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PLANT STARTUP PRODUCTIVITY

MEASURING AND PREDICTING PROGRESS IN CONTINUOUS STEEL CASTING MACHINES

by

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of the requirements for the degree of
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ABSTRACT

Plant startup, the period of time from production of the first acceptable product until the plant is operating regularly at full capacity, presents greater opportunities for improvement than businessmen commonly recognize. Managers frequently discover that the amount of time and money required to bring a new plant to the desired level of production, especially a plant involving a new technology, is greater than expected. How long it will take to reach the desired output level is difficult to predict. This seriously affects financial planning, delivery promises to customers, and internal scheduling. What action to take to speed the process is often not clear. The objective of this research was to find improved methods to measure and predict startup progress and to reduce its duration and cost, and

thus provide managers with solutions to the above uncertainties.

Monthly production tonnages for the first thirty-six months of operation of thirty continuous steel casting machines were gathered. These machines were designed by one supplier, Concast, Inc. and its parent Concast AG, and are located on four continents in ten countries. The productivity data thus gathered were regressed against the Manufacturing Progress Function: $Y = a X^b$, to obtain measurements of startup. Predictions by trend projection, parameter model, and chronological trend in the technology, based upon these measurements, were investigated. The effect of four plant variables on startup characteristics was examined. The four variables are: degree of advance of technology, management experience, product quality sophistication, and materials and energy supply. An analysis of eight vignettes of CONCAST startup sought to explain the mechanism of productivity progress. This research procedure disclosed better ways to measure and predict productivity progress during startup in this one technology, CONCAST, and the findings are believed generalizable to other machine-intensive startups.

Well defined measures of startup progress, duration, and lost capacity were secured. The median duration of startup of the plants studied was over two years. A method of predicting these measurements using productivity at a

plant during the first few months was determined. Product quality sophistication was found to retard startup significantly. Modifications of the production system were indicated as the process by which productivity gains were achieved. These research results should aid managers to attain enhanced performance during machine-intensive plant startups.

Measurement of productivity progress using the Manufacturing Progress Function is recommended. Prediction of final startup measurements using early months productivity data and startup parameters from earlier plants in the same technology is suggested. Selection of plant variables which will shorten startup duration is discussed. A startup modification group structure which may speed startup is described. These concluding recommendations are expected to permit improved measurement and prediction of startup in machine intensive plants and to assist in reducing the amount of time and money required for such startups.

ACKNOWLEDGEMENTS

I am greatly indebted to a number of people in the steel industry who gave generously of their time and thought in order to provide the essential data for this study. Unfortunately, they must remain anonymous to maintain confidentiality. However, I can thank Mr. Tom Preston of Concast, Inc., a steel man of unusual intellect and personal warmth, for his continuous and absolutely necessary assistance throughout the project. Mr. Horst Precht and Mr. Herb Fastert of Concast, Inc. have also given invaluable aid.

Dr. Michiel R. Leenders must be awarded a 'Distinction' as adviser. His perceptive discussion and thorough critiques were accompanied by an unparalleled record for fast response to interim submissions. His total commitment to the position of chief adviser counted heavily in the completion of this thesis.

I must also thank Miss G. M. Law, my junior high school English teacher, for her devoted assistance in editing. After thirty years, she still is trying to lead me safely within the pale of proper language usage, which she professes so impeccably. The final stages of manuscript preparation owe much to the meticulous typing of Miss Carol McQuarrie at the computer console. Readability was noticeably enhanced by her unique skill with the computer editing program.

The study also owes a substantial debt to Shell Canada Ltd. for the Doctoral Research Support Grant which underwrote the extensive travelling and communication expense. Canada Council support, too, reduced the material constraints of this work. Additionally, a Xerox of Canada Ltd. Doctoral Fellowship provided initial assistance to launch the study.

The assistance of many others should be acknowledged, but it is difficult to be exhaustive. I would like to mention the aid of: Mrs. Barb Cunningham, Mr. Walter Doran, Dr. Bruce Johnston, Mr. Les Norris, Dr. Richard Rosenbloom, Dr. K. G. Standing, Mrs. Lois Stewart, and Mr. Sol Udow.

Finally, I must thank my ever-patient wife, Jeanette, who managed our three vigorous, and strong-willed sons and our depleted purse, alone in Winnipeg, while I commuted to London and other cities to write this thesis. I'm lucky to have such a fine and understanding wife.

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CHAPTER I

INTRODUCTION

Plant startup, the period of time from production of the first acceptable product until the plant is operating regularly at full capacity, presents greater opportunities for improvement than businessmen commonly recognize. Managers frequently discover that the amount of time and money required to bring a new plant to the desired level of production, especially a plant involving new technology, is greater than expected. How long it will take to reach the desired output level is difficult to predict. This seriously affects financial planning, delivery promises to customers, and internal scheduling. What action to take to speed the process is often not clear.

Several authors have examined the pattern of productivity increases in new plants which have different kinds of operations. The possibility of discerning precise progress among the hectic activities in a new plant, through such an examination, might seem unlikely to many practising managers. Yet, one study of twenty different new process installations in the steel industry showed remarkably predictable startup patterns. The rate of production increase in these examples followed a simple mathematical formula called the Manufacturing Progress Function, however, its author pointed out the need for a much greater understanding of startup productivity increases.

In this thesis, the productivity increases during startup of a series of CONCAST plants have been examined to determine whether there is a pattern of increasing output which is consistent. No one previously has examined a group of similar plants. It was expected that the productivity in each one of this set of comparable plants in a sequence of evolving technology would also follow the Manufacturing Progress Function. In designing this study, it was also hoped that the similarity of plants would make the constants in the formula predictable for future installations. Additionally, it was anticipated that the sequence might show that plants incorporating major process design changes have different startup characteristics. Further, discovery of some factors which accelerate the rate of startup was a prospect of this investigation.

Plant startup challenges managers to discovery in our technologically innovative world. Change in our social and economic environments escalates the need for ever better ways of handling operations during this initial phase in the life of an industrial plant. Other segments in the sequence of technological innovation, from formal research and development onward, have received special research attention. Startup has suffered relative neglect, and displays attractive opportunities for improvement. Functional areas of management from marketing and finance, to accounting, personnel, and production can benefit from such improvement. A look at some of the changes in our world which make the need and opportunity for better startup especially pertinent at this time will help to set this research into perspective.

Changing Environments

All of our environments: sociological, political, economic, and technological are changing in ways which tend to lengthen and proliferate startup. The sociological environment holds powerful aspirations of people for a stream of new products, for higher quality, and for a broadened choice. Politicians both encourage and frustrate these aspirations. Increasing amounts of capital in the economy provide for greater plant expenditure, so that investment per employee, as well as the variety of processes using expensive assets, continually grow to help satisfy such aspirations. Munificent technology frequently finds new ways to satisfy old and new wants with innovative processes which can be installed with the increasing plant expenditures. The technological changes have their own effect on the other environments in turn. Some people, therefore, regard it as malevolent technology due to these changes. Such alterations in all the environments of our world impact forcefully on startup.

Our society demands a continuous parade of new products which television and other media convey into the living room. Changed living habits lead to requirements for further new products, and conversely decrease sales of others. People's thirst for better quality sometimes dooms a process of manufacture, when a new process with better natural quality attributes appears. The steadily enlarging proportion of discretionary income permits people to select a broader and broader range of products in addition to their basic food, clothing, and shelter. All this means that many more products are made by an increasing number of processes. Therefore, more plants of different kinds are started up to satisfy these demands of society.

