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I R E A P S

STANDARDS FOR PRODUCTION PLANNING AND CONTROL IN SHIPYARD SHOPS

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ABSTRACT

This paper addresses the problem of establishing meaningful work order labor budgets for use in a shipyard pipe fabrication shop. Two methods are described for developing planning or scheduling standards. The first builds upon an existing base of detailed fabrication labor standards, which may be engineered standards or measured standards. The second uses sampling and statistical analysis to develop the planning or scheduling standards in situations where there are no existing labor standards. The first approach was applied in a seven month pilot project sponsored by the Maritime Administration through the Ship Producibility Research Program. The procedures and results of this pilot project are described. The primary result was a fifty percent increase in the perceived capacity of the shop, with no additional investment in .equipment or labor.

1.0 INTRODUCTION

AS early as 1881, Frederick W. Taylor proposed that the work of each employee be planned out by the management in advance, with the worker receiving complete task instructions as well as the means with which to complete the task. Taylor's system fixed a standard time to each job following time studies by "experts" based upon the work possibilities of a "first-rate man." This worker was instructed in the proper work method and able to do the work regularly. Thus began the systematic study of motion and time. Taylor's guiding principles of planning the work, designing the proper work method, and measuring the time to complete the work are still valid today.

In the U.S. shipbuilding industry today, the development of labor standards is not universal, although it is reasonably wide spread. The two most common applications of labor standards are for methods analysis and justification, and for incentive wage systems. While these are certainly important applications of standards, they are only the beginning. In this paper-, we will describe the methodology used and the results obtained in a pilot project for the application of labor standards in production planning. This pilot project was conducted at Peterson Builders, Inc., and sponsored by the Ship Production Committee Panel on Industrial Engineering, SP-8.

The pilot project addressed a shop loading problem, that is, the problem of deciding how much work to release to a shop for a given planning period, say one week. The estimate of work order labor content represents the single most important data element in the shop loading problem, and as such, is crucial in the interaction between planning and production. Underestimating the work content results in overloading the shop with obvious effects on performance and the relationship between production and planning. The result of overestimating the work content is more insidious, since it may lead to a general underloading of the shop. Inconsistency combines the worst of both.

Thus, shop loading is a very important activity, since it impacts directly on the working relationship between production and planning and on the productivity of the shop. Labor standards in shipyards have not been widely used in shop loading, so this represents an ideal pilot project.

2.0 TERMINOLOGY

Because many shipbuilders use different terms to describe the same thing, we will try to give an explicit definition for the terms used to describe the method and the case study. The reader can then substitute his own "correct" terms as required.

STANDARD TIME--The time which is determined to be necessary for a qualified workman, working at a normal pace under capable supervision with ordinary fatigue and delays, to do a defined amount of work of specified quality when following a prescribed work method. Usually referred to as a LEVEL TIME where worker pace, and allowances for personal time, fatigue and delays have already been included,

NONPROCESS TIME--On amount of time to be added to the level time to reflect additional and expected delays in accomplishing the work. Such delays may result from other work being performed around the worker, e.g., crane delays, or because the means to complete the task are not readily available, e.g., searching for material or tools.

PLANNING STANDARD--The time assigned to a particular task, including both LEVEL TIME and NON-PROCESS TIME, which represents how Iong it will actually take to perform the work (sometimes referred to as a SCHEDULING standard).

FORMULA) STANDARD--C1 planning standard stated in the form of an algebraic expression. The variables in the algebraic expression correspond to values that can be obtained readily from the description of the work to be performed.

The work order system for planning and controlling work is common to many shipyards. The manhours assigned to a work order is management's prediction of the work content of the work order. These manhours are budgeted in a manner equivalent to dollars, and become the index used for releasing work orders, measuring progress, and estimating cost or productivity. This leads to some additional terms.

RETURNED COST--The manhours charged against a work order, calculated from the time card data and available as a normal report from the accounting system.

DID COST--The true number of manhours expended for the work order, which may be larger or smaller than the RETURNED COST.

