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THE TRADEOFF BETWEEN LEARNING AND INFLATION IN SHIPBUILDING,(U)
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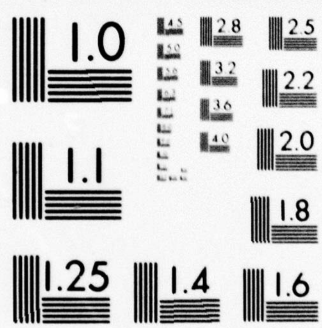

MICROCOPY RESOLUTION TEST CHART

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THE TRADEOFF BETWEEN LEARNING AND INFLATION IN SHIPBUILDING

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ABSTRACT

Learning leads to a decrease in program cost. Inflation leads to an increase in program cost. At a certain time, the benefits of learning and the penalty due to inflation will balance each other. This time is defined as the critical time.

The critical time depends upon the number of ships to be built because this determines the possible gain in learning. The critical time depends also on the assumed inflation, upon the achievable learning rate and on the material/labor ratio of the first ship. Learning expectation can be influenced by planning and the material/labor ratio by a make- or buy-decision. Assumptions on future learning are as vague as assumptions on inflation.

The paper shows that it is almost impossible to beat inflation. It shows that accelerated programs are preferable and that make-decisions supersede the value of buy decisions. The result is derived from an abstract treatment of the subject.

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INTRODUCTION

The present paper shall clarify the interplay between inflation and learning as it relates to shipbuilding programs. The subject may be an academic delight and could initiate a series of Ph.D. dissertations: economic consideration, O.R. pearls, problems of labor psychology and other topics can be brought together. For the practitioner, however, all those scientific beauties are utterly useless. Learning and inflation are ambiguous and not predictable with exactitude. Therefore, the interest to the practitioner is an explanation of what can happen when certain events occur. To do this, not much formalistic play is necessary and the problem can be portrayed in a rather simple fashion.

This has been done in the report. However, attention should be given (1) to the inherent uncertainties in the subject and (2) to the fundamental problems of money flow, dictating the developed procedures and approach.

UNCERTAINTIES

Neither *learning* nor *inflation* is a precise phenomenon; one knows only after the fact how much it has been. In advance, one can only guess what it might be. The same uncertainty applies to the *cost estimate* of a ship; the term of estimate implies already that no exact calculation is possible.

The *learning,* the *inflation* and the *cost* (estimated for the first ship) are three interlocking uncertainties. The form of the interlocking relationship is of complicated non-linear nature. For example, a five percent error (in man hours) in the original estimate, combined with a less than two percent error, in the prediction of learning can lead, in a six ship series, to the loss or gain of all man hours needed to build a complete ship. This extreme sensitivity of the result to very small errors in the assumption must be recognized.

THE PRINCIPLE AND GOAL OF ANALYSIS

For analytical purposes, the cost of a ship will be depicted as the interface between three elements:

- Element #1, the original *estimate*
- Element #2, the assumed *learning*
- Element #3, the predicted *inflation*

Other influences such as change orders, field changes, etc. are not considered. Each element can be depicted in the form of a money flow or money stream. In *rudimentary* form, the three money streams are:

- Money Stream #1 - The money stream which would result if each ship in a series would cost the same amount.
- Money Stream #2 - Where the effect of learning is considered as a repayment against the ship (payable to the Navy). This repayment of course reduces the price for each consecutive ship of the series.
- Money Stream #3 - Where the cost due to inflation is considered as payment above the original estimate.

The use of the three money streams is submerged in the analysis and may not be always obvious. Nevertheless it is the leading concept throughout the entire analysis.

The goal of the analysis is to develop a simple nomogram or descriptive-geometrical model which will permit to study all possible interactions between learning and inflation. Of course, a nomogram is by its nature not an instrument or tool of great precision. However, it is well within the tolerance of all assumption.

If the nomogram is computerized, many games can be played. A probability distribution for delay can be introduced, assumption of payment along a progress curve can be postulated, annual variations of payment along a progress curve can be postulated, annual variations of inflation rates can be played, a probability distribution for achieving a learning rate, a nonlinear degredation for learning over extended time can be assumed and many similar refinements introduced.

The nomogram permit the formulation and answering of many problems. Some of the key problems related to *inflation-learning-scheduling* will be addressed, without need for a mathematical treatment.

First however, the two phenomena of learning and inflation will be dealt with separately.

1. LEARNING

Learning is defined as the reduction in manpower requirements in the repetition of a particular process (for example, building a second ship). In shipbuilding, we are talking about the manpower which we count in the shipyard. But a learning occurs also in the labor force of all subcontractors. We consider this in the following way:

- *Learning for labor force in shipyard.* (Considered as an 85%, a 90% and a 95% unit learning effect).
- *Learning of all subcontractors, expressed as learning on material.* (Considered as a constant unit learning effect of 98%).

For clarification, a learning effect of, for example, 90%, means that the second ship in a series needs only 90% man hours of the first ship and the fourth ship of a series (the double of two) needs only 90% man hours of the second ship. The eighth ship needs only 90% of the fourth, the sixteenth only 90% of the eight, and so forth.

It should also be noted, that learning is expressed in man hours, however, the learning process depends only to approximately 15% on the workers but to approximately 65% on the lower and middle management and to about 20% on the top management.

1.1 Material/Labor Ratio

Since we apply a different learning rate (or learning effect) to labor in the yard and to the material which includes the man hours spent by the subcontractor, the *combined learning* for labor and material will be less that the labor learning on the shipyard and higher than the material learning. This higher or lower, however, will depend upon the original breakdown (of the first ship of a series) into material and labor. We considered a 60/40 ratio, a 50/50 ratio and a 40/60 ratio. The 50/50 ratio dominates.

A 40/60 material/labor ratio, for example, means that the price for the first ship consists of 40% for material and of 60% for labor in the shipyard. To the 40% of the price we apply a constant 98% learning and to the 60% of the price 85%, 90% and a 95% learning.

Figure 1 shows the combined learning for labor and material for three material/labor ratios and for three learning rates. The material/labor ratio will depend upon the type of ship and upon the make or buy decisions on a particular shipyard.

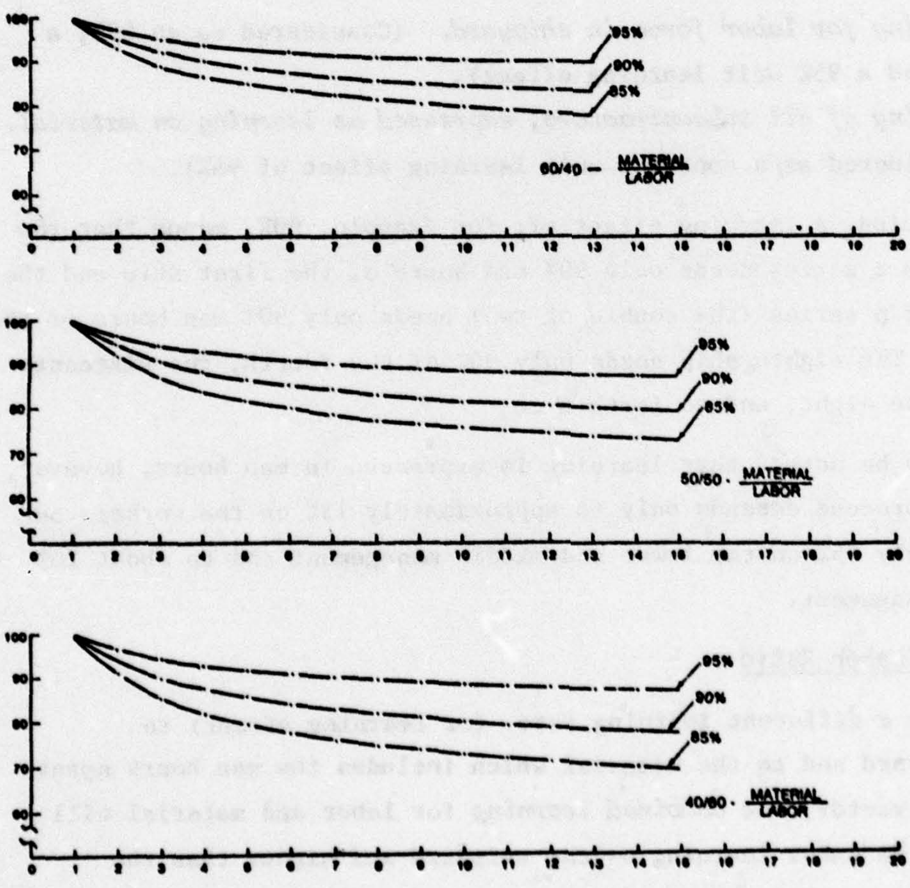


FIG. 1 UNIT LEARNING CURVES FOR DIFFERENT MATERIAL/LABOR RATIOS

1.2 Learning Trend

The trend of learning is illustrated in Figure 2. It is shown that the difference Δy for each consecutive ship must always be smaller than the difference for the foregoing ship for a constant rate of learning. Using some mathematical notation, we may say:

$$\Delta y = 0 \quad n \to \infty \quad i = \text{const.}$$

This reads: if the number of ships n goes to infinity, the absolute difference (in man hour consumption) between two consecutive units will be zero if the learning rate i is kept constant.

