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LINE OF BALANCE ACCURACY

Final Report

S. F. Claggett, Project Leader

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Prepared by:
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Department 114

Final Report

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ABSTRACT

A study was made to define the sources of error and their effects on the Line of Balance. Construction of the Line of Balance is described. Line of Balance, properly applied, is shown to be an effective status-reporting technique for a continuing production process.

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SUMMARY

The Line-of-Balance (LOB) chart is used at the Bendix Kansas City Division to indicate production bottlenecks and production status by offering a comparison of the status of a final assembly and its bill of material to the planned progress. It is a useful tool for the proponents of management by exception.

The LOB is developed for critical parts from the Objective, the Production Plan, and the Measurement of Progress. The status of each part is measured in "units worth" which makes allowance for the total quantity used in each final assembly.

The accuracy of the LOB depends upon the accuracy of the part-criticality prediction, of the delivery schedule for the final assembly, of the units-worth determination for each part, and of the flow time assigned to each part.

The LOB can be a useful technique for determining production status if its limitations are recognized and errors in its construction and interpretation are avoided.

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LINE OF BALANCE APPLICATION

The LOB technique is used to determine the number of components and sub-assemblies that must be completed by a given date to support a continuing production process. The technique was developed to improve status-reporting by offering a comparison of the status of a final assembly and its bill of material to the planned progress. Utilizing a simple time-based charting format, LOB is a useful tool for the proponents of management by exception.

The LOB technique can be applied successfully to a variety of situations. For example, the LOB should be considered a possible solution to the following typical problems:

- A final assembly has been lagging behind schedule and the cause cannot be located;
- A manager needs a reporting medium that will indicate bottlenecks on an exception basis; or
- The scheduling of incoming material must be synchronized with the production process.

The LOB chart is used at the Bendix Kansas City Division to indicate production bottlenecks and production status. These objectives are accomplished by displaying and weekly updating LOB charts in the assembly departments.

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BACKGROUND

LINE OF BALANCE CONSTRUCTION ELEMENTS

The LOB technique utilizes three essential construction elements:

- Objective,
- Production Plan, and
- Measurement of Progress.

The combination of these elements forms a basic tool for production surveillance. Each element is discussed separately before the procedure for constructing the LOB chart is presented.

Objective

The purpose of a production process is to meet the final-assembly delivery schedule, as defined by contract, or to meet the anticipated end-item demand. The delivery schedule therefore is used in constructing the LOB chart as the Objective.

A typical Objective is illustrated by Figure 1. The solid line shows the final-assembly (or the end-item) cumulative delivery schedule, while the broken line indicates the cumulative total of assemblies produced. The totals for each month are determined by the left-hand edge of the box indicating the month. Thus the planned delivery schedule for the final assembly can readily be compared to both past and present production totals.

Because the Objective is concerned only with final assemblies, the "units worth" shown on the chart is always equal to the total number of units. Units worth is discussed further under "Measurement of Progress."

Production Plan

The Production Plan consists of an assembly tree, for a final assembly, drawn on a time-based scale. The assembly tree is a flow chart of the bill of material that indicates the sequence of assembly; the Production Plan goes one step further by scaling the branches according to the time required for the parts to be assembled. Each branch of the Production Plan represents a particular component, and the length of the branch indicates the time required for manufacture.

Figure 2 depicts a typical Production Plan that consists of eight critical parts. Noncritical parts are excluded from consideration. The time scale

Figure 1. Objective

at the bottom of the figure shows the flow time required for each component. For example, part 6 will be required three weeks before the required date for part 3 and 5 weeks prior to the ship date of the final assembly.

Figure 2. Production Plan

Measurement of Progress

The Measurement-of-Progress bar graph shown in Figure 3 indicates the production progress of each part included in the Figure 2 Production Plan. The numbers at the bottom of the bars correspond to the numbers designating the parts shown in the Production Plan. The height of each bar indicates the cumulative number of final-assembly units worth of a particular part that has been manufactured and is available for use.