SHOULD COST--The number of manhours that the work order should require. Equivalent to the PLANNING STANDARD time. In an ideal environment the SHOULD COST would equal the LEVEL TIME,

In practice, planning standards will be different from engineered or measured labor standards. The difference must account for delays and work interruptions not directly related to the fabrication operations themselves. Some examples are: waiting time for a bottleneck operation (several mechanics need to saw at about the same time), material shortage delays, equipment malfunction, power outage, rework, and so forth.

In describing the implementation and results of the project, the following additional terms are used:

WORK ORDER--the documentation package used to describe a set of related pipe fabrications.

PIPE DETAIL--an individual sheet of a work order describing the specific material, configuration, and process requirements for one spool piece or finished assembly--also referred to simply as a detail.

ESTIMATE-labor hours budgeted for a work order by planning, based on requirements of the work order and historical return cost data for similar work on previous hulls.

3.0 DEVELOPING PLANNING STANDARDS

A pipe fabrication shop converts pipe stock and fittings into pipe "details," i.e., subassemblies ready for on-block or on-board outfitting. The advantages of fabricating the details in a shop are better working conditions and better access to bending and sawing equipment, thus better manpower and equipment utilization. In *order* to reap the maximum benefit from in shop fabrication, there should be accurate standards for machine and labor hours.

Two approaches to establishing planning standards are described below. The first is based on the use of engineered or measured labor standards for detail fabrication. A method *is* described for converting these level times into planning standards. The second approach does not require the availability of level times for detail fabrication but instead uses regression analysis to develop the planning standards.

3.1 Formula Approach with Level Times

This approach to establishing planning standards is based on the assumption that an adequate planning standard can be obtained through a simple adjustment to the existing fabrication standards or level times. This implies that the nonprocess time in the shop can be distributed to the individual work orders and pipe details in proportion to their level times, which may or may not be a valid assumption.

3.1.1 Testing Proportionality Assumption

The proportionality assumption says that if a pipe detail consumes ten percent of the standard hours released to the shop for a week, then it also generates ten percent of the nonprocess time in the shop for that week. If this assumption is correct, then the standard time assigned to the pipe detail should be a very good predictor of the time that actually will be required to fabricate the detail.

One way to test this assumption is to obtain a sample of actual detail fabrication times and compare them to the fabrication level times using regression analysis. If there is a sufficiently large positive correlation between the level times and the actual times, then the assumption of proportionality *is* good enough to work from. Two simple models for the relationship between level times and actual times are a "ratio relationship" and a "linear relationship."

$$AT = b * LT \qquad \text{(ratio model)}$$
$$AT = a + b * LT \qquad \text{(linear model)}$$

The linear model implies that there is some nonprocess time to be distributed to each pipe detail which is not directly related to its labor content. These models were evaluated in the pilot project and the results are described in section 4.3 below.

3.1.2 Developing the Formula

The actual time to fabricate a detail or set of details is obviously affected by process time <average amount of time each day spent in fabrication) and by pace. Both of these, in turn, are directly affected by "shop load," or the amount of work available in the shop and planned for completion. If there is no backlog of work orders, then the pace (intensity with which work *is* done) and the process fraction will tend to decline. *As a* result, the actual time to fabricate a particular detail will tend to be greater when the shop is underloaded than when it is fully loaded. These considerations should be reflected in the adjustment to the level times to obtain planning standards,

The planning standard formula used in the pilot study was:

$$PT = LT / (PFDa * PF * SWF * SP)$$

Where:

- PFDA= personal, fatigue and delay allowance in level time
- PF = predicted shop process factor
- SWF = standard work factor; the fraction of work that is covered by standards
- SP = average shop pace factor between zero and one (a value of 1 corresponds to the pace assumed in the level time)
- LT = pipe detail level time
- PT = pipe detail planning standard

To use this formula, the level time is computed for each detail in a work order, then the corresponding planning standard times are computed. Adding all of the detail planning standards gives the work order planning standard.

This approach has several desirable attributes First, it is based on existing fabrication standards, and requires relatively little additional standard development effort. Second, it can be used to set production goals, based on best practical pace and best practical process factor, as well as to establish standards based on average realized pace and average realized process factor. Third, it can be used to guide the work method improvement effort toward reducing the factors causing delays and congestion. Fourth, it can easily be automated, so that relatively little time is required to apply the standard. The primary drawback is that this approach does require an existing base of fabrication standards.