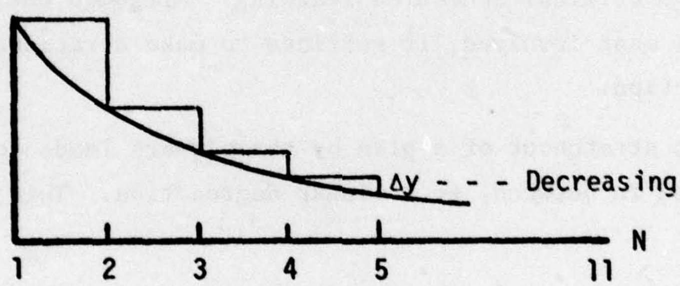


FIGURE 2

TREND OF LEARNING

The learning is (in the first approximation) a function of the number of ships to be built in a series in a single shipyard. We will assume that learning is related to the original planned execution of a specific shipbuilding contract and that such a particular modus operandi in ship erection is selected, which permits full gain of learning within the planned time frame.

It is suggested to assume a 5% reduction in man hours from the lead ship to first follow-on ship in all cases where the follow-on ship is built in another yard than the lead ship yard; however, a 10% reduction is suggested in man hours from the lead ship to the first follow-on ship whenever the follow-on ship is built in the same shipyard as the lead ship. The first follow-on ship is considered as the first ship in a series for the application of the learning calculation. Of course, if no lead ship is built, the first ship of the series will be the first ship of the learning curve. Transfer of learning across shipyards is not considered.

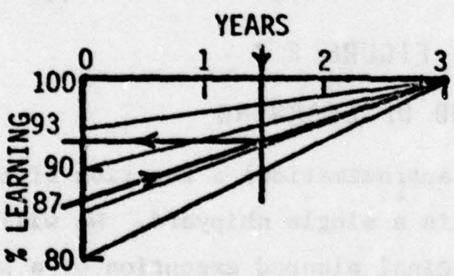
Again, these are simplifying assumptions, but livable ones.

1.3 Loss of Learning

The learning rate applied to the future is related to the originally planned unfolding of the construction process. If the time frame of this original construction process is changed, the learning rate will also change.

Assuming the original plan was this particular plan, which assured the highest learning probability, then each plan elongation or plan compression will depart from the original scheduled learning. Although the relationship of this behavior is most involved, it suffices to make a rational assumption toward a simplification.

We assume that each stretchout of a plan by three years leads to a complete loss of learning and in between, to a linear degradation. This is illustrated in Figure 3.



Example: Original learning - 87%
Delay - 1½ years
Degraded learning 93%

FIGURE 3

DEGRADATION OF LEARNING

Any and every elongation of the building time will influence the result, because payments will be made in a progressed inflation. But not only this - every departure from the original plan will also lead to a deterioration of the learning effect because of changes in the roll over plan, turnover of workers, weather conditions departing from normal, and other causes or influences.

All these influences leading to the deterioration of learning are real and cannot be denied. On the other hand, they also cannot be separated. However, it is suggested to use an approximation, sufficient for the purpose at hand: (1) Learning takes place between consecutive ships; (2) if the time between corresponding events (i.e., keel laying of ship #2 to keel laying of ship #3) is elongated by three years beyond the original plan, all learning effects are lost and (3) the loss of learning occurs in a linear manner within the two year elongation period.

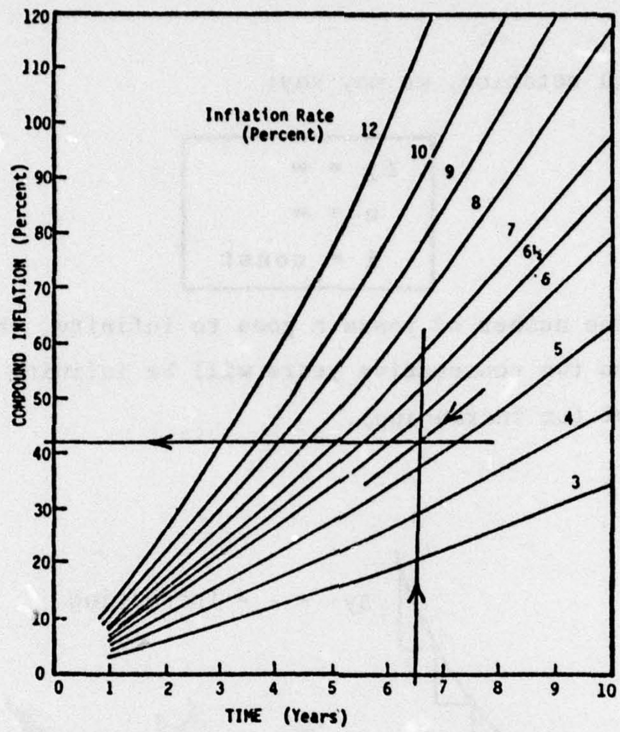
2. INFLATION

Inflation is defined as the decrease in purchasing power of money. In reverse, inflation is defined as the amount of money which must be paid above the contract price (because of inflation) for the contracted product or service.

2.1 Inflation Rate

Commonly, the inflation is measured in percent of cost (or price) increase for consecutive inflation rates can be variable from year to year; however, each follow-on inflation rate carries in its basis the foregoing inflation rates. If the inflation rate were constant, the compound inflation over "n" years would be the same as the compound interests (of the same magnitude as the inflation rate) for the same time period.

The early changing *inflation rates for the future* to be used in NAVSEA estimates are approved by DoD. However, for the purpose of the model, inflation rates from 3 percent to 12 percent are assumed. Figure 4 shows the cost of such inflation rates in years beyond the validity date of the contract. Variable inflation rates can be translated into a single inflation rate.



Example: Time - 6½ years
Inflation Rate - 5½%
Compound Inflation - 42%

Note: Inflation applies on the Total Cost (of material and labor).
Point (0.0) = Validity of contract at Time Zero with 100% cost.

FIG. 4 INFLATION

Inflation is a phenomenon outside of the shipbuilding process but super-imposed upon it. We can also say that inflation is not a function of ship related elements; however, the payments due to inflation are a function of the time frame of the program. The later a ship is delivered, the more it may be affected by the inflationary trend. Inflation itself can be considered as a non-predictable element. Inflation rates are also not stable, but highly fluctuating. All that the analysis can do is to cover a range of inflationary factors, leaving it to the perception of the reader to select what he may consider as probable.

2.2 Inflation Trend

The trend of inflation is illustrated in Figure 5. It is shown that the absolute difference Δy for each consecutive year must be always greater than the difference for the foregoing year for a constant rate of inflation.

Using mathematical notation, we may say:

$$\Delta y = \infty$$
$$n \rightarrow \infty$$
$$i = \text{const}$$

This reads: if the number of years n goes to infinity, the absolute difference (in price) between two consecutive years will be infinite if the inflation rate i is kept constant (or increasing).

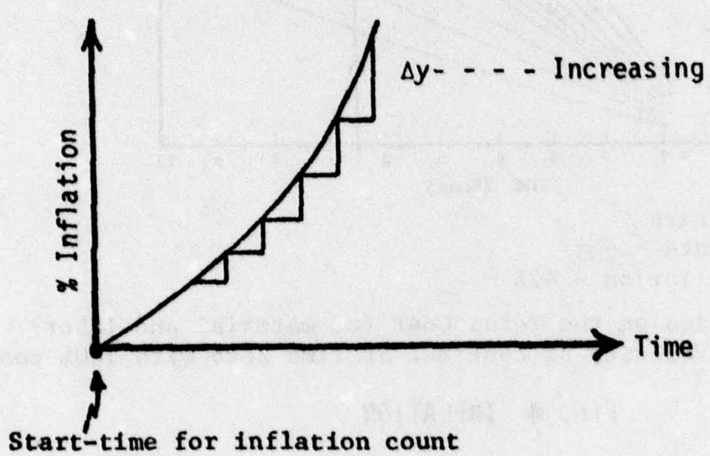


FIGURE 5
TREND OF INFLATION

In practice it may happen that at a particular time only the contract of a lead ship will be made and some time later the contract for the follow-on ships. In this case, it can be expected that the follow-on contract will have different validity dates and the inflation clause may refer to two different dates. Conceptually, however, this is irrelevant. The second contract can easily be reduced to the present worth at the time of the lead ship contract.