The economy registers these added plants in its own terms. Huge amounts of capital are expended each year on new plants and equipment. In Canada, the 1969 figure was $2.5 billion; in the U.S., $31.7 billion, for all manufacturing industries. A growing pool of capital in the industrialized countries makes these expenditures possible. The new facilities are rarely replicas of existing facilities. Accelerating research and development activities present a challenge to industry, to incorporate new technology into production processes to provide better and cheaper products. Growing investment per employee indicates a successful search for higher productivity, the justification of capital expenditures due to higher wages, and the opportunity to satisfy these drives through the technology which has become available from research and development. Plants can often be made bigger to supply a larger population, a continental, or even a world market, and thus take advantage of the economies of scale. The economic indicators, as a result, show that plants cost much more per employee, are more varied in process, and are often, individually, more expensive. Startup at each of these plants can be expected to present more problems, due to more expensive and complicated equipment. In addition, a greater number of large, complicated plants must be started up.

It was noted earlier that technological innovation, coupled with growing capital availability in the economy, has frequently been instrumental in providing new processes at these plants being started up for the purpose of satisfying the heightened aspirations of our society. This procedure of technological innovation originally relied upon fortuitous invention by gifted individuals. Gradually, a scientific knowledge base permitted methodical research into unexplored combinations of established phenomena. The flow of new technology, yielded by this exploration, became more certain. Formalization of product design and market testing of new products extended the reliable portion of the sequence for introducing new technology. The complete sequence of seven stages in the process of technological innovation has now been formalized.[1] Substantial investigation into some links of this sequence, especially research and development, has improved the odds for successful innovation. The synonymous terms of startup, debugging, or warmup are recognized as part of stage six, commercial introduction or first operational use, but little investigation has been carried out to facilitate this stage. However, successful technological innovation at the prior stages keeps supplying more new processes to the first operational stage. More new plants containing untried processes are designed and built, and have to be started up. The difficulties of this task, unguided by research discoveries, can be tortuous.

The concern of this study is with that task, startup, not with the whole process of technological innovation. Technological change has become prolific, more formalized, and is here to stay. But here, attention will be focused on the utilization of new technology in production processes, and with any innovation during the startup period that is

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[1] James R. Bright, A Brief Introduction to Technology Forecasting Second Edition (Austin, Texas: The Pemaquid Press, 1972), pp. 4-2 and 4-3.

required to make the new process work at anticipated output levels.

It will be increasingly more important to a company's survival and profitable operation, to be able to incorporate and digest siceable technological leaps forward, without being stalled for several years by that digestion. New paper plants are becoming computer controlled, completely continuous processes. Brass mills are arranged so that, from the incoming scrap to the computerized automatic warehouse of finished brass rod, the material virtually never stops. The automated engine block fabrication lines of auto manufacturers have been well documented. Glass moves smoothly and continuously on molten lead, to emerge as a higher quality, lower cost, window or mirror. Concrete structural members squeeze from a machine, like toothpaste, strong enough to support their own weight while curing. Steel comes as an endless, red-hot ribbon, eighty inches wide and nine inches thick, and is rolled to thinner dimension, miles in length, without ever being detached from its liquid tail in the continuous casting machine.

These marvels are dreamed in the minds of men, converted to equipment designs by engineers; the plans are reviewed by company treasurers and the expenditures approved by presidents. The building is put in place by construction company and equipped by machinery builders. The local mayor cuts the ribbon; the wife of the chairman of the board throws the champagne bottle; and with luck the machinery whirs and a small quantity of product is created.

This event signals the beginning of the long, arduous period called startup, which is complete only when production levels out at a value somewhere near design capacity. This may take as long as four or five years.

The investigation of this startup period in all of the new technologies mentioned above, plus the countless others now in use, would pose an unmanageable task. Limitation to only one technology can allow comparability between findings at different locations. A technology of moderate difficulty, new enough to yield data from the first installation, but old enough to have a history and sequence of plants in operation, suits the research requirements. The continuous casting of steel has now been operational commercially for about twenty years, and it meets these needs. This thesis will explore startup at plants using the process of continuous steel casting.

Dynamic Startup Management in Today's Environment

Benefits can accrue to all functional areas of management by unravelling the dynamic concepts underlying the startups generated by the changing environment. Static management concepts conceived seventy-five years ago are not appropriate for the rapidity of change today. Marketing, finance, accounting, and production managers must all fire ahead to hit the accelerating bird on the wing. Improved startup management is intricately involved in gaining the ability to fire ahead accurately and hit the market, with good quality products from a new plant, in the needed volume, at a profit.

Frederick Taylor thought that management must find the one best way to do a job, and then require workers to do it over and over, in that manner. This envisaged a production system where product, equipment, method, and probably volume, were all static for a long period. Today's changing environments frequently preclude this approach. The management job is now more involved with bringing a new product, made by a machine-intensive new process, onto the market in ever increasing quantities. The product is sometimes phased out a short time later. This means that making a series of rapid changes, or modifications, to the production system has become a more important management function than meticulously finding the one best way for a laborer to do a manual job, which will be repeated for an extensive time. Investigation of startup can disclose such a dynamic management procedure operating to create the essential productivity process.

Marketing depends upon a close forecast of the quantity and quality of products coming from a new plant. Over-optimism by managers about these two properties will cause broken promises to customers who may subsequently be chary about placing orders with the new plant. Pessimism regarding these factors may garner high inventories or lower prices than necessary. Forecasting the market growth of a new product from a new plant doubly complicates the structure. Understanding productivity progress during startup can benefit marketing through improved performance of these factors.

Financial, accounting, and personnel managers may all be able to perform better with more correct expectations of productivity during startup. Financial managers can provide sufficient funds to weather the lengthy loss period at the beginning of startup, and so avoid the non-liquid position which has sometimes caused bankruptcy during this period. Accountants can be better assured that their budgets are meaningful. The need to explain large, unexpected, and unfavorable variances should be less common. Personnel managers may find that people are happier when productivity expectations are more realistic. The dynamic concept of a moving productivity target, with a sequence of dissimilar modification jobs creating the increase, helps managers in all these areas.

Production managers, of course, benefit most. The burden of achieving capacity production at an unrealistically early date can be removed from their shoulders. Provision of sufficient cash for modifications will reduce their sometimes frustrating role as funds advocate. A happy crew, working to realistic productivity expectations, will be easier to manage. Then, too, some suggestions may be generated by the research through which production managers can markedly speed the startup, so that both they and the whole organization will benefit. These are some of the favorable dividends which may be obtained by this research into startup.

Existing Theoretical and Practical Bases for Startup

Contrasted with the knowledge required to capture the benefits suggested above, existing theory wants woefully. Manual productivity increases in aircraft assembly have been documented for several decades in the form of the Aircraft Learning Curve. Machine - intensive startups have been virtually ignored by empirical researchers, but the Manufacturing Progress Function has been used for measurement in at least one research project. Both of these relationships show exceedingly regular productivity progress, but a theoretical explanation of such relationships has not been forthcoming. This lack of explanation indicates the paucity of conceptual underpinnings of startup.

It probably reflects the conventional wisdom that very long startups are not really experienced. Statements by seemingly knowledgeable corporate officers often indicate that a new plant is expected to be producing at capacity in a few weeks or months after the first product is produced. Managers of financial institutions show some signs of being particularly biased toward these expectations, possibly due to their lack of technical knowledge. It is really amazing how this expectation of the conventional wisdom of responsible men is repeatedly disappointed.

Actual management practice seems to be a crude dichotomy of theory and conventional wisdom. For public consumption, all managers gather together on the day of first production and announce that the new plant is operating smoothly, except for a few bugs which will be ironed out by the end of next month. Behind the scenes, they plot production weekly, or monthly, on arithmetic charts, always hoping that approximately another three months will bring production to full capacity levels. Usually, it is many times three months before success arrives. Meantime, the managers exert strenuous efforts to complete a sequence of difficult modifications, each of which increases productivity a little.

It is felt that both this actual management practice and sketchy theory can be improved if the objectives of this research project are achieved.

Objectives and Structure of the Thesis

Measurement and prediction of productivity growth based upon the Manufacturing Progress Function are investigated in this research. This has been done by gathering and examining productivity data during startup of thirty continuous steel casting machines. These machines have been designed by one supplier, Concast, Inc., and its parent Concast AG. The results of this research, with the particular technology, CONCAST, are considered generalizable to other forms of machine - intensive, new process technologies.