The units-worth values shown on the Measurement-of-Progress chart indicate the total number of final assemblies that available supplies of each part will build by considering the quantity of each part that is used in each final

Figure 3. Measurement of Progress

assembly. Thus if equal quantities of Component A and Component B are available, but two units of Component A and one unit of Component B are used in a final assembly, then Component A will have only one-half the units worth of Component B.

CONSTRUCTING THE LINE OF BALANCE

Figure 4 illustrates the method used for constructing the Line-of-Balance chart. The LOB shown was constructed for a final-assembly ship date of June 1 and was developed from the data previously presented in Figures 1, 2, and 3. The LOB indicates that quantities of parts 1 (the final assembly), 2, 3, and 6 are deficient, while there is a surplus of parts 4, 5, 7, and 8. The units worth of each deficiency and each surplus can be determined from the distance between the end of the applicable bar and the Line-of-Balance line.

In constructing the LOB, the Measurement-of-Progress chart is placed on the right-hand side of the Objective chart so that they share common units-worth values. The final-assembly ship date (arbitrarily chosen as June 1

Figure 4. Determination of Line of Balance

for the Figure 4 example) is then plotted on the time-base at the bottom of the Objective chart as the zero-time point from which the flow times of the various parts are measured. The flow time for each critical part considered is determined from the Production Plan and is plotted to the right of the zero-time point. In every case, the flow time of the part is measured on the Production Plan from the final-assembly ship date.

Vertical projections of the points plotted on the time-base are made to establish a series of secondary points on the "scheduled units" line of the Objective chart. A horizontal projection is then made of each of these secondary points to establish a line above the applicable bar (or bars) of the Measurement-of-Progress chart. Connecting these line-segments defines the Line-of-Balance line.

If the parts are numbered in the Measurement-of-Progress chart so that their flow times increase from right to left as the numbers increase, the Line-of-Balance will descend stepwise from left to right. The units-worth value of the line will be the same for all parts having the same flow time.

SOURCES OF ERROR

Any error that causes the Line-of-Balance line for a given part to appear higher than it should will make the supply of the part appear more critical than it actually is. Conversely, any error that causes the line to appear lower than it should will make the supply of the part appear less critical.

The accuracy of the LOB depends upon

- The accuracy in predicting critical parts;
- The accuracy of the cumulative delivery schedule for the final assembly;
- The accuracy in determining the units worth for each part; and
- The accuracy of the flow time assigned to each part.

An error in any one or more of these factors will distort the results shown by the LOB chart. The effects of errors in these factors on the LOB are examined in the remainder of this report.

CRITICAL PARTS PREDICTION

In applying the principle of management by exception to the use of the LOB, the criticality of each part is prejudged. Items that unexpectedly prove to be critical therefore do not appear on the chart. If the LOB chart is used as the only indicator of critical parts, a false sense of security may result. Thus the LOB must be considered an indicator of criticality for only those parts that are included in the analysis. It should be noted that the problem of unexpected criticality can be eliminated by including all parts in the LOB.

DELIVERY SCHEDULE ACCURACY

Because the LOB indicates production status only with regard to the specified Objective, it can be no better than the estimate of the delivery schedule. If the delivery-schedule estimate is too high, the Line-of-Balance line will be too high for all parts; if the delivery-schedule is too low, the line will be too low for all parts.

If the final-assembly cumulative delivery schedule is changed or if production falls behind schedule, the LOB must be redrawn to obtain a true indication of the part-status.

UNITS WORTH DETERMINATION

An error in determining the units worth of a particular component will affect the corresponding bar on the Measurement-of-Progress portion of the LOB chart. Because the units worth can be obtained from an inventory of the parts, the likelihood of a significant error is small unless a large attrition rate exists on the production line and is not properly accounted for. The following provides an example in which it is supposed that a second-level component has an attrition rate of P percent and the inventory of unused parts is some amount denoted by I. If the final-assembly usage is U for 1, the units worth calculation, ignoring attrition, is

$$\frac{I + W}{U} + S, \quad (1)$$

where S is the number of final-assembly sales to date and W is the number of components in the work-in-process inventory.