3. COMBINATION OF LEARNING AND INFLATION

Learning and inflation have different causes and of course different time frames, depending upon the selected building schedule.

3.1 Trend Combination

The trend of learning (see 1.2) and the trend of inflation (see 2.2) are opposite trends.

Whenever two trends of this nature occur simultaneously, the increasing trend *must* supersede the decreasing trend as indicated by the integral curves. It is only a question of *"when."* This *when,* however, *cannot be generalized quantitatively* because of the double dependency on units and time. It can only be calculated in the abstract - or by accepting a series of assumptions of how reality might look. The time *when* the inflation equals learning may be called *the break-even time* or in *critical time* of the problem.

The determination of the break even time will be illustrated and be discussed under the term of critical time and absolute critical time.

3.2 Shipbuilding Program

The trend of learning and the trend of inflation will be forced into a combination by a specific building program. Of course, something like a *"typical shipbuilding program"* does not exist. There are small ones, large ones, some for a short time, some for a very long time - and small, large, short and long can have an infinite amount of meanings. To pick one or two actual examples under such conditions means only one thing: the example is not representative for the total problem, but only for a specific part of it; generalization needs a very large amount of *"examples."*

For purpose of demonstration, we bypass this problem of *case studies versus concept* and develop, for example, a set of hypothetical programs which embrace the area of all possible conditions. Such example may read as follows:

- A program of six ships - running over a ten year period - is assumed to be built in a single shipyard. (Base Programs)
- *The program of six ships - running over a five year period only -* is subdivided between two shipyards. (Two full programs in half time)
- The program stays with the ten year period but is subdivided between two shipyards. (Two half programs in full time)

These three examples are illustrated in Figure 7. Of course other examples can be selected.

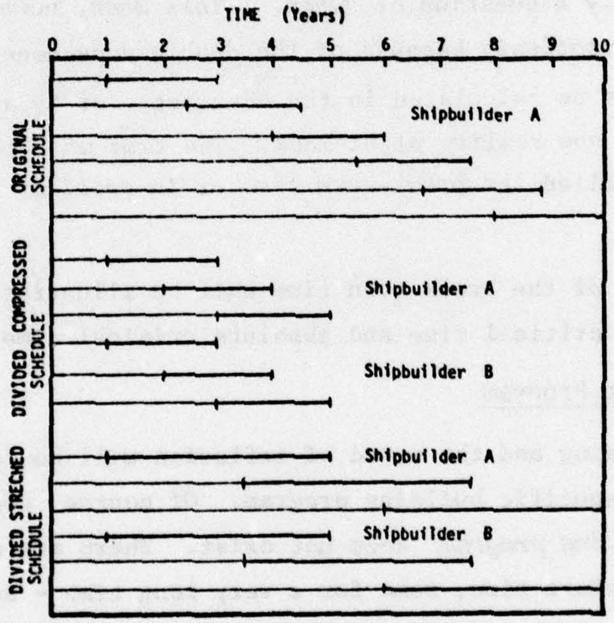


FIG. 7 EXAMPLE PLAN SCHEDULE

4. THE NOMOGRAM

The previous described phenomena of learning and inflation, as well the schedule are combined in the Nomogram for Inflation, Learning and Scheduling by Frisch. The nomogram is shown in Figure 8. The nomogram is subdivided into four fields. The *field* #1 depicts the compound inflation in percent over a 10 year period for an inflation rate from 3 to 12 percent (as previously shown in Figure 6). The *field* #2 shows (a) the learning curves and (b) the correction diagram *for loss of learning*. The shown learning curves (also see Figure 8) are for a material/labor ratio of 50/50. The correction diagram (also see Figure 5) is laid out for a range up to 80% learning. *Field* #3 is left blank in order to lay out any desired shipbuilding program in this field. *Field* #4 is finally a simple graphical adding device for the cost of inflation to the benefits of learning.

The *Field* #2 (a) can be substituted by the learning curves of other material/labor ratios. It would also be possible to replace the *unit*-curves for inflation and learning with the integral curves of benefits and penalties. Many other refinements could be added - but all this would complicate the case more than can be justified. However, as mentioned elsewhere in this report, all those refinements will be considered in a computerization of the model.

A fundamental example of "how to use the chart" is shown in Figure 9. The example reads as follows:

Step (1): Select program and sketch program in the empty field of the nomogram.

Step (2): Assume, for example, expected delay for ship #7 with one and one half year.

Step (3): *Formulate question,* i.e., how much will the delay for ship #7 cost?

Step (4): Select learning for the original program, i.e., 82%

Step (5): Determine reduced learning rate due to delay for the seventh ship in Step (5_1) and enter in Step (5_2)

Step (6): Determine center of payment for the seventh ship without delay. (For demonstration purposes, the mid-time between keel laying and delivery is selected. It would be possible to plot each scheduled payment individually or work with a specific payment distribution).