The monthly productivity gathered from steel plants with the CONCAST machines have been fitted to the Manufacturing Progress Function. The accuracy with which parameters of this function can be predicted is reported. The effect of plant variables on the startup characteristics of this function have been tested for significance. Some descriptions of plant startup activities sketch a background for productivity progress and its cause. The objective of this research is to find improved methods to measure and predict startup progress, and to reduce its duration and cost.

The structure of the thesis closely follows the sequence which has been described above, to attain this objective. A literature review commences the study, so that existing theory and knowledge can be detailed, and certain conjectures formed. Hypotheses are then stated regarding anticipated relationships within the startup knowledge gap, and methodology is specified to test each hypothesis. Vignettes of startup follow the methodology, to provide a descriptive portrayal of the CONCAST technology and startup activities, and to support the conjectures. Following this evidence, three chapters report the results of the research for measurement, prediction, and effect of plant variables upon the startup of CONCAST machines. A final chapter examines the implications of these reported results, and recommends certain startup actions to managers, as well as subsequent projects to future researchers.

CHAPTER II

LITERATURE, CONCEPTS, AND CAUSES

Long expensive startups are ubiquitous, and generally unexpected. They are often more susceptible to management control than sales volume and price, which also hinder the attainment of planned production levels.[1] Bright recognized the existence of an extensive startup or "debugging" period for technologically new, machine-intensive systems, fifteen years ago.[2] Unfortunately, most research on productivity during startup has been in the labor-intensive, air frame and electronic industries. The learning curve has received considerable use and refinement in these applications.[3,4,5]

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[1] Ross Henderson, "Improving the Performance of Capital Project Planning," Cost and Management, Vol. 45, No. 5, (September - October 1971), pp. 33-41.

[2] James R. Bright, "Automation and Management," (Boston: Harvard University 1958), p. 127.

[3] T. P. Wright, "Factors Affecting the Cost of Airplanes," Journal of Aeronautical Sciences, Vol. III, (February, 1936), pp. 122-128.

[4] Armen A. Alchian, "Reliability of Progress Curves in Airframe Production," (RM 260-1; Santa Monica, California: The Rand Corporation, April 14, 1950).

[5] Harold Asher, "Cost - Quantity Relationships in the Airframe Industry," (R-291; Santa Monica California: The Rand Corporation, July 1, 1961).

Several authors have applied the learning curve to other labor-intensive operations.[6,7,8] With one exception, little has been done in machine-intensive, process manufacture, although some authors have broached the subject.[9,10]

Nicholas Baloff has carried out the only study focused solely on startup in machine-intensive manufacture. He has written at least eleven journal articles on this subject,[11,12,13,14,15,16,17,18,19,20,21] mostly based upon

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[6] Frank J. Andress, "The Learning Curve as a Production Tool," *Harvard Business Review*, (January - February 1954), pp. 87-97.

[7] M. D. Kilbridge, "Predetermined Learning Curves for Clerical Operations," *Journal of Industrial Engineering*, Vol. X, No. 3, (May - June 1959), pp. 203-8.

[8] John G. Carlson, "How Management Can Use the Improvement Phenomenon," *California Management Review*, Vol. III, No. 2 (Winter 1961), pp. 83-94.

[9] R. W. Conway and Andrew Schultz, Jr., "The Manufacturing Progress Function," *The Journal of Industrial Engineering*, Vol. X, (January - February, 1959), pp. 5-10.

[10] Winfred B. Hirschmann, "Profit From the Learning Curve," *Harvard Business Review*, Vol. XLII, (January - February, 1964), pp. 125-139.

[11] Nicholas Baloff, "Startups in Machine Intensive Production Systems," *The Journal of Industrial Engineering*, Vol. XVII, (January, 1966), pp. 25-32.

[12] Nicholas Baloff, "The Learning Curve - Some Controversial Issues," *Journal of Industrial Economics*, Vol. XIV, No. 3, (July, 1966), pp. 275-283.

[13] Nicholas Baloff and R. W. McKersie, "Motivating Startups," *The Journal of Business*, Vol. XXXIX, (October, 1966), pp. 473-484.

function coupled with industrial dynamics methodology. All of these functions are mathematically more complicated and present some difficult parameter estimating problems. However, in examples where the Manufacturing Progress Function did not fit real data well, in order to sample the measuring ability of these exponential functions, the claimed advantages of the Levy and Pegel Functions were tested here.

If the Manufacturing Progress Function measures productivity growth well, it would be desirable to estimate the parameters at an early date in the startup, and so determine the full curve. Asher noticed in 1961 that if initial productivity was low, then the slope of the relationship was steep.[38] Baloff formulated and tested this relationship between parameters, and found the intercept was a very good estimator of the slope.[39,40] Much of this relationship seems to be due to leverage of the intercept about $\overline{X}$ and $\overline{Y}$, due to slope steepness. Baloff, however, showed clearly that ordinal ranks of productivity in the first month were inversely related to slope.[41] This

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[38] Asher, p. 78.

[39] Baloff, "Manufacturing Startup: A Model," p. 114.

[40] Baloff, "Estimating the Parameters of the Start-up Model - An Empirical Approach," p. 250.

[41] Ibid, p. 251

which has a logarithmic transformation:

$$\text{Log } Y = \text{Log } a + b \text{ Log } X \qquad (2)$$

where:

Y = productivity, units of production per time period

a = theoretical productivity for the first unit

b = slope of the line

$M.P. = 2^{b}$, where M.P. means Manufacturing Progress, and it represents the increase in productivity each time cumulative production is doubled.

Baloff's results, based upon this function, show a relationship between the parameters of the function in the various startups. He concludes his thesis by calling for further research to confirm his fingings. He does not compare the startup rates within a sequence of installations which use the same technology. Neither does he discuss the effect of greater or lesser degrees of technological advance upon the parameters of the Manufacturing Progress Function. Nor does he test his data to find what effect other plant variables, such as management experience, product quality and mix, or other material supplies, might have upon the progress of productivity. Further, he does not indicate how initial production data might be used to forecast parametors, using his parameter model. These gaps have been addressed by the research done here.

Fortunately, the mathematics of the Manufacturing Progress function, and its inverse, the learning curve, are well established. Wright established the learning curve in 1936. Hirsch first used the term "Manufacturing Progress Function" in 1952.[23] Conway and Schultz further developed the mathematical relationships for this function in 1959.[24] Baloff established some definitions to standardize productivity and steady state values in 1963.[25] He formalized the regression analysis procedure for the Manufacturing Progress Function at the same time. Morse presented a model for predicting the confidence levels and confidence intervals of cumulative average cost, based upon the first few points in the learning curve, in 1971.[26,27,28] Computer procedures for linear regression of the logarithmic transformation of the Manufacturing Progress Function are well established. This foundation of mathematical knowledge

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[23] Werner Z. Hirsch, "Manufacturing Progress Functions," *The Review of Economics and Statistics*, Vol. XXXIV, (May, 1952), pp. 143-155.

[24] Conway and Schultz, pp. 39-41.

[25] Baloff, "*Manufacturing Startup: A Model*," pp. 66, 74-76.

[26] Wayne J. Morse, "*The Allocation of Production Costs With the Use of Learning Curves*," Unpublished Doctoral Dissertation, (East Langsing, Michigan: Michigan State University, 1971).

[27] Wayne J. Morse, "Reporting Production Costs that Follow the Learning Curve Phenomenon," *The Accounting Review* (October, 1972), pp. 761-73.

[28] Wayne J. Morse, "The Use of Learning Curves in Financial Accounting," *CPA* (January 1974), pp. 51-57.

and procedures is available to analyse the progress of startup productivity with the Manufacturing Progress Function.