3.2 Formula Approach without Level Times

A question of obvious concern to many shipbuilders is, "What can be done if there are no existing fabrication standards?" The results of this case study indicate that a similar approach can be used to develop planning standards based on actual performance rather than on fabrication standards. The approach requires the development of a regression model for predicting actual time, based not on level time, but on the pipe detail attributes themselves.

For the pipe fabrication shop, the detail attributes which most strongly affect fabrication time are:

- MTL : the type of material, e.g., copper, steel, etc.;
- DIA : the pipe diameter;
- BND : the number of bends required;
- JNT : the number of made-up joints in the detail; and
- PCS : the number of pieces (pipe or fittings) required to fabricate the detail.

The values of these attributes can be determined easily from the pipe detail drawings used in the shop.

To develop the regression model, a sample of pipe details is required. The number of details in the sample depends to some degree on the form of the regression model, but in general, the more details included, the better the results. For each detail in the sample, the actual fabrication time must be recorded, either by an observer or by the mechanic. The actual time recorded must be as accurate as possible. Using the actual time and the detail attributes, a regi'ession model can be developed to predict actual time based on detail attributes:

AT = f<MTL, DIA, BND, JNT, PCS)

The specific form of the regression model may depend on the nature of the details, the organization of the shop, etc,

Once the necessary regression models have been developed, the planning standards can be determined by:

PT = AT * (SPF * SSP) / (PF * SWF * SP)

where

SPF = process factor during the sampling period;
SSP = shop pace during sampling period; and
PF, SWF, SP are as defined earlier.

Note that the ratio SP/SSP reflects the projected shop pace relative to the sampling period. If during the sampling period the shop was underloaded or overloaded, this ratio allows an explicit compensation in generating the planning standard.

This approach to setting planning standards has not been directly tested in the pilot project. However, the pilot project data has been used to verify that the necessary regression models can be developed; the resulting predictions were quite accurate. The formula standard without level times does require a substantial sampling program and sophisticated statistical modeling and analysis. On the other hand, it does not require a pre-existing base of fabrication labor standards, and it can be implemented in an evolutionary process, i.e., the regression models can be refined as more data becomes available. This approach may appeal particularly to smaller shpyards with little or no in-house Industrial Engineering capability for developing fabrication labor standards.

3.3 Explicit Nonprocess Factors

Both approaches to setting planning standards are crude in one respect, namely, they are based on the implicit assumption that the actual time for a given pipe detail is not affected, directly, by the other details being worked concurrently. This is clearly a simplifying assumption. For example, if all the details loaded on the shop for one week required an unusually large number of bends, the bending operation could easily become overloaded, leading not only to delays;, but to forced idleness while mechanics wait on delayed jobs.

What this argues for is a system for setting planning standards that considers not only each individual pipe detail, but the entire set of pipe details in the shop at one time. This could be thought of as a standard for "congestion." For the present at least, such a system appears beyond the scope of current practice. Fortunately the simple approaches described here can have dramatic impact on productivity, as demonstrated by the pilot project results.

4.0 PILOT PROJECT RESULTS

The pilot project was conducted in the Pipe Fabrication Shop, Building 70, at Peterson Builders, Inc., during the seven month period from September, 1981 through April, 1982. The project team included personnel from PBI, the SP-8 Program Manager, a representative of H.B. Maynard Co., Inc. and the authors.

4.1 Project Baseline

Work orders are released to the pipe shop to maintain a two week shop load with a one week rollover. Estimated hours are the basis for deciding how many work orders to release each week. In general, the shop foreman assigns a work order to a mechanic, who then works the details, more or less in order9 until the work order is completed. The work orders range between 5 and 400 manhours, with an average at about 40 manhours. The number of details in a work order varies from one or two up to thirty or forty.

One of the first project activities was to audit a randomly chosen set of work orders to compare the estimated hours to the return cost. While it was found that the total estimated hours was roughly equal to the total return cost, the individual work order estimates could be as much as an order of magnitude greater or smaller than the return cost. At this point, it was decided that both the estimates and the return cost should be included in the project analyses.