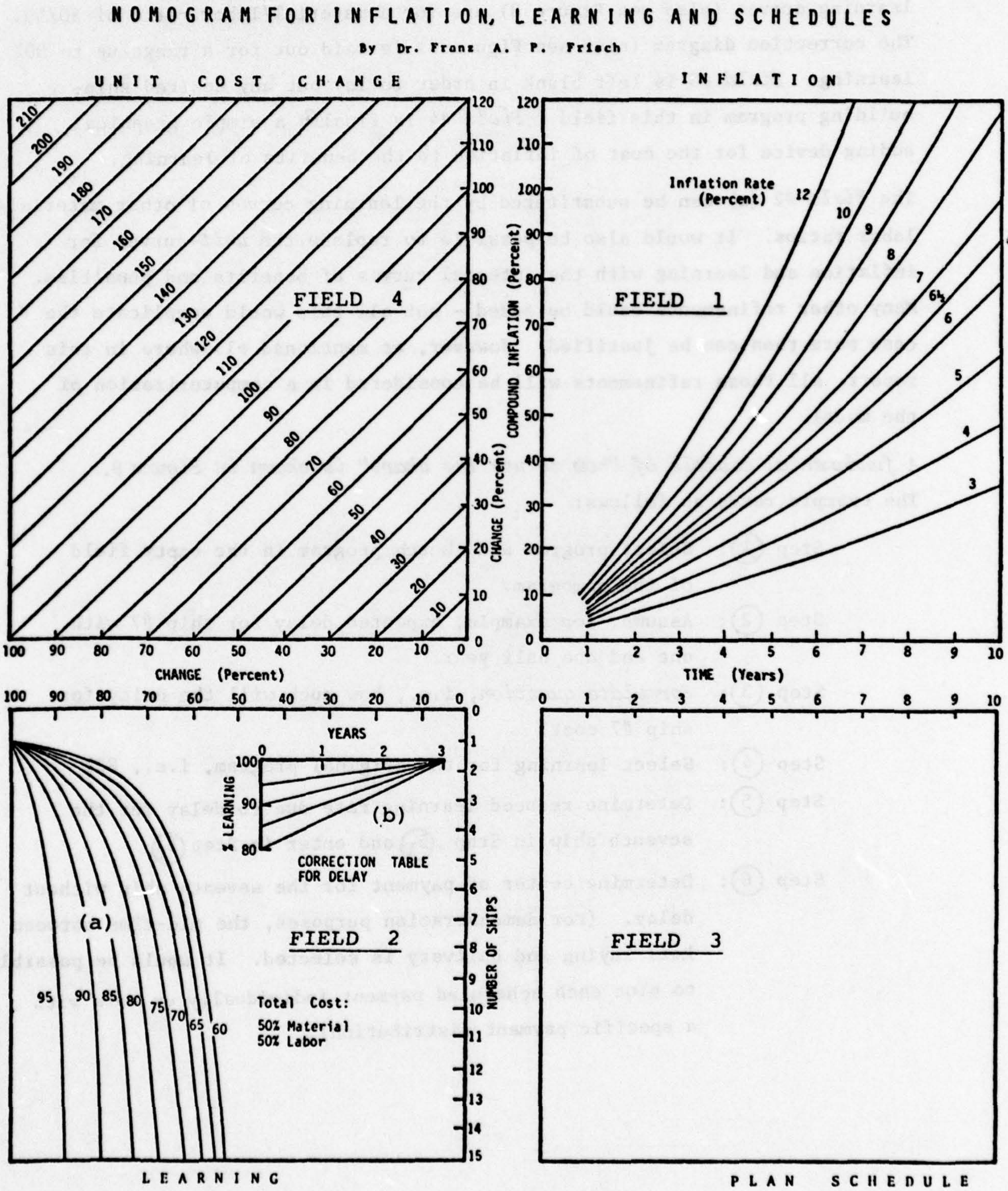


FIG. 8 THE NOMOGRAM

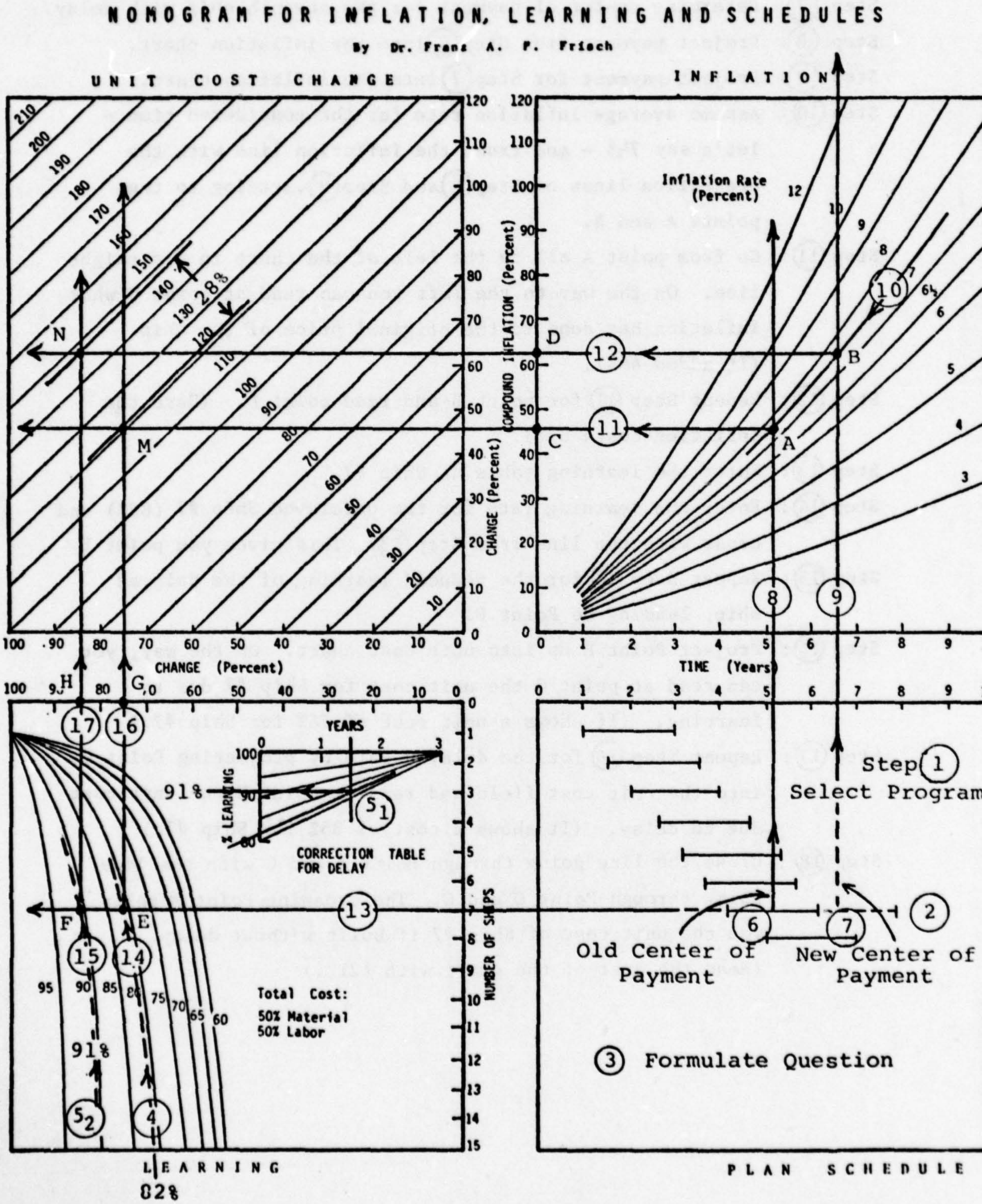


FIG. 9 USAGE GUIDE EXAMPLE

Step (7): Determine center of payment for the seventh ship with delay.

Step (8): Project payment from Step (6) into the inflation chart.

Step (9): Project payment for Step (7) into the inflation chart.

Step (10): Assume average inflation rate for the considered time - let's say 7½% - and cross the inflation line with the projection lines of Step (8) and Step (9), leading to the points A and B.

Step (11): Go from point A all to the left of the chart in a straight line. On the way to the left you can read at point C what inflation has done to the original price of the ship (It added 46%).

Step (12): Repeat Step (11) for point B and read point D. (Here the inflation costs 63%).

Step (13): Enter the learning table at Ship #7.

Step (14): Enter the learning rate for the undelayed Ship #7 (82%) and cross with the line from Step (13). This gives you point E.

Step (15): Repeat Step (14) for the reduced learning of the delayed ship, leading to Point F.

Step (16): Project Point E up into unit cost chart. On the way, you can read at point G the unit cost for Ship #7 due to learning. (It shows a unit cost of 76% for Ship #7.)

Step (17): Repeat Step (16) for the delayed ship by projecting Point F into the unit cost field and read at Point H the unit cost due to delay. (It shows a cost of 85% for Ship #7.)

Step (18) : Cross the line going through Point A and C with the line going through Point E and G. The crossing Point M tells you the unit cost of Ship #7 if built without delay. (Read the cost of the chart with 121%.)

Step (19) : Repeat Step (18) for line through B and D, crossing with line through F and H leading to Point N. Point N tells you the unit cost for ship #7 with delay. (Read the cost of the chart with 149%.)

Step (20) : Subtract the unit cost for Ship #7 without delay (expressed in percent) from the unit cost for Ship #7 with delay. (It amounts to 28% due to delay.)

5. INFLATION/LEARNING PROBLEMS

A series of problems are selected, rotating around the interaction of learning and inflation. They are considered as key problems. The problems will be addressed by using the nomogram.

5.1 Trade-Off Problem

Assume a series of seven ships will be built; the ships will be built in a time period of a yearly average of 5½% inflation. The shipyard assumes that a learning rate of 87% will be achievable. *How fast must the seven ships be built so that the gain because of learning compensates for the cost of inflation?*

To search for the answer, we enter the nomogram at Point 1 in Figure 10. Continue with the Steps 2, 3, 4, and 5 and read the result at Point R, showing that the seventh ship must be represented by a payment in the third year. We repeat the process for the second and fourth ship and interpolate the other ships. Since the payment is assumed at mid-time of construction, we may lay out a building schedule as shown. This particular building schedule (Total Schedule) will result in a break-even between the profit from learning and the penalty of inflation. The result, if derived in graphical form from the nomogram, is not of overwhelming precision and the subtle problem of the first ship is ignored. Nevertheless, the answer is sufficient to evaluate the possibility of beating the inflation for the particular example:

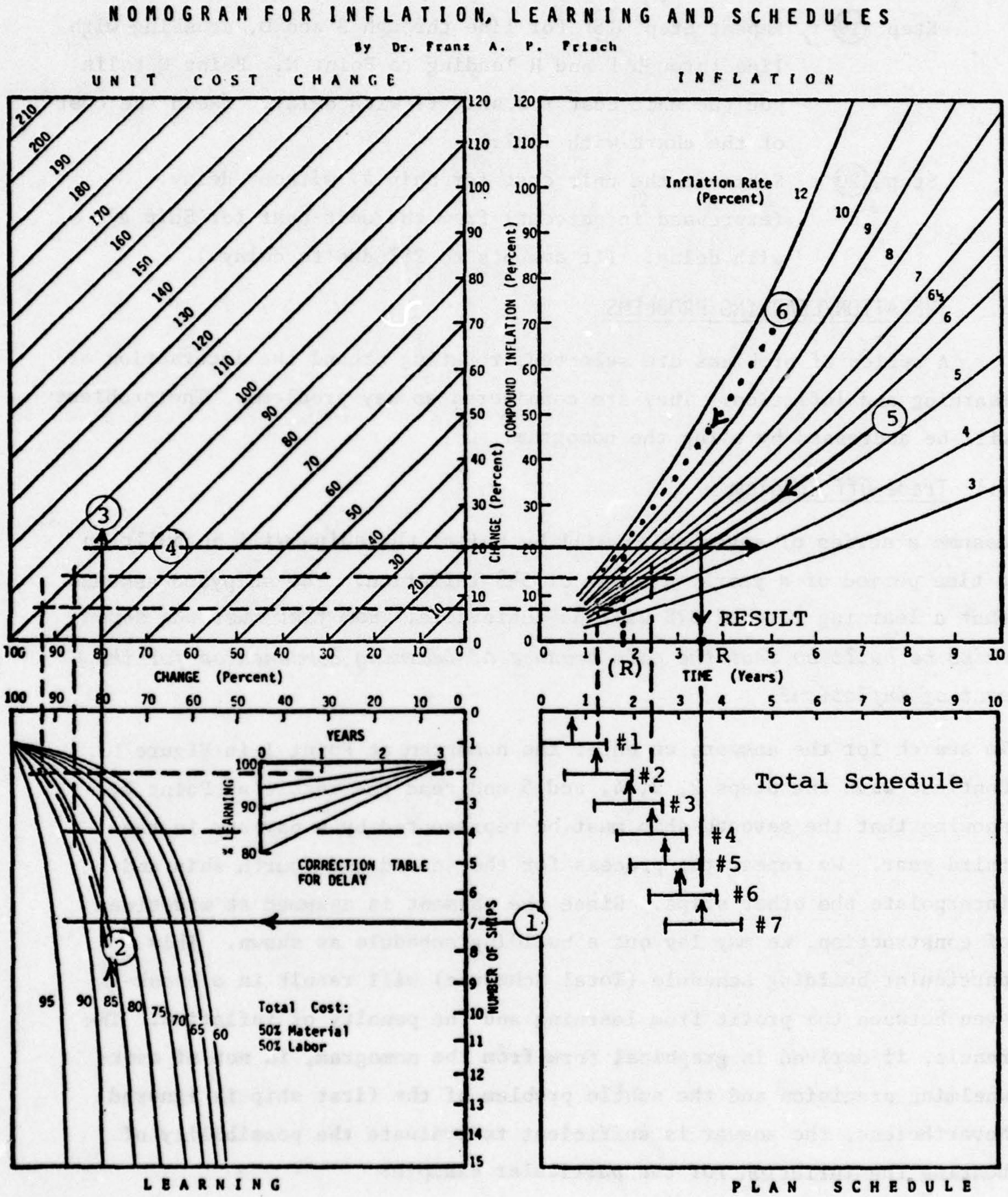


FIG. 10 TRADE-OFF PROBLEM

- If the average inflation is 5½% and the learning will be 87%, then it is possible to beat the inflation if the total program is concluded (from contract to last delivery) within approximately 3½ to 4 years.
- If the average inflation is 11% (see entry #6 in chart), the program must be concluded within 1½ to 2 years in order to break even between inflation and learning. (See Point (R).)

Now *judgment* enters the problem: if we know that either (1) the building of the 7 ships is simply not physically possible in the critical time-frame, or (2) the appropriation for such time frame is highly improbable, it must be concluded that the break even time *cannot* be achieved. Only if the two constraints of physical performance and budget allocation appear as non-existant, then learning may pay for inflation.

The result derived from the nomogram will tell *"what to expect."* Only if the expectation makes sense, a more detailed analysis is appropriate. Of course, *if the nomogram were computerized*, a precise result can be achieved immediately, provided we define precision within the framework of the guesses for learning and future inflation.

5.2 The Necessary Learning Rate

Within limits, the learning rate can be manipulated by specific planning procedures of the modus operandi of the construction process. Although this is largely guesswork, the theoretical possibility for such manipulation exists (but will not be discussed).

This may lead to the *search for the particular learning rate which is able to beat inflation.* This problem is illustrated in Figure 11.

Let's assume ship #7 shall be delivered at the same cost as ship #1. The midpoint for payment for ship #7 will be the year 6 of the building program. What learning rate must prevail, if it should be possible to compensate for a predicted inflation of (a) 4½% and (b) 9%? Again, the problem is solved with the *nomogram* in Figure 16, following the entries and Steps 1, 2, 3, 4, 5, and R and also 1, 2', 3', 4', 5, and (R). The result shows that a 78%

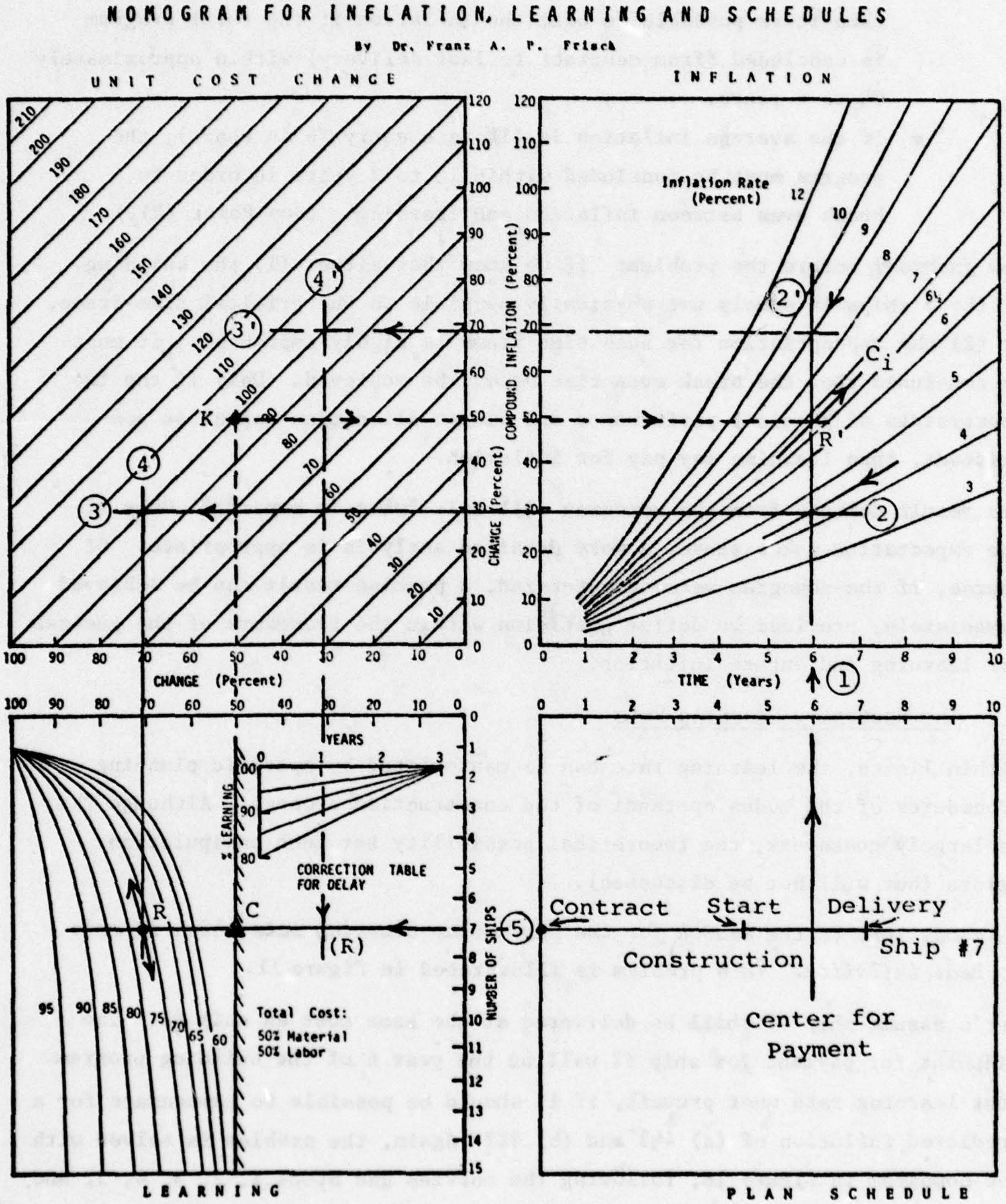


FIG. 11 NECESSARY LEARNING RATE

learning may be able to beat the 4½% inflation but it will not be possible to beat the 9% inflation because the absolute theoretical gain in learning can never be greater than the total manpower to build the ship as limes value. (A limes value is a value which can be approached but never reached.) This is indicated with the point C. Going back from point C to point K and R', we find that the absolute theoretical maximum inflation (C_i) can be 6 3/4% in order to have no cost increase for ship #7. This will be considered for the moment as a rather academic consideration. However, we will return to this thought process in Section 4 in order to arrive at generalized conclusions.

5.3 Range of Uncertainty

The determination of the learning rate for the future is a guess. Although the guess is based on historical experience, one never can be certain of what to expect from the future just for the simple reason that a duplication of all details determining the learning in the past will not occur in the future. In the same way, the forecast of future inflation belongs in the discipline of making computerized fortune cookies.

At best, we may determine a *range for learning and inflation*. So let's assume learning will never be less than 95% and never be more that 85%. For inflation, historically we will never have less than 3% and pray, never more than 12%. What does this mean for a program 5, 10 and 15 ships, to be accomplished within 3, 6 and 9 years after contract?

The answer to this question is (again with the nomogram) shown in Figure 12.

The range for the 5th ship is bound with A', B', C' and D': the range for the 10th ship with A", B", C" and D", and for the 15th ship with A"', B"', C"' and D"'.

The points A represent 12% inflation combined with 95% learning.
The points B represent 12% inflation combined with 85% learning.
The points C represent 3% inflation combined with 85% learning, and
The points D represent 3% inflation combined with 95% learning.