This mathematical foundation generally assumes or argues that production levels off at some steady state productivity in machine-intensive manufacture. Baloff proposed that an abrupt, visible break in the data points plotted on Log-Log paper would determine the commencement of steady state productivity.[29] However, Hirschmann argued that progress could continue indefinitely if management was determined to achieve continued productivity increases.[30] Baloff noted that steady state was not achieved in some startups he studied, but assumed it would occur at a later date. Further examination of actual data to find whether steady state productivity is achieved, and if so on what occasions, was undertaken in this research in an endeavor to throw light on this difference of opinion.

The foregoing discussion of the literature has assumed that CONCAST startup productivities will closely follow the Manufacturing Progress Function. It may be well to consider the work of Levy,[31] Pegel,[32] de Jong[33,34] and Towill[35] who

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[29] Nicholas Baloff, "Manufacturing Startup: A Model," p. 75.

[30] Hirschmann, p. 139.

[31] Ferdinand K. Levy, "Adaptation in the Production Process," *Management Science*, Vol. XI, (April, 1965), pp. B-136 to B-154.

propose slightly different mathematical formulations of the progress function. The chief difference between these formulae and the Manufacturing Progress Function is that they curve asymptotically towards steady state productivity rather than having a sharp, angular break at the junction of two straight lines. Levy assumes that the rate of increase of productivity is proportional to the amount the process can improve.[36] Pegel claims only the rational feature of gradually levelling out to a steady state productivity.[37] Pegel draws attention to the third function, put forward by de Jong, which is exponential like his own and Levy's. He claims in his analysis that de Jong's function fits better than Levy's but not as well as his own. A fourth exponential function has been proposed by Towill, who in addition suggests a predictive procedure based upon this

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[32] C. Carl Pegels, "On Startup or Learning Curves: An Expanded View," AIIE Transactions, Vol. I, (September, 1969), pp. 216-222.

[33] J. R. De Jong, "The Effects of Increasing Skills On Cycle Times and Its Consequences for Time Standards," Ergonomics, Vol. 1, No. 1, (1957).

[34] J. R. De Jong, "The Effects of Increasing Skills and Methods - Time Measurement," Time and Motion Study, Vol. 10, (1961), pp. 17-24.

[35] Denis R. Towill, "An Industrial Dynamics Model for Startup Management," IEEE Transactions On Engineering Management, Vol. EM 20, (May 1973), pp. 44-51.

[36] Levy, p. B-138.

[37] Pegel, p. 218.

function coupled with industrial dynamics methodology. All of these functions are mathematically more complicated and present some difficult parameter estimating problems. However, in examples where the Manufacturing Progress Function did not fit real data well, in order to sample the measuring ability of these exponential functions, the claimed advantages of the Levy and Pegel Functions were tested here.

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[38] Asher, p. 78.

[39] Baloff, "Manufacturing Startup: A Model," p. 114.

[40] Baloff, "Estimating the Parameters of the Start-up Model - An Empirical Approach," p. 250.

[41] Ibid, p. 251

parameter relationship was further developed here, and an effort was made to validate it for assistance in prediction.

Startup parameters are predicted in order to estimate the duration of startup and the lost capacity during startup. Baloff has recorded the duration of startup in the facilities he studied. One basic oxygen furnace was still in the startup stage after forty-three months.[42,43] Hirschmann has reported continuous productivity gains over many years.[44] The previous research does not show calculations of the lost capacity during startup. The mathematical form of the Manufacturing Progress Function facilitates this calculation. Predictions of both lost capacity and duration of startup were sought in this thesis to provide a useful addition to startup knowledge.

Unknown factors in the new technology may be a prime cause of extensive startup duration and lost capacity. Measures of the degree of advance of technology have been defined for some technologies in the literature of technology forecasting.[45,46,47,48,49] Such a measure has

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[42] Baloff, "Manufacturing Startup: A Model," p. 95.

[43] Baloff, "Startups in Machine Intensive Production Systems," p. 30.

[44] Hirschmann, p. 136.

[45] James R. Bright, "A Brief Introduction to Technology Forecasting," (Austin, Texas: Pemaquid Press, 1972).

[46] Alan R. Fusfeld, "The Technological Progress Function: A New Technique for Forecasting," Technological Forecasting, Vol. I, (1970), pp. 301-312.

not been achieved for continuous steel casting technology. Nevertheless, the trade literature indicates features which permit classification of some CONCAST machines as technologically advanced, and others as technologically unchanged, when the structure of technology forecasting is applied.[50,51,52] No evidence has been discovered in the literature that the degree of technological advance effects the duration of startup, or the amount of lost capacity, in machine-intensive manufacture. Such evidence was sought in this thesis.

Other factors may also affect startup parameters. Rosenbloom noted that well qualified managers failed to anticipate problems in the initial manufacture of products based on new processes.[53] He did not extend this finding to

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[47] Erich Jantsch, "Technological Forecasting In Perspective," (Paris: OECD, 1967).

[48] Donald A. Schon, "Technology and Change," (New York: Delacorte Press, 1967).

[49] M. J. Cetron, "Forecasting and Technology," Science and Technology, (September, 1967).

[50] Iain M. D. Halliday, "Continuous Casting for Steel: New Significance and Development," (New York: United Nations Organization, Centre for Industrial Development, 1963), presented at Prague, Czechoslovakia.

[51] "33 Magazine," (April, 1973).

[52] Iain M. D. Halliday, "The Main Issues of Continuous Casting," The Iron and Steel Institute, (London: Percy Lund, Humphries & Co. Ltd., 1965).

[53] Richard S. Rosenbloom, "Facility Development for a

the process industries. It did seem reasonable to investigate whether product quality sophistication multiplies the difficulties of starting up a new process such as CONCAST. Many other factors may have an effect, but examining the six flows in Buffa's general model of a production system suggested a structure for other variables which might be included.[54] His capital equipment flow can be represented by degree of technological advance, and orders flow by product quality sophistication. People flows in machine-intensive manufacture may be best represented by management experience. Information flows are pervasive but elusive to measure. Material and energy flows are essential and prohibit continued startup if they are interrupted. Buffa's model thus provided some structure for selecting a set of variables, which encompass the whole production system, and which may individually represent causes which affect the duration of startup.

Several authors have issued practical advice on startup based upon their own experience rather than theoretical considerations, but most of these do not concentrate upon the effect of a few chosen variables. John W. Hackney[55] and

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New Product," unpublished doctoral dissertation, (Boston: Graduate School of Business Administration, Harvard University, 1960), pp. 4 and 6.

[54] A. Reisman and Elwood S. Buffa, "A General Model for Production and Operations Systems," Management Science, Vol. X, (September, 1964).

[55] John W. Hackney, "Control and Management of Capital

L. L. Farkas[56] have included short sections on startup in their books on managing new capital installations. Peter Grieve[57] and Jay Matley[58] have listed a number of items to be taken into consideration for a prompt startup, in their journal articles. None of these suggest any theory to support their counsel of experience. Richard Feldman[59] does proffer formulae for estimating startup cost and startup duration. He introduces four variables as the cause of variation in cost and duration; newness of the process and technology, newness of the type of equipment, quality and quantity of labor available, and the interplant dependency factor. He has provided coefficient values for different degrees of intensity of these variables, for use in his formulae. The variables which Feldman uses are not so different from those suggested above, but he does not show any evidence of their validity. Thus, while all of this unvalidated, practical advice may prove useful in the field, it can hardly be used as a firm foundation upon which to

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Projects," (New York: John Wiley and Sons, 1965).

[56] L. L. Farkas, "Management of Technical Field Operations," (New York: McGraw-Hill, 1970).

[57] Peter Grieve, "Plant Startup as a Career," Chemical Engineering, (September 8, 1969), pp. 148-50.

[58] Jay Matley, "Keys to Successful Plant Startups," Chemical Engineering (September 8, 1969), pp. 110-30.

[59] Richard P. Feldman, "Economics of Plant Startups," Chemical Engineering (November 3, 1969), pp. 87-90.

build a set of principles for measuring, predicting, and understanding startup.

