number of slabs	: 405
Total area (sq ft)	: 62,148
Number of lengths	: 9
L1, Q1 =	8.75, 33
L2, Q2 =	11.25, 26
L3, Q3 =	14.00, 60
L4, Q4 =	14.75, 22
L5, Q5 =	16.17, 37
L6, Q6 =	20.00, 25
L7, Q7 =	23.83, 179
L8, Q8 =	26.50, 14
L9, Q9 =	32.00, 9
Length of form	: 240.00 ft
End bulkhead	: 12.00 in.
Intermed. bulkhead	: 12.00 in.

The job was scheduled manually for 37 cycles with 18 setups. According to the computer run, the minimum limit for total number of production cycles was 34.199. It took some computer effort to find the best production path consisting of 35 cycles with only six setups.

Two days and 12 setup changes were saved. According to the precaster, the new schedule saved him $3325 in strand and labor alone.

Conclusions

1. Every setup change is expensive, causes overtime and often slows down or delays production, resulting in lost days.

2. Every possible effort should be exercised in order to reduce the number of setup changes to its practical minimum.

CASE 17: Time comparison between manual and computerized scheduling

ELEMENTS OF CASE 17

Product	: TT
Number of slabs	: 896
Total area (sq ft)	: 73,173
Number of lengths	: 3
L1, Q1 =	26.80, 539
L2, Q2 =	21.70, 133
L3, Q3 =	21.50, 224
Length of form	: 420.00 ft
End bulkhead	: 8.00 in.
Intermed. bulkhead	: 8.00 in.

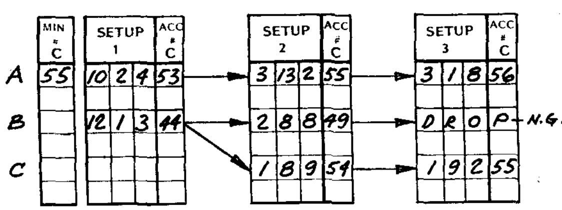


Fig. 28. Production path for Case 17.

A well experienced scheduler did a detailed study of the above job and, after many trials and changes, determined that the job would require 57 production cycles and six setups. Total time spent for scheduling this job was 3½ days including some minor miscellaneous administrative functions performed in between.

After developing and evaluating three production paths, we scheduled this job for 55 production days (minimum limit for total number of cycles was 54.29) and three setups in 25 minutes (see Fig. 28).

Conclusions

Computerized scheduling was accomplished more than 60 times faster than manually, freeing the scheduler from tedious calculations which gave him more time to explore alternatives and to be creative.

Cases That Merit Attention

Other long line products

Piles, stadium seats, flat slabs and similar products cast in long line forms present similar scheduling problems as stemmed products and hollow-cored slabs. The same principles of scheduling and the conclusions reached in the preceding case histories apply equally well to all these products.

Exact length of forms

One of the shortcomings in scheduling jobs with high precision is that schedulers and estimators use the nominal and not the exact length of the form. The difference between the nominal and actual lengths, as we have observed, varies from a few inches to a few feet and unavoidably affects the schedule and even the outcome of the job.

We recommend that all producers remeasure the length of each form in the yard and start using the actual length in scheduling. Surprisingly, form lengths such a 238.0, 253.1, 304.0, 399.08, 419.85 and others will emerge.

Most economical bay size

Determining the most economic bay size has been an important subject in our industry during the last 25 years.

Although many marketers and engineers have been engaged in promoting economy in building design, somehow they could not answer this simple question of "what is the most economical bay size in prestress construction?"

Despite much study and deliberation, there is still no single industry agreement to this important question.

With the exception of specific products and their cross sections, the industry does not offer any specific information on economy in building design.

As a result, architects and engineers, not being properly guided and motivated by the precasters in terms of economic spans, design buildings to their own liking, utilizing what they call "design freedom" in concrete.

Consequently, producers acquire projects containing many intangibles which impede and hinder a normal flow of production (as we described under "Marketing Strategy" in Part 1). Thus, the industry's industrialization process has been adversely affected.

On the other hand, in the steel industry, the most economical bay size was settled many years ago. It is given as a function of the available "mill length" of the structural steel shape.

If the most common "mill lengths" are 40, 50 and 60 ft, then the most economical lengths are those that can be cut out without waste, namely, 10, 12.5, 15, 20, 25, 30 and 40 ft. If the structural steel products are cut in other than the above lengths, waste results; and someone has to pay for it.

In comparing both competing industries, the current situation appears to be as follows:

The steel industry has established specific length standards. It has trained and motivated the design professionals in the use and application of these standards. Waste of material (if any) is charged to the customer.

In contrast, the prestressing industry has never established standards or economic criteria and has always allowed buildings to be designed free of any restrictions. This philosophy has created waste.

Computerized production planning and scheduling of all long line prestress products may change the entire situation in favor of the precasters.

It is apparent that the product economy, besides production considerations, also depends on design efficiency and shipping regulations. But in view of the foregoing case histories and the conclusions we developed, it is easy to understand that the production optimization bears the heaviest influence on the product economy in lowering sales price.

Computerized production planning and scheduling also provides all the necessary means for the precast producers to reach high production efficiencies and low material losses with minimum setups.

If all means, principles and techniques are properly employed, the industry's biggest competitive drawback can be turned into the best marketing tool: while promoting "design freedom" to the professionals, take the highest advantage of what computerization of production process can afford.

Most economical form length

This is another problem that troubles many precasters, especially newcomers. Fig. 27 clearly indicates that the maximum utilization of the form depends on the form-length-to-product length relation.

If a particular company specializes in the marketing of one-length products (which is an unlikely case), the most economical form length can be easily calculated from the product waste standpoint.