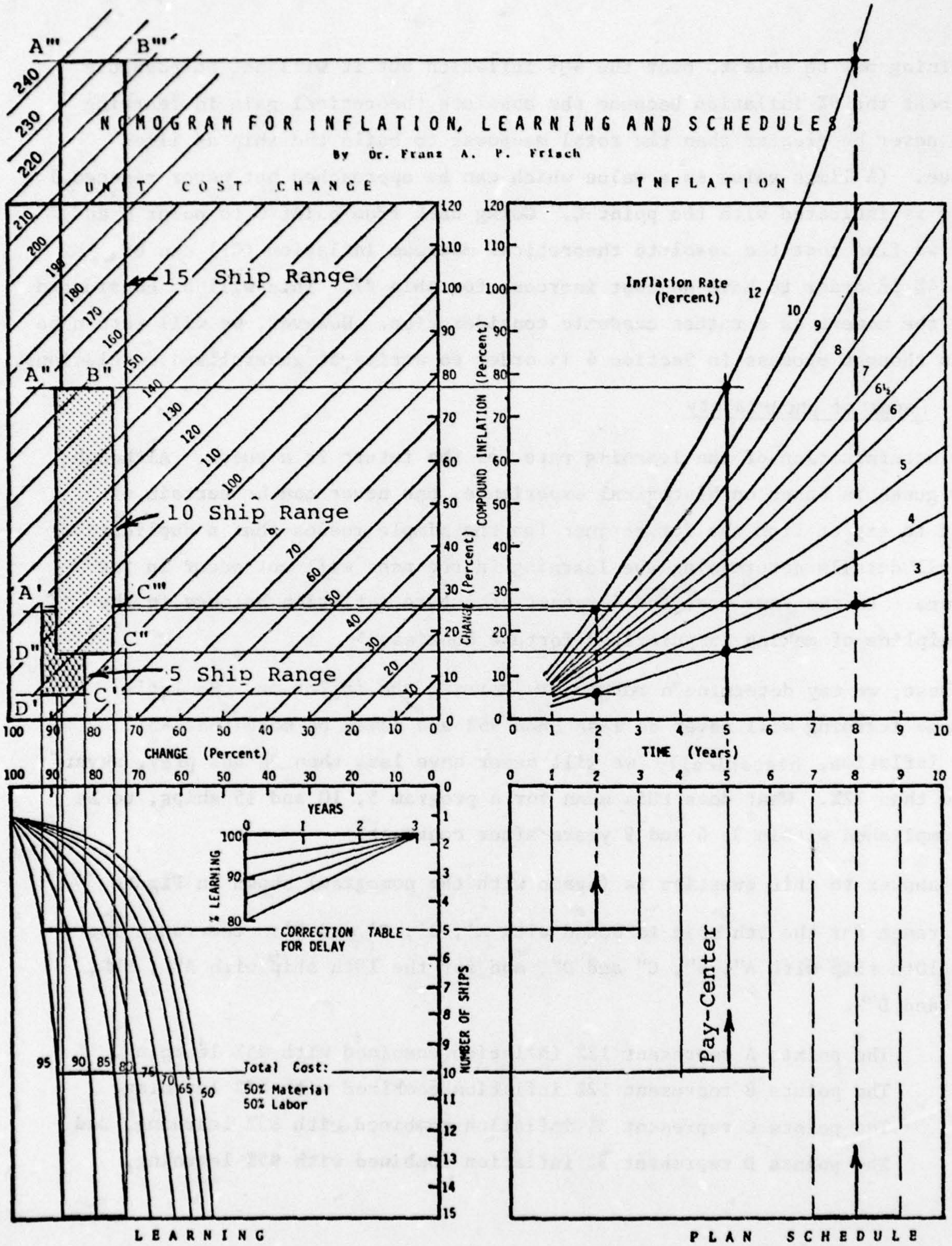


FIG. 12 MAX - MIN EXPECTATIONS

The values for the points A, B, C and D can be read from the nomogram. Within this collection of points, the points A represent the *maximum value of expectation* and the points C the *minimum value of expectation*. The values for A and C are shown in Table I.

Table I

MAX. AND MIN. EXPECTATIONS FOR CERTAIN ASSUMPTIONS

Point	Ship #	% Cost vs. 1st Ship
A'	5	118
C'	5	88
A"	10	170
C"	10	89
A"'	15	242
C"'	15	98

6. GENERALIZATION

In order to generalize the problem at hand, an attempt has been made to portray the interaction of all elements of the learning-inflation-scheduling problem into a single figure. The result of this attempt is shown in Figure 13.

Figure 13 is a *"guide"* to the total understanding of the problem under discussion. However, *Figure 13 is NOT a tool for exact calculation.* The Figure 13 depicts the absolute critical time for a program with n = infinite and this limit is independent of the learning rate. (For explanation see point C in Figure 11.) The Figure portrays the *logical relationship* between the following variables:

a. The assumed *inflation rate* on the ordinate; limited with 12%.

b. The deviation of the program - the *critical time* for various material/manhour ratios on the abscissa of the coordinate system.

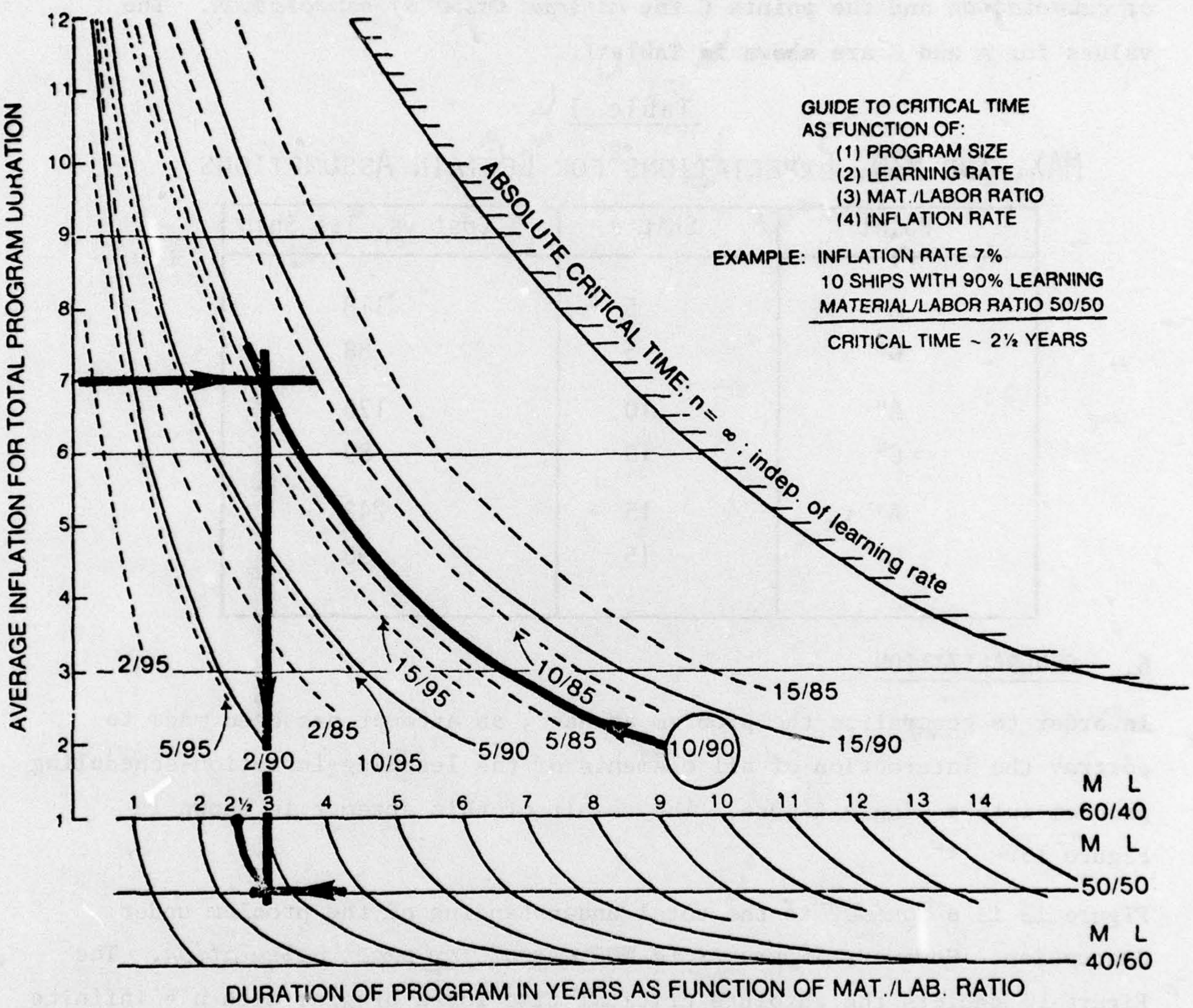


FIGURE 13 CRITICAL AND ABSOLUTE CRITICAL TIME

c. *Various program* sizes of 2, 5, 10 and 15 ships.

d. Different *learning rates* of 85%, 90% and 95% for the various programs.