The total literature on startup of machine-intensive, technologically new processes is rather sparse. Managers are faced with costly and extensive problems due to startup. A few gaps in the literature which this research set out to fill, as described above, can be of substantial value to managers in this situation.

Concepts and Conjectures:

The major objective of this research was to improve the measurement and prediction of startups in machine-intensive plants using new process technologies. It was hoped to reach this objective by collection and analysis of empirical data from actual CONCAST plants. This empirical approach, based upon the Manufacturing Progress Function and the learning curve, was designed to extend the boundaries of knowledge a little way beyond that available in the current literature. Such results would still be empirical knowledge, without a sound conceptual base.

All authors of literature in this area comment on the empirical nature of the phenomenon, and the lack of theory for its cause.[60,61,62,63] Baloff has discussed the subject

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[60] Wright, p. 123.

[61] Hirsch, p. 147.

under the title "Systems Adaptation", but does not indicate why the productivity increases should follow such an exact mathematical function. It was deemed desirable here to express some conjectures regarding the underlying cause of the Manufacturing Progress Function and the learning curve. Such conjectures are intended to outline the total knowledge gap in this area, and the small portion which could be charted in this research.

A concept of startup can commence with the observation that only human desire, and will, cause productivity to increase. It follows that humans perceive the possibility of increasing productivity to a certain level, and take action accordingly. It is conjectured here that Weber's law of perception applies:

> "The size of the least detectable change or increment in intensity is a function of the initial intensity . . . the stronger the stimulus, the greater the difference needs to be."[64]

Thus, if productivity is very low at the beginning of a startup, a large discrepancy from the desired level will be perceived by managers. Action will be taken to make

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[62] Conway and Schultz, p. 53.

[63] Baloff, "Manufacturing Startup: A Model," p. 37.

[64] Bernard Berelson and Gary A. Steiner, "*Human Behavior: An Inventory of Scientific Findings*," (New York: Harcourt, Brace & World, Inc., 1964), p. 95.

modifications in the production system, which will create large productivity changes. However, modifications which could create small productivity changes, will initially be overlooked, because by Weber's law, the "just noticeable difference" will be too large for them to be perceived.

The perceived productivity gap will proceed to be closed by a problem solving feedback loop. The original productivity is measured, or sensed and compared to the desired level, and the perceived discrepancy established as described. Alternatives are searched for, which will modify the existing production system, and increase productivity, to close the perceived gap. The alternatives are screened and a decision made to carry out the modification which seems best.[65] The modification is next implemented, and the feedback loop commences again, with sensing or comparing.

Many modifications are effected in a sequence, according to their expected effect and the ease of implementing them. The effect of each modification occurs gradually, and the stream of modification effects is achieved at random intervals, and in random increases in productivity. Productivity is measured as the modification effects occur, and as the perceived gap decreases, the least detectable changes become smaller. The feedback loop is repeated for ever smaller differences, with ever smaller

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[65] James G. March and Herbert A. Simon, "Organizations," (New York: John Wiley and Sons, 1958), pp. 178 and 179.

effects, until the desired steady state productivity is reached.

The modifications are implemented in all portions of the production system: equipment, raw materials, energy, product specifications, customer orders, job designs and information flows. Some modifications take total effect immediately upon implementation. Some, such as revised job design, occur gradually, according to the manual learning curve. Many are delayed in part or whole, until some other bottleneck is removed. Thus a stream of productivity increases flows in as a result of earlier decisions to modify, and they are of ever decreasing size and number.

The flow of modification productivity increases is determined initially by the perceived productivity discrepancy. Subsequently it is dependent upon the feedback loop time cycle for each modification of: comparing and perceiving the discrepancy, searching for alternatives, screening alternatives and deciding upon one, implementing, and sensing its effect. Furthermore, it is limited by the portions of the production system which are perceived to be operating well enough, and thus are frozen to further change. It is conjectured that this last perception tends to create slow productivity increases in a plant which initially starts up at a high percentage of desired productivity.

If such conjectures could eventually be confirmed, some valuable courses of action might be opened to managers. For example, the feedback loop time cycle might be drastically shortened by a Startup Modification Project Group, structured and motivated especially for rapid communication, problem solving, and modification implementation. Another set of alternatives where managers might optimize the input would be the cost of startup preplanning versus modifications during startup, so as to minimize the sum of these two plus the cost of lost capacity during startup. Proof of the conjecture that high initial productivity which might be obtained by preplanning, can freeze so much of the system into unchangeable components that the subsequent startup productivity increases will be very gradual, would be instrumental in establishing such an optimum relationship. Other specific uses of such wider knowledge might be suggested, but certainly the broad area of startup theory which has been discussed here would be of substantial value to managers, if it were confirmed.

These conjectures, about the concept underlying the mathematically accurate progress of productivity during startup, serve to outline the large amount of research which is required to illuminate this area fully. It would require the continued examination of managers' perceptions, of modification decisions, implementations, and gradual effects throughout the extensive duration of a number of startups to confirm such conjectures. Such extensive observation to achieve full explanation was not possible here.

Explanation eludes discovery with ease. Therefore, the choice of observations which would yield explanatory evidence was uncertain. Perceptions were ruled out as being exceedingly difficult, if not impossible, to observe. The productivity progress effect from each modification could be observed if this was done comprehensively for all modifications, but such a comprehensive study was too large to be contained here. It can be noted that only the actions of people create productivity growth. It follows that the action of people should be observed in order to understand this growth. Although the repetitive production and maintenance procedures which are repeated over and over again by operating men undoubtedly cause progress, this is likely a minor portion of total progress. The modification activities in a machine-intensive startup, whereby the production system is changed or modified by managers, technical staff, and operating people, are thought to create the major portion of productivity progress. Therefore, the observation of activities of people carrying out modifications was selected here in an attempt to make some initial explanatory discoveries.

Eight vignettes of CONCAST startups are included as evidence of these modification activities in an attempt at partial explanation of the foregoing conjectures. They also serve as a descriptive background for the quantitative data, by disclosing the vital components of a CONCAST machine and how it operates. These glimpses of startup were chosen from anecdotes related by managers in charge of startup, by CONCAST managers, in published reports, and in unpublished documents. They were selected to provide a variety in descriptions, of what steel producing men do during CONCAST startup. No obvious connections were made with quantitative data, in order to preserve confidentiality. The descriptive aim was to produce a series of word pictures, which would build mental images of a steel plant during startup, inside the lay reader's mind.

These vignettes were then briefly classified along the following four dimensions:

1. TYPE OF MODIFICATIONS:

   Equipment Modifications
   Supply, Materials, or Energy Modifications
   People:
      (a) training and retraining procedures
      (b) changing people
   Information Flow Procedure Modifications
   Product Mix or Order Modification
   Cash Flow

2. SECTOR OF FEEDBACK LOOP:

   Measuring and Comparing -- Find the Gap
   Search for Alternatives to Correct
   Screen Alternatives and Decide Upon One
   Implementation of the Chosen Alternatives

3. TIME SPAN:

   Time Required for Activity Described

4. PERCEPTION OF:

Gap in Productivity
Time for Modification Described

This classification of startup activities is intended to give some support to the foregoing conjectures about the cause of the mathematically accurate progress of startup. The method of descriptive data selection and classification prohibits its use as proof. However, the reader can at least ponder about the startup scene before he plunges into the more rigorous analysis of quantitative startup data. The methodology of this quantitative analysis, which will be discussed next, is designed only to probe the ability to measure and predict startup using the Manufacturing Progress Function, based upon a test of six hypotheses. It is hoped, however, that the foregoing discourse about the complete concept sets these hypotheses in perspective within the total knowledge gap.

CHAPTER III

HYPOTHESES AND METHODOLOGY

The broad gap in startup knowledge disclosed in the previous chapter presented many opportunities for discovery by research. The successful explorer facing such a broad, unmapped gap in an area first defines the particular regions and boundaries to be surveyed. Similarly, the regions of research for this project had to be defined to ensure its thorough and prompt completion. Availability of industrial data, too, bounded the opportunities for discovery. These essential boundaries of the research were established by hypotheses concerning several regions of the total, unknown area. A rigorous methodology to test these hypotheses, with the aid of available facts, was specified. The selection of particular research regions, of data, the statement of hypotheses about the data, and methodology to test the hypotheses are detailed in this chapter.