When the attrition is properly considered, the units worth calculation becomes

$$\frac{I(1-P) + W}{U} + S. \quad (2)$$

Thus, the resulting error (E) is given by

$$E = \left(\frac{I + W}{U} + S \right) - \left(\frac{I(1-P) + W}{U} + S \right);$$

$$E = \frac{I}{U} - \frac{I(1-P)}{U};$$

$$E = \frac{PI}{U}. \quad (3)$$

While this quantity probably is not significant for second indent-level parts, the error is magnified for lower indent-level components and can be significant. If the attrition of a part is not properly considered, the status of the part on the Measurement of Progress chart appears higher than it should.

FLOW TIME ACCURACY

Of the errors that may occur in constructing the LOB, errors in flow time are the most common and they have a great effect upon the appearance of the production status. If a flow time is too long, the Line-of-Balance line for the affected parts will be raised and the production status thus will appear lower

than it should. Conversely, if a flow time is too short, the line will be lowered and the production status will appear higher.

The bill of material and the Production Plan for a timer, shown in Figures 5 and 6, respectively, illustrate the effect of incorrect flow times upon the Line-of-Balance line. Numbers in parentheses in Figure 5 correspond to the part numbers assigned in Figure 6.

Figure 5. Bill of Material for Timer

The LOB constructed for the Figure 6 Production Plan is shown in Figure 7. A study of Figure 6 indicates that if the flow time for part 5 is increased from two to three weeks, parts 8 through 12 will have to be started a week earlier. The modified LOB constructed to incorporate this change is shown in Figure 8. The shaded portion of the figure indicates the amount by which the Line-of-Balance line has been raised for parts 8 through 12.

Figure 6. Production Plan for Timer

In general, the amount of error for a single erroneous flow time is given by the following formula:

$$E = S(t = n) - S(t = i); \quad (4)$$

where $S(t = j)$ is the delivery-schedule function defined at time j ; n is the actual flow time plus the current date; i is the estimated flow time plus the current date; and $n-i$ is the amount that the estimated flow time is in error. Thus, a one-week error in a flow time will affect the lower-assembly LOB parts by

$$E = S(t = t_o + 1) - S(t = t_o). \quad (5)$$

If the scheduled ship rate is 20 final assemblies each week, the resulting error will be 20 units worth.

Figure 7. Line of Balance for Timer (Simplified)

Figure 8. Modified Line of Balance for Timer (Simplified)

The effect of errors made in estimating flow times is intensified by the fact the errors are cumulative. Thus the accuracy of the LOB depends greatly upon the accuracy with which the flow times of the parts can be established.

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CONCLUSIONS

While the simplicity of the LOB status-reporting technique invites its widespread application, the inherent chances for error make its use and interpretation difficult. Because it is subject to error, its use can result in an inadequate or inaccurate portrayal of production status.

The person constructing the LOB should make every effort to obtain the most complete and accurate information available. Likewise, persons who interpret the LOB should evaluate the completeness and accuracy of all factors required in its construction.

The LOB can be a useful technique for determining production status if its limitations and potential sources for error are recognized and considered.

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GLOSSARY

Assembly Tree	A flow chart of a bill of material showing the assembly of a final unit.
Attrition	The loss in parts along a production line. Includes allowances for scrap and for destructive testing.
Available Parts	Parts that have been completed and moved to stores for use in a subsequent assembly.
Bill of Material	A list of the parts and material required to build a final assembly with the record-of-assembly and usages indicated.
Critical Part	A part that is anticipated to be in short supply.
Delivery Schedule	A schedule indicating the final-assembly ship dates.
End-Item	The final product or final assembly in a bill of material.
Final Assembly	The final product or end-item in a bill of material.
Flow Time	The time required to manufacture an item from the receipt of material until production is completed.
LOB	Line of Balance.
Measurement of Progress	The chart showing the status of available parts.
Objective	The delivery schedule for a final assembly.
Production Plan	A time-based flow chart of a bill of material.
Units Worth	The available number of a component or sub-assembly divided by the number required to make one final assembly.
Usage	The quantity of a component required to complete the next assembly.
Work-in-Process Inventory	All parts that are in an unfinished state for a particular manufacturing operation.

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