Fabrication standards have been developed in the pipe shop using the Maynard Operational Sequence Technique (MOST) and cover virtually all work in the shop with the exception of some material handling and housekeeping. These standards assume a 100% pace and include a 15% allowance for personal time, fatigue and delay.

4.2 Project Method

The project had two phases, data collection and analysis, and trial application. The data collection and analysis phase was to determine if the scheduling standards could be developed, and if so to determine the appropriate factors for adjusting the MOST standards to planning standards.

Data collection involved three basic elements: work order level times, actual fabrication times, and nonprocess time. The work order level times were determined initially using the existing MOST standards. Because this was felt to be too time consuming for typical use by planners9 a simplified classification standard was developed and found to perform adequately.

Actual fabrication times were determined from a time sheet filled out by the mechanic as details were being worked. The mechanics *were* instructed to work as usual, no faster or slower, with their usual method. It was assumed that the mechanics were using the proscribed standard work method. The time sheets permitted a detailed trace for a mechanic or for a pipe detail, making it easier to validate the data. The time sheets caused minimal disruption, were well accepted by the mechanics and gave very accurate actual fabrication hours.

During each data collection or testing period, work sampling was used to asses the shop's overall nonprocess time.

There were three sampling periods during the project. In the first, a sample of work orders was tracked in the shop using the time sheets, and the nonprocess fraction was estimated from work sampling. This nonprocess factor was then used to calculate a planning standard for comparison to the estimates and the actual hours.

During the second sampling period, all work orders in the shop were tracked. Planning standards were computed using the results of the first sampling period, before the actual hours were known from the time sheets.

In the third testing period planning standards were used to load the shop.

4.3 Project Results

Analysis of the data collected and the returns from trial application can be summarized in four categories.

4.3.1 Proportionality Assumption

The level times and actual times for individual pipe details were used in regression analyses of the ratio and linear models given in section 3.1.1. In general, the results of these analyses were positive, i.e., there was a strong correlation between level time and actual time. For both models there was a significant difference between values of the model parameters when considering material specific subgroups of details.

The linear relationship provided a better explanation of the data, for several technical reasons. It resulted in smaller residual mean squares, and its residuals were less correlated than with the ratio model.

The statistical analyses indicated that planning standards based on level times were superior to the previous planning estimates. *However*, in the statistical analyses, there is a significant amount of "unexplained" variability in the planning standard prediction of actual time. The actual causes of the variability are not known, but might include deviations from the standard method or other similar factors in addition to the natural variation in actual work element times. Even so, when the planning standards are used for loading the shop, and a number of work orders are involved, the planning standard estimate of the total shop load should provide a reasonably accurate prediction of actual time.

4.3.2 Planning Standards

In all three sampling periods, the planning standards were found to be in close agreement with the actual hours reported on the time sheets, both as a total for the period, and by individual work order. In contrast9 the estimates were found to vary widely around the actual hours by work order. To be sure, the planning standards also varied around the actual hours, but to a much smaller degree than the estimates. In addition, the planning standards were uniformly smaller than the estimates.

4.3.3 Shop Loading

When the shop was loaded using the planning standards, the planning standard hours were found to be only 55% of the corresponding estimate hours. In spite of this "apparant" shop overload, the work orders were completed and required only 104% of the planning standard hours. This represents a fifty percent increase in shop capacity with no additional investment, simply because there are better predictions of the real labor content of the work orders with which to more properly load the shop.

4.3.4 Regression Models

Using the data from the three sampling periods, a regression model was developed relating actual detail fabrication time to detail attributes. This model for predicting actual time was technically superior to the model based on level times. It seems reasonable to conclude that useful planning standards could have been developed from this regression model had the MOST standards not been available.

5.0 CONCLUSIONS

This pilot project demonstrated that the specific method of approach used could generate planning standards that are superior to the estimates baseed only on experience and history. This is not a theoretical result--it has been proven in a shipyard shop through actual use by shipyard planners. The benefits indicated in this particular case are substantial--a fifty percent increase in productivity in the pipe shop--and the implementation costs were negligable.

In a broader sense, the pilot project demonstrated that planning need not rely only on experience and historical performance data. On the contrary, a systematic, scientific approach to planning can yield impressive results.

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