The Chosen Research Alternatives

The choice of research regions had to be appraised according to some pertinent criteria. The basic drive was to aid managers in starting up new plants quickly. This meant that measures of startup and startup duration had to be established. Without these, it would be difficult to find whether one method of startup is faster than another. Secondly, the ability to predict progress of a startup was desired. Subsequently, the various actions which might be taken to improve that progress were sought. A complete understanding of the cause of regular productivity progress would undoubtedly be very valuable for discerning which one of various available actions would accelerate startup. This, however, could hardly be accomplished without at least the prior ability to measure, and probably to predict. Thus, the choice of measurement, prediction, and some explanation, as regions for research, was determined more by the essential sequence necessary for discovery, than by the intrinsic value of these individual regions.

Measurement presented several facets for investigation. The Manufacturing Progress Function has been challenged by Levy's Function, Pegel's Function, and others. A thorough quantitative study, fitting a set of data to the first three functions, and possibly to one or two of the other challengers, would compose a comparative model investigation of some significance. However, the minute comparative measurement differences of this study were not deemed justifiable at this time. A study to determine whether productivity values might be distributed log-normally around the Manufacturing Progress regression line also showed some promise of making measurement more precise, but it, likewise, was rejected as too refined at this stage. The Manufacturing Progress Function was chosen as the measuring instrument, due to its earlier successful application and its adaptable mathematical characteristics. Its mathematical amenability allowed it to be extended to express several new startup characteristics, and so give startup measurement some new dimensions.

Investigation into prediction was based primarily upon the statistical regularity of startup data fitted to the Manufacturing Progress Function. The parameter model suggested by Baloff also appeared to be worth further efforts of development. In addition, since machine intensive processes often involve rapidly changing new technologies, an investigation into chronological trend seemed to merit attention. Although past reports did not seem to disclose as many options for research into prediction, as options for research into measurement, those above looked promising.

The relative speed of startup at different plants seemed to be the next region requiring exploration, after provision had been made for answers about the regions of measurement and prediction. Plants possess an endless number of differences, and some of these differences must cause the various startup rates. Since the initial plant utilizing a new technology often seems to encounter serious obstacles to startup, while latter plants in the same series of technology apparently avoid these obstacles with the aid of thorough documentation and experience, novelty of the technology was chosen as the first difference to investigate. The next difference identified was the experience of managers and crew at one plant compared to another. Thirdly, the number of products and their quality was observed to create differences of some consequence to plants during startup. Finally, the distinct difference between startups at plants with interrupted versus uninterrupted raw material or energy supplies was noted. These four factors arose consistently in discussions with knowledgeable people. Many other differences were pointed out, too. These included: extent of industrialization around the plant site, basic skills of the local work force, quality of equipment fabrication and plant construction, variety of staff services, and availability of cash. Another, which was frequently quoted, was simply the vigorous determination of management. Since these last items were less frequently mentioned and more difficult to determine, research was concentrated on the first four differences named.

Research into an explanation for the exceedingly regular productivity progress expressed by the Manufacturing

Progress Function could be considered, once the prior steps of measurement, prediction, and plant differences had been explored. Because explanation presented a large, difficult topic for research, it had to be limited to the conjectures, vignettes, and their analysis which were described in the last chapter.

These regions, selected for research out of the total knowledge gap, have not been demonstrated to be the very best selections out of all possible alternatives. It has been shown that they possess certain advantages over several other alternatives for making research discoveries, that may aid managers to start-up plants more quickly. This satisficing approach seems appropriate for the choice of research regions within the large, unknown area of startup knowledge.

Choice of CONCAST Technology and Empirical Data

Continuous steel casting technology has been chosen for investigation here, due to its several advantages. Narrowing the research to one technology provided for substantial comparability between sets of data. Then, continuous steel casting is a relatively new technology, but it nevertheless presented a sequence of plants stretching back over twenty years which could be researched. The startups at these plants have ranged from the extremely difficult to nearly routine, but virtually all have been started up and operated successfully. This indicated a technology which is innovative and onerous to regulate, but not esoteric. Total installations number over two hundred, so that a sufficient number of plants could be included in the sample to meet statistical requirements. Every installation is large and expensive enough so that all could be located and contacted. Also, because the plants are large and expensive, management is concerned about productivity and about the duration of startup, which is significant. As a further advantage for research, each installation possesses enough staff so that production data were likely to be available. The technology was further narrowed for comparability between plants by investigating only plants designed by one supplier, Concast, Inc. of New York and its parent Concast AG of Zurich. The CONCAST machines designed by this supplier account for the majority of continuous steel casting machines throughout the world. Added to these many advantages, the possession of some experience with the technology by the author clinched the selection.

The number of CONCAST machines from which data should be gathered was determined by statistical considerations. The central limit theorem has established that a sample size of thirty will display parameters which adequately represent the universe from which it has been selected. Thus, startup data from thirty CONCAST machines were used as the quantitative base for this research.

The particular startup productivity data to be gathered presented a simple choice. The number of tons of raw steel produced is recorded by steel companies more commonly than any other statistic. That is a basic unit of production used by this industry over most of the world. Companies have traditionally reported this statistic monthly. Consequently, the tons of raw steel cast by a CONCAST machine each month were chosen as the basic data unit, with some confidence of its availability at companies contacted for data. The number of months of production data posed the next question for decision. Thirty-six months was selected as a long enough period to encompass most startups, and about as lengthy a series of data as some companies might have available. Finally, it was necessary to adjust production for dips due to lack of sales, vacation shutdown, strikes, or other such contingencies. Since scheduled operating hours are very frequently recorded by steel companies, this piece of data was chosen for use in converting monthly tons of production to standardized monthly productivity. Thus, a set of data was defined which adequately describes productivity progress in CONCAST machines, and which was within the limitation of information available from industrial companies. The Production Data Form, shown in Exhibit 3-1, displays the form of request to the steel companies for this data.

EXHIBIT 3-1

PRODUCTION DATA FORM

Please record the Tons of acceptable Billets or Slabs produced from your Concast machine during the first 36 months of operation, or during all months of operation if you have not yet completed 36 months. Please show the scheduled operating hours for each of these months, or if this data is not available note unequal reporting periods, such as 4 week and 5 week, or vacation shutdown.

	YEAR ____		YEAR ____		YEAR ____		YEAR ____	
Month	Tons Produced	Sched. Oper. Hours	Tons Produced	Sched. Oper. Hours	Tons Produced	Sched. Oper. Hours	Tons Produced	Sched. Oper. Hours
Jan.								
Feb.								
Mar.								
Apr.								
May								
June								
July								
Aug.								
Sept.								
Oct.								
Nov.								
Dec.								

COMMENTS: ______________________________

1. Please indicate by a check mark, during which week of the first month in which you have reported production, the first billets or slabs were cast.

1st. Week ✓ 2nd. Week ____ 3rd Week ____ 4th. Week ____

2. Does your company happen to be familiar with the Manufacturing Progress Function ($Y = AX^{b}$), or its inverse, the Aircraft Learning Curve?

YES ____ NO ____

3. If so, did you use the Manufacturing Progress Function to estimate, plan or control production outputs for Concast startup?

YES ____ NO ____

Hypotheses:

This research was designed to test six hypotheses regarding measurement and prediction of startup, using the Manufacturing Progress Function. These hypotheses, which can be used by managers as a basis for prediction and control of productivity during startup, if true, now follow:

HYPOTHESIS 1: Productivity growth data from CONCAST installations will follow the Manufacturing Progress Function during startup, and regression lines will indicate high R^2 values.