The triple abscissa, representing various material/labor ratios eliminates a shift of the curves in the main body of the graph.

6.1 General Conclusions

The lessons learned from this study are in generalized form:

- *The negative influence of inflation tends to supersede the positive influence of learning under most practical conditions.*
- The shortest possible building time will always result in the lowest program cost during time of inflation, while the possibly associated unused learning potential will be negligable, or in reverse:
- Each program stretch in building time will always result in a substantial increase in program cost during time of inflation and can never be compensated by gain in learning.

As a rule of thumb, the inflation may easily supersede the effect of learning by a factor of ten.

6.2 Critical and Absolute Critical Time

Theoretically, it is possible to compensate with learning for inflation, provided the building program can be finished (from contract to last ship delivery) within (what we have defined as) the *CRITICAL BUILDING TIME*. The critical building time depends upon:

- The inflation rate
- The learning rate
- The number of ships in the program
- The material cost/labor cost ratio of the first ship in a series.

The *ABSOLUTE CRITICAL BUILDING TIME* is the time beyond which the power of inflation takes over under all circumstances if the program is not finished within this time. The absolute critical building time requires building an *infinite* number of units and is independent of the learning rate. Although the absolute critical building time is an abstract construct, it has still great practical value: for example, it tells us, *regardless of all marvels of management which one may perform, a 12% inflation can never be beaten if the program is not finished within four years; a 9% inflation takes over after six years; a 6% inflation permits a nine year building time and a 3% inflation provides a comfortable fourteen year building time.*

Table II informs us about the critical building time and the absolute critical building time for different conditions for ships with a 50/50 material/labor ratio. It should be noted that already a series of fifteen ships brings the critical building time into the 60% to 75% range of the absolute critical building time. For example, at a 12% inflation rate, the critical building time for fifteen ships (with 85% learning) is three years, while the absolute critical building time for a series with infinite ships is four years.

The determination of the critical building time as a function of the inflation is at the core of the problem. Other aspects such as the cost of delay and the loss of learning are also analyzed. However, all those investigations are variations of the same theme - the critical building time.

Considering 6% as the mundane inflation rate, blessed by soothsayers of various shades and assuming in infinite wisdom a learning rate of 90% as the average, one can conclude that any program of ten to fifteen ships and a total building-time of more that three or four years is bound to run into budgetary trouble. If the inflation should search toward 9% and the learning be only 95%, the critical state will already be reached for the ten and fifteen ship programs within one to two years. All forecasts for inflation (and other elements) are at best logically supported expectations but not dependable facts which must occur with necessity in the future. However, a rigid use of forecasts as limiting factors of a contract bears danger: whenever the forecast is wrong, the incentive for a claim formulation is given. Definitely a point, deserving further contemplation.

Series of Ships	INFLATION RATE											
	3%			6%			9%			12%		
	Learning Rate			Learning Rate			Learning Rate			Learning Rate -		
	95%	90%	85%	95%	90%	85%	95%	90%	85%	95%	90%	85%
2	1	2	3	1	1	2	1	1	1	1	1	1
5	2	4	6	1	2	3	1	1	2	1	1	1
10	4	6	8	2	3	4	1	2	3	1	1	2
15	5	8	9	3	4	5	2	3	4	1	2	3
..												
..												
..												
Infinite 2/	14	14	14	9	9	9	6	6	6	4	4	4

TABLE II CRITICAL BUILDING TIME IN YEARS 1/

1/ Rough approximation for a constant 50/50 Material/Labor ratio.

2/ Absolute critical time.

Note:
- For a time below the critical building time, the benefits of learning supersedes the penalty of inflation.
- For a time above the critical building time, the penalty of inflation is greater than the benefit of learning.

Figure 13 was called a *guide* because no exact time determination for criticality is possible without knowledge of the specific payment schedule for a program. What is plotted is general analysis.

6.3 Sensitivity

Figure 13 can also be used to portray some sensitivity aspects of the problem. This is shown in Figure 14. The figure gives an insight into the sensitivity of the total problem to changes of individual inputs. The sensitivity is underscored for a specific case. For example, for a 10 ship program and a change of inflation from 8% down to 6%, and an improvement in learning from 95% to 85%, as well as a *make or buy decision* changing the material/labor ratio from 55/45 to 45/55 will increase the critical building time from 1½ years to 3½ years.

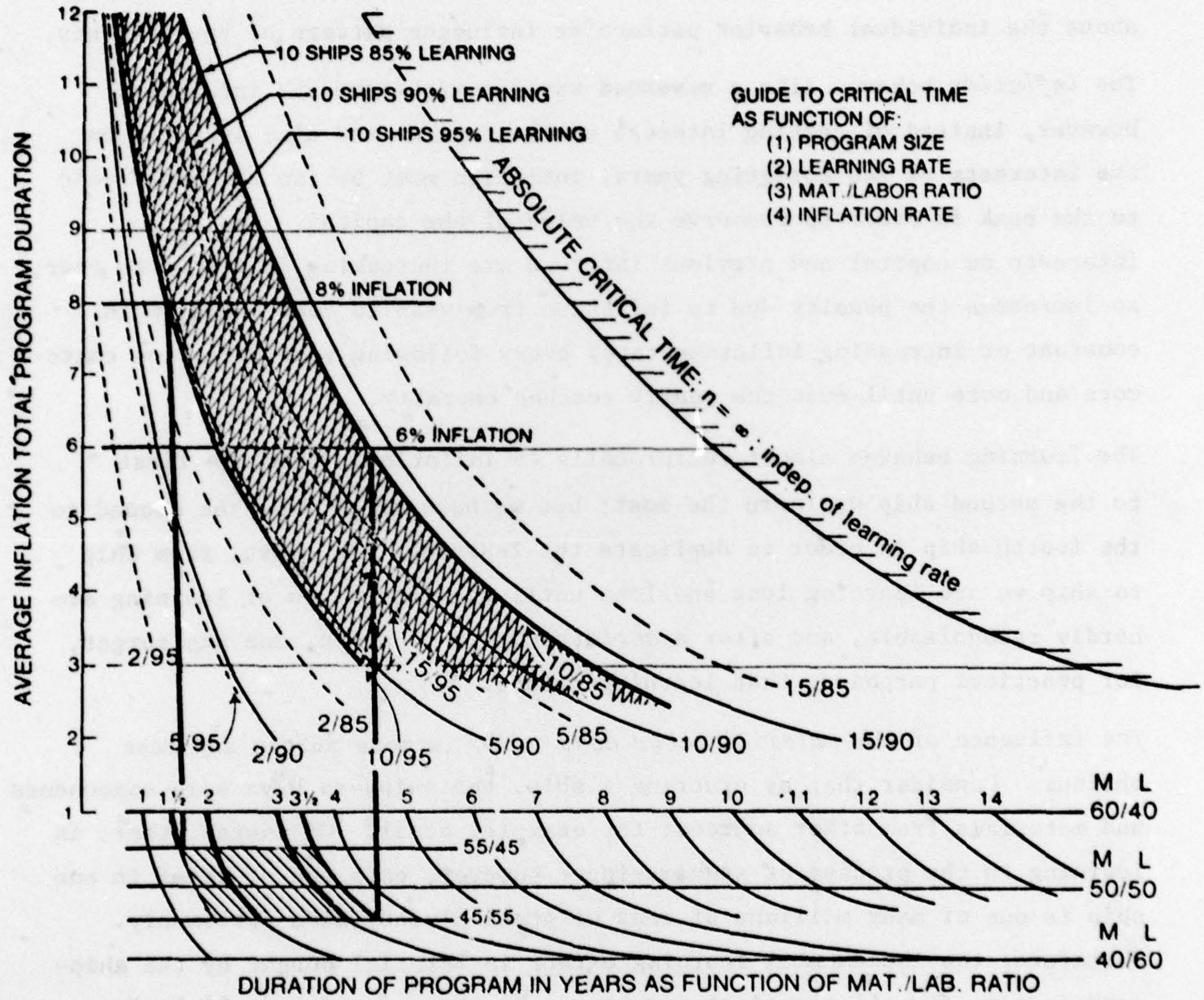


FIGURE 14 SENSITIVITY INDICATION

7. SUMMARY

Learning, inflation and Material/Labor Ratio are the key elements of the analysis.

The interaction of the elements may become self evident if one has clarity about the individual behavior pattern or influence pattern of the elements.

The *inflation* behaves like a reversed savings with compound interests. However, instead of getting interest on the capital and also interest on the interests of the foregoing years, inflation must be (so to speak) paid to the bank in order to preserve the value of the capital. And like interests on capital and previous interest are increasing from year to year, so increases the penalty due to inflation from year to year - and (with constant or increasing inflation rate) every following year inflation costs more and more until even the yearly reaches enormity.