If the precaster sells to a wide range of clientele (like everyone does), he is faced with all the problems (and many more) that have been described in Cases 1 through 16. The most economical length of form cannot be assumed based on precedents or calculations—it simply does not exist.

Summary and Conclusions

What we have learned

Although not all-inclusive, we can do some generalizing on what we have learned based on our research and case histories. Many of the principles presented by functions may affect the profitable operation of a precast/prestress company.

Prestressing industry in general

As a group, precast prestressed producers have a unique opportunity to ease the materials shortage. The industry has already made a substantial contribution to conservation by replacing certain other structural and architectural materials thereby freeing them for other uses.

But the industry can do more. The abundance of the past encouraged us to over-design prestress products. Excessive amounts of what are now critical materials were used and products far in excess of code requirements were produced.

Better quality products designed and produced with a minimum of critical materials while maintaining compliance with code standards are possible. Allowing a proper margin for contingencies, a careful approach could minimize the use of scarce materials and improve product quality.

Conservation will become a way of life in plant procedure as well as in design, even though the difficulty of changing old practices is always an obstacle in itself. Prestressed products were originally developed to conserve materials. Prestress producers must go back to this root in the coming years to take full advantage of the opportunities prestressed concrete offers in this area.

Organization and administration

The aim of computerized production planning and scheduling as it appears now is the coordination of managerial efforts toward the goals of the firm. It has as its objective the coordination of actions involving people, equipment, time and money and produces the following results:

1. The right information is furnished to the right people at the right time and at the right cost.
2. Decrease of uncertainty and improvement of decision quality.
3. Increased capacity to process present and future volume of work.
4. Ability to perform profitable work that was previously impossible.
5. Increased productivity of employees, capital and equipment and reduced costs.

The generated production data may also be viewed in terms of "timing" information flowing between departments. This information flow of timing is the life blood of an administrative system and is necessary for making plans and decisions. It is also necessary for initiating and directing actions in many operating departments as well as for comparing results against plans.

Marketing strategy

Computerization of the production planning pays off in any size plant. The monetary gains are proportional to the percentage gain in productivity. Precise real-time data give management a chance to optimize efficiency and obtain maximum yields.

Higher production yields mean either lower sales price or higher profit and as such become very important marketing considerations. Marketing and production functions should be coordinated to a maximum.

Estimating methods should also be completely revamped. In order to take full advantage of computerization, labor, and strand usage, calculations should be based on the precise numbers of production cycles and setup changes.

In the estimating process, good scheduling is just as important as in the final process—getting ready for production. A precaster's bid based on precise production data should give him a higher degree of confidence especially where competitive bidding is involved.

The philosophy behind this is very simple—if the company gets the project, there is a good assurance that a profit can be made, and if the company loses the job, the chances are that the competitor has made a mistake and may lose money.

Production advantages

In the past most producers were happy with 90 to 95 percent form space utilization. With computerized scheduling, we are now aiming at 99 percent or better form space utilization.

Computerized production planning and scheduling enables every planner and estimator to turn out desired quantities of valuable data and make decisions in a short time. In general, the computer will do far more and better in less than half an hour than the scheduler can accomplish in 2 to 4 days.

Statements that only large volume jobs require special attention in scheduling is a misconception. It is much more difficult to schedule small jobs, but the savings and the resultant profits are much higher than can be obtained on large projects. It is especially important for small- and medium-sized producers.

Despite the sophistication of prestress design, the profit for the precaster is in production efficiency. Production with a properly arranged and operated planning and scheduling department in our opinion is essential.

Personnel considerations and new ideas

Computerized scheduling is able to carry out complex routines quickly and precisely. This is especially valuable in emergencies and sudden changes. A human operator is essential to provide judgment and decisions. Computerization should combine the human intellect with the speed of the machine and extend the working capabilities of the scheduler to provide extra time for creative thinking.

Observing the schedulers at many plants and under different working conditions, we have concluded that in many cases a drastic improvement in the quality of personnel is needed. In fact, the proper use of the scheduler coupled with computerization can save vast sums of money for the company.

We also feel that the selection of the head of the production planning and scheduling department should be done as carefully as chief engineer or sales manager. We see this as the first great opportunity for the prestressers to start industrializing their operations.

Cost benefits

The most important part of computerized scheduling is the significant economic benefit that can be achieved. Based on cost-benefit studies that were performed on a variety of jobs, we estimate that each individual plant using computerized production planning has a good chance of saving up to 6 percent of total production cost annually. This increase in productivity does not require any investment in plant facilities or increasing the labor crew.

Utilization of computer time-sharing eliminates investment in computers. It provides convenience and economy—the user pays only for the time used. This cost is relatively small.

In our evaluation the range of benefit to cost ratios spans from 40 to 600 and even more.

Closing thoughts

The prestressing industry is almost tailor-made for computerization in production control because it manipulates daily vast quantities of materials into finished structural products. Computerization will focus management's attention on production control which will become increasingly important in the future.

Product complexity and variety are growing while there are ever-stronger pressures to optimize production for higher efficiencies. Unquestionably, the greatest influences in the field of production control will come from a growing professionalism, better education, and wider application of the computer.

The computerized production planning and scheduling technique is only the means to an end. It introduces a powerful new way of thinking about the manufacturing process—precise, calculated, analytical—a process that will boost the prestressing industry to higher levels in efficiency and control.

Acknowledgment

The personal involvement of Charles H. Raths, president of Raths, Raths and Johnson Inc., in pointing out the need of computerization in production planning and providing early advise was most helpful and, therefore, greatly appreciated.

Discussion of this report is invited.
Please forward your comments to
PCI Headquarters by July 1, 1977.