HYPOTHESIS 2: The parameters 'a' and 'b' of the Manufacturing Progress Function can be forecast from productivity data during the early startup period, because of the high R^2 values, and this prediction can be a basis for management planning of the remainder of the startup.

HYPOTHESIS 3: Most managers do not forecast startup using the Manufacturing Progress Function.

HYPOTHESIS 4: Those managers who do forecast startup using the Manufacturing Progress Function have difficulty predicting parameters 'a' and 'b' accurately.

HYPOTHESIS 5: It should be possible to make increasingly more accurate predictions of the startup characteristics of the Manufacturing Progress Function, at each subsequent plant using a specific new technology. Startup characteristics are: parameters 'a' and 'b', and M.P., startup time, and lost capacity.

HYPOTHESIS 6: Four plant variables tend to have a significant effect upon the startup characteristics. The four plant variables are: degree of advance in the specific new technology, management experience, product quality sophistication, and materials and energy supply reliability.

Methodology

The methodology to test each of these six hypotheses has been stated in point form. This details the analytic procedure with some clarity, so that it can be reliably repeated by others, if they so desire. A short discussion follows the statement of methodology for testing each hypothesis, in order to indicate some of the logic and theory which were taken into account in establishing the procedure. These sections serve to specify and explain the process of analysis used in this research.

Analysis to Test Hypothesis 1:

(1) Standardized productivity tonnages were calculated by dividing monthly production tonnages by the scheduled operating hours, and multiplying by a standard number of hours, for months subsequent to first attainment of this standard number of operating hours, for North American plants.

(2) Cumulative production tons were calculated by adding the actual production in tons to each monthly date.

(3) Standardized monthly productivity tonnages were plotted against cumulative production in tons, on Log-Log graph paper.

(4) A steady state productivity value was selected through an examination of this graphical presentation of the data. It was expected that the continuous increase in productivity would appear to follow a straight line closely throughout the startup phase.

(i) The end of startup is indicated by a noticeable discontinuity in the linear trend, followed by monthly variations about some steady state level of productivity, for a subsequent period of at least twelve months. This selection of a steady state productivity from graphical data is supported by the following conditions:

(a) The last month in the regression is the first month in which productivity exceeds the chosen steady state level.

(b) Average productivity during the subsequent twelve months is approximately equal to this steady state value.

(c) Productivity during any one of the subsequent twelve months does not exceed the steady state productivity level by more than 10%.

(d) The least squares regression line through the following twelve months has a slope less than one quarter of 'b' during startup.

Where steady state productivity for a twelve month period was not evident in the graphical data, the value was chosen in one of the two ways following:

(ii) The value for machines which have operated for at least one year beyond the data gathered was chosen within / 10% of the productivity level which has actually been achieved. This value was obtained from Concast Inc., Concast AG, or the steel company.

(iii) The value for machines which had not yet operated for at least one year beyond the data procured were chosen equal to the highest reported productivity value, / 10%.

(5) Percent productivity efficiency for each month was calculated by dividing the standardized production tonnages by the steady state productivity value for the plant.

(6) Values in (2) and (5) were converted to logarithms.

(7) The logarithmic values obtained in (6) were entered into the revised "LNREG 1" linear regression program in the BASIC time sharing computer system, so as to regress them against the log transformed Manufacturing Progress Function:

$$\text{Log } Y_s = \text{Log } a \ / \ b \text{ Log } X_s \qquad (2)$$

(8) The statistical characteristics of this regression, including R^2, 'a', and 'b', were recorded.

(9) Each set of data was tested for auto-correlation by the Durbin Watson test.

(10) In a few cases where correlation with the Manufacturing Progress Function was not high, or where auto-correlation as indicated by the Durbin-Watson test was high, tests of productivity data were made against Levy's Function and Pegel's Function, to find whether these explained the progress of productivity better.

LEVY'S FUNCTION: $Q_q = P (1 - e^{-(a + hq)})$ (3)

PEGEL'S FUNCTION: $P_x = A (1 - a^{(x - 1)}) + B$ (4)

These last two functions can be converted into symbols consistent with those of the Manufacturing Progress Function. (For an example, see Exhibit 5-7, page 127.)

Discussion of Methodology for Hypothesis 1:

Although this methodology uses the relatively standard linear regression to fit productivity data to the Manufacturing Progress Function in a manner which has been done before, it nevertheless seems appropriate to comment on preparation of the data for analysis, and upon the statistical characteristics of the procedure. Heterogeneous data from the field require some recalculating to make it comparable from month to month, and from machine to machine. Selection of steady state productivity is not an obvious choice, and, in fact, is disclaimed by some of the authors mentioned earlier. The statistical procedure and parameters of linear regression, while well defined in the literature, are not instantly recalled even by a person experienced in this field. Explanation of these points will help support the methodology which has been specified.

Productivity was standardized by dividing monthly production in tons by the scheduled operating hours for the month. This was done because operating hours might have been substantially reduced in some months if sales were not sufficient to distribute the total production available. Also, a vacation shutdown, or strike during the month, would have the same effect of reducing scheduled operating hours. Clearly, less steel would be cast in fewer hours, and so the standardized productivity expresses a value for a standard number of monthly hours, such as 672 hours or 720 hours. However, production in months prior to first attaining this standard number of scheduled hours was not adjusted, because usually every effort is made to operate around the clock. Due to inability to produce, this may not be achieved. Therefore, actual tons of production are the proper measure of productivity for the early months. Additionally, the

(7) The number of months required for the final 'a' to lie within the range 'a' ± 2% has been reported as the period required to obtain a 95% confidence level estimate of 'a'.

(8) The percentage confidence limits of 'a' and the R^2 that were obtained with the number of months have been reported.

(9) The number of months in the regression, and the R^2 for each 5% improvement in the confidence limits at the 95% confidence level were intended to have been reported, but this proved inapplicable.

Discussion of the Methodology for Hypothesis 2:

The analysis incorporated in this methodology utilizes a strictly statistical procedure, which implicitly postulates several standard assumptions. It assumes that any single point is taken from a universe which is normally distributed about the theoretical point that is subsequently calculated on the regression line. Secondly, it assumes that each set of startup data possesses homoscedasticity about the regression line, for all points in the sequence. That is, it implies that the postulated normal distribution for each point possesses the same amount of scatter, or strong market may progressively remove the constraints, including the final one, as they occur, but this does not seem to be common. Since the ultimate mechanical capacity of the CONCAST machine could not be used for a theoretical steady state productivity, which occurs instead due to a variety of lesser constraints, the definition of this state had to be pragmatic. The statements defining steady state productivity in the methodology were arrived at in just that way. They are believed to provide a practical and reliable definition of steady state productivity in light of the actual performance of operating CONCAST machines.

It should next be noted that productivity tonnages were all converted to a percentage of this steady state productivity. This was done by dividing both the standardized monthly productivity tonnages, and the actual tons of cumulative production, by the steady state productivity tons. These values were then called Percent Productivity Efficiency (PPE). This was done especially to ensure confidentiality of production data for all the steel companies who so generously contributed. It has the added advantage of simplifying and aiding comparability of data, and analyses between machines.

The logarithms of the standardized, disguised, monthly productivity data were then regressed against the logarithms of cumulative tons production, using a standard computer linear regression program. This linear regression[1] calculated a line which minimizes the sum of squared deviations of the logarithm of the actual monthly standardized productivity values, expressed as FPI, from the calculated regression line. This least squares criterion has traditionally been shown by the Gauss-Markov theorem to be, and is accepted as the criterion for best fit.[2] Once the regression lines were established in this manner, certain standard parameters were easily calculated, and these, too, were provided by the computer.

The parameters can be briefly described for convenience here. The regression line is generally considered to commence at the intercept 'a', where it intersects the 'y', productivity, vertical axis. Using logarithmic coordinates, this 'a' value actually represents the monthly productivity for the first ton of production, since the logarithm of one equals zero. Productivity climbs upward from point 'a', along slope 'b' of the regression line. This slope expresses the increase in percentage productivity for each unit increase in cumulative production, both on a logarithmic scale. It could be used to calculate the

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[1] See for example, Wilfred J. Dixon and Frank J. Massey, Jr. Introduction to Statistical Analysis, Third Edition (New York: McGraw-Hill Book Co., 1969), pp. 193-217.