The *learning* behaves almost reciprocally to inflation. From the first to the second ship we learn the most; but we have to go from the second to the fourth ship in order to duplicate the learning. In short, from ship to ship we are learning less and less until the increments of learning are hardly recognizable, and after a *certain number of ships*, one may forget, for practical purposes, that learning exists.

The influence of the *material/labor cost ratio* is more subtle and less obvious. Consider that by ordering a ship, the shipyard buys some components and materials from other sources; for example, steel. Of course, there is learning in the process of steelmaking - however, each ton of steel in one ship is one of many millions of tons of steel already made previously. Therefore, the incremental learning effect in material bought by the shipyard is zero for all practical purposes. In short, we do not "*learn*" on material and the quantity discount (if given at all) has nothing to do with learning. All measurable learning takes place in the yard - and the more components the yard builds itself, the more the yard will learn. This is the point where the make and buy decision enters the picture. Of course, this is a strong simplification of the problem. Taking everything else equal, we may well say that the material/labor ratio depends upon the ship type. A ship type with a material/labor ratio of 60/40 will have less chance to utilize the learning effect than a ship type with a 40/60 ratio, simply because there is more labor percent available where one can learn.

If we overlay the inflation-learning problem with the material/labor ratio, we will not change the logic of the result - but influence only slightly the result in a favorable or unfavorable manner. However, the influence will be sufficient to be recognized.

The behavior patterns are summarized in simplified form in Figure 15. The horizontal axes are years, the vertical axes the average inflation rate during the total contract time. Two assumptions are made: (1) a material/labor ratio of 50/50 and (2) a learning rate of 90%. These are good averages for most programs. The relationship between inflation and time is plotted for a 5 ship series (Points A and B) and a 10 ship series (Points A' and B')

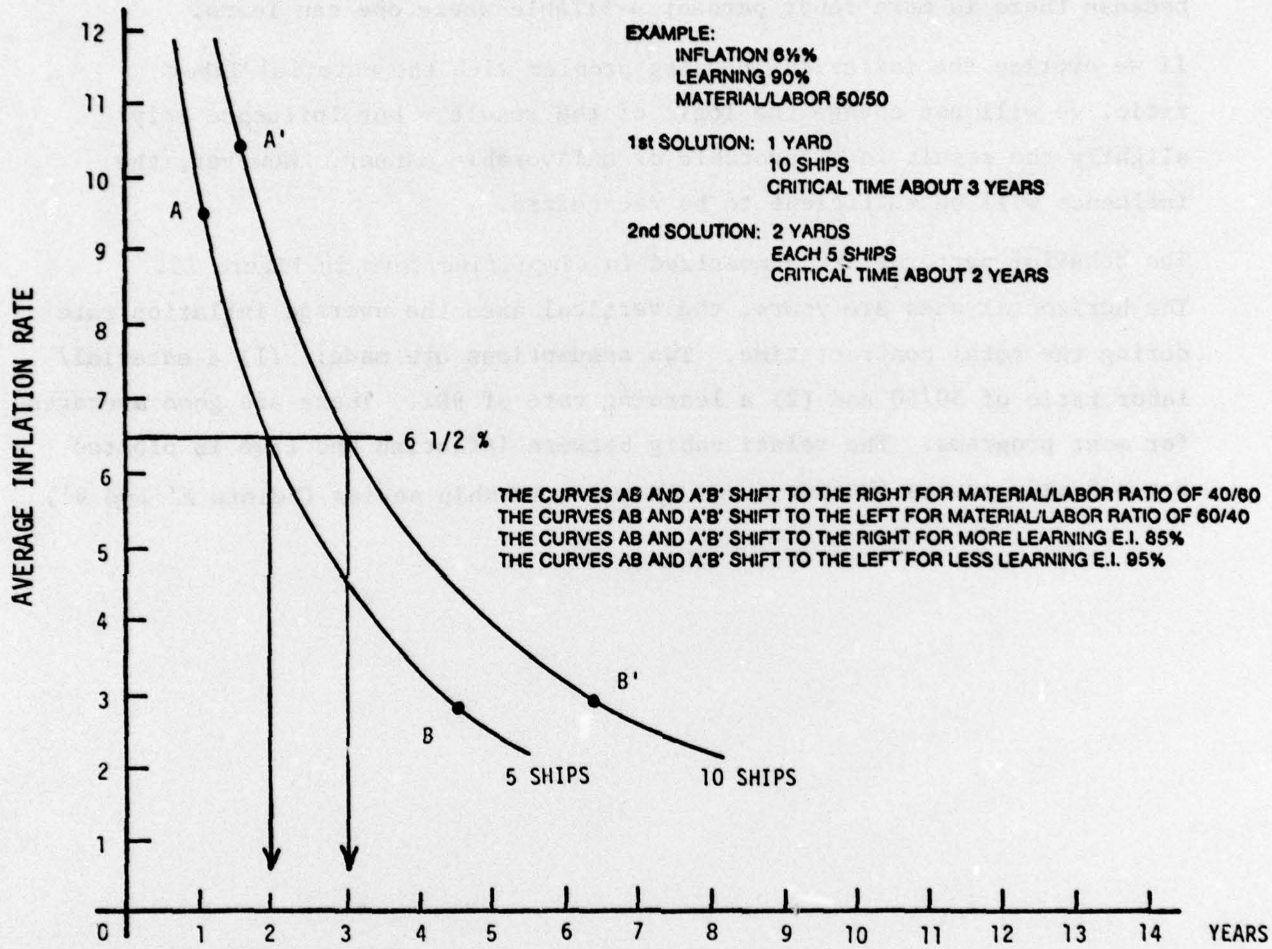


FIGURE 15 BEHAVIOR PATTERN OF LEARNING AND INFLATION

(whereby the curve represents the critical time). Two examples are shown for an assumed inflation rate of 6½%: (a) either all 10 ships are built in one shipyard or (b) 5 ships are built in each of two shipyards. In the first case, the total program must be finished in the critical time of about 3 years and in the second case in the critical time of about 2 years. If this cannot be done, inflation costs more than learning can buy. Also, the higher the inflation, the shorter the critical time. Under different assumptions, the curves will shift as indicated in the text below the figure.

Because of the non-linear behavior of all elements involved, the combination of the individual influences follows complicated rules. If we consider in addition to inherent uncertainties in forecasting inflation and learning - even suppressing the inherent uncertainties of the original estimate, we may at best bracket a range of expectations. This *range of expectation* will have maxima and minima value but will not give informations about any probability distribution. For clarification, let's assume a 12% average inflation combined with a 95% learning determines the maximum cost growth in a program and on the other hand a 3% inflation with a 85% learning shall determine the minimum cost growth condition. Let's also assume these two limits apply to a series of 5, 10 and 15 ships, to be executed within 3, 6 and 9 years. Under these assumptions the result will look like this:

	In % of the First Ship	
	Min	Max
Cost of the 5th Ship	88	118
Cost of the 10th Ship	89	170
Cost of the 15th Ship	98	242

We notice that the spread between the min and the max value increases drastically with increased number of ships in the program and therefore, increased building time.

8. FINDINGS

From a purely theoretical point of view, it is possible to compensate for inflation with learning in multiple ship programs of *extremely short* duration. Depending upon the inflation rate and the achievable learning rate, the *critical time* for a total program execution (from contract to last delivery) may be in the neighborhood of one to three years. All contracts which cannot be fully executed within the critical time have practically no chance to beat inflation with learning.

More specifically:

a. *The negative influence of inflation tends to supersede the positive influence of learning under most practical conditions.*

b. The shortest possible building time will always result in the lowest program cost during time of inflation, while the possibly associated unused learning potential will be negligible, or in reverse:

c. Each program stretch in building time will always result in a substantial increase in program cost during time of inflation and can never be compensated for by gain in learning.

As a rule of thumb, the detrimental effect of inflation can easily supersede the positive effect of learning by a factor of five to ten.

The study shows interaction of *four elements:*

a. The *inflation rate* as the driving element of the total problem during the contract time.

b. The *learning rate*, an important but surprisingly weak element in the problem.

c. The *number of ships* in the program; but only the first three or four ships are of importance.

d. The *material/labor ratio* for the first ship, pointing to the importance of the make and buy decision in contracting.

The individual influences of all those four elements are discussed. However, in order to appreciate the problem at hand, all findings may be summarized into a single sentence:

> *Inflation will always take over. It is not a question of the "if" but of the "when."*

This is determined by the relative power of the four elements, listed above.

If we may again summarize the findings of the study, one may well restate that inflation drives the problem and no trick is able to beat inflation. Therefore, in times when inflation controls the destiny, ship allocation to shipyards may well be made in a quite liberal way and industrial base considerations, labor availability and other non-econometric determinants may be considered without hesitation.