[2] Ronald J. Wonnacott and Thomas H. Wonnacott, Econometrics (New York: John Wiley & Sons, 1970), p. 21.

Manufacturing Progress, M.P., since 2^b equals M.P. The coefficient of determination, R^2, can be used to determine how well the calculated regression line fits the data. It represents the percentage of squared deviations about the mean value of productivity, which is explained by the regression line. It was calculated by finding the sum of squared deviations of theoretical productivity points on the regression line about the mean, and dividing that total by the sum of squared deviations of actual points, about the mean. All points will fall on a regression line that fits perfectly, and R^2 will equal 1.00. These are the chief measures obtained by linear regression analysis, and it is expected that the above explanations are sufficient for comprehension of the analysis.

However, the description of a good fit, represented by a high R^2, as explained above, can be misleading in the event that auto-correlation is present. Auto-correlation occurs where one error influences the next error of an actual point in relation to the regression line; and so a series of actual points follow consecutively, first on one side of the regression line, and then on the other side. Where auto-correlation exists, it indicates that the regression line is not really a good representation of the data, and some other function may fit better. The Durbin-Watson statistic measures the amount of auto-correlation, by totalling the sum of error first

It is the correctness of the underlying assumptions which primarily influences the analysis. No doubt, it would be preferable if tests were made to show whether these are in fact justifiable, but the effort to carry out such tests would likely be extensive. If the assumptions are incorrect to a substantial degree, this situation would be disclosed by inaccurate predictions from the early months data, so it does not seem essential to conduct the separate tests for the assumptions. This reasoning indicates that obtaining accurate predictions depends not only upon high R^2 values, but upon meeting all of the above assumptions as well. If such conditions exist in the data, the methodology described above, furnishes a good basis for prediction indeed.

Test of Hypotheses 3 and 4:

It was expected that most managers do not use the Manufacturing Progress Function. This has merely been reported to confirm or disprove Hypothesis 3.

Those managers who did forecast 'a' and 'b' in using the Manufacturing Progress Function, were asked for their forecast values. These were compared to actual values to find how accurately they did predict 'a' and 'b'.

These hypotheses had to be corroborated just to make sure that managers do not already use the Manufacturing Progress Function, and so have a satisfactory instrument for five months, etcetera, up to the 'N' months available in each set of productivity data, were regressed against the Manufacturing Progress Function.

(2) The statistical values for 'a', 'b', S_b, $\bar{Y}$, S_y, and R^2 were recorded for each regression.

(3) The number of months required for the final 'b' to lie within the range 'b' $+ 2\ S_b$ has been reported, as the period required to obtain a 95% confidence level estimate of 'b'.

(4) The percentage confidence limits of 'b', and the R^2 that were obtained with this number of months, have been reported.

(5) The number of months in the regression and the R^2 for each 5% improvement in the confidence limits at the 95% confidence level were intended to have been reported, but this proved inapplicable.

(6) The values for $+ 2S_a$ and $-2S_a$ were calculated by finding the intercept of the line through $\bar{Y} + 2S_y$ with the slope '$b - 2S_b$', and through $\bar{Y} - 2S_y$ with slope of '$b + 2S_b$', respectively.

(7) The number of months required for the final 'a' to lie within the range 'a' $\pm 2S_a$ has been reported as the period required to obtain a 95% confidence level estimate of 'a'.

(8) The percentage confidence limits of 'a' and the R^2 that were obtained with the number of months have been reported.

(9) The number of months in the regression, and the R^2 for each 5% improvement in the confidence limits at the 95% confidence level were intended to have been reported, but this proved inapplicable.

Discussion of the Methodology for Hypothesis 2:

The analysis incorporated in this methodology utilizes a strictly statistical procedure, which implicitly postulates several standard assumptions. It assumes that any single point is taken from a universe which is normally distributed about the theoretical point that is subsequently calculated on the regression line. Secondly, it assumes that each set of startup data possesses homoscedasticity about the regression line, for all points in the sequence. That is, it implies that the postulated normal distribution for each point possesses the same amount of scatter, or

(6) A distribution of Startup Time was compiled, and the mean, median, and range reported.

(7) Lost Capacity in years was calculated for each point, according to the following formula:

$$\text{LOST CAPACITY} = b\,X_{FC} / (1 - b)\,Y_{FC} \qquad (9)$$

(8) A distribution of Lost Capacity in months was compiled, and the mean, median, and range reported.

(9) The startup characteristic values 'a', 'b', M.P., startup time, and lost capacity were arranged in chronological order, and tested non-parametrically by the Spearman Rank Correlation Coefficient, to discover whether there is a trend, or order in these values, as the technology becomes established. Where a trend is evident by this test, its level of significance has been reported.

(10) Hypothesis 5 has been tested by examining the predictions of the startup characteristics which can be obtained with the parameter formula, distributions of lost capacity and startup time, and trends in the five startup characteristics, to find whether these predictions are increasingly accurate as the technology becomes established.

It is the correctness of the underlying assumptions which primarily influences the analysis. No doubt, it would be preferable if tests were made to show whether these are in fact justifiable, but the effort to carry out such tests would likely be extensive. If the assumptions are incorrect to a substantial degree, this situation would be disclosed by inaccurate predictions from the early months data, so it does not seem essential to conduct the separate tests for the assumptions. This reasoning indicates that obtaining accurate predictions depends not only upon high R^2 values, but upon meeting all of the above assumptions as well. If such conditions exist in the data, the methodology described above, furnishes a good basis for prediction indeed.

Test of Hypotheses 3 and 4:

It was expected that most managers do not use the Manufacturing Progress Function. This has merely been reported to confirm or disprove Hypothesis 3.

Those managers who did forecast 'a' and 'b' in using the Manufacturing Progress Function, were asked for their forecast values. These were compared to actual values to find how accurately they did predict 'a' and 'b'.

These hypotheses had to be corroborated just to make sure that managers do not already use the Manufacturing Progress Function, and so have a satisfactory instrument for measuring and controlling startup. If a few managers do use it, then it seemed desirable to show whether they can forecast the startup accurately in advance, by predicting the parameters. The value of this research would be demonstrated if it were shown that managers do not now use this function for measurement, or else do not predict very well with it; because then the measurement and prediction procedure of the research would clearly provide a distinct improvement over actual management practice.

Analysis to Test Hypothesis 5:

(1) Values of 'a' and 'b' were regressed against the formula:

$$M.P. = s - t \text{ Log } a \qquad (5)$$

where $M.P. = 2^b$, and means Manufacturing Progress, and 's' and 't' are parameters of the formula.

(2) Since the R^2 in this parameter formula was high, for all points combined, then the first three plants, four plants, etcetera, in chronological order, were regressed against the above formula. The estimates of 's' and 't' along with their accuracy as estimates for 's' and 't' for all plants, have been reported.

(3) Since these estimates of 's' and 't' were accurate within the first few years of this chronological order, values of M.P. were calculated for one sample plant, which was started at each subsequent two year interval. Three values of M.P. were calculated for each of these plants, using the 'a' from the regression for three months, six months, and nine months of productivity data.

(4) These M.P. values have been compared with M.P. values calculated from 'b' in the Manufacturing Progress Function regression to those points, to determine which method is most accurate.

(5) Startup time in years was calculated, for each plant, according to the following formulae, using the regression line complete to steady state productivity:

$$\text{Log } X_{FC} = (\text{Log } Y_{FC} - \text{Log } a) / b \qquad (6)$$

where the subscript 'FC' means at full capacity, or steady state productivity, and

$$\overline{Y}_{FC} = (1 - b) Y_{FC} \qquad (7)$$

where $\overline{Y}_{FC}$ equals cumulative average productivity to full capacity, tons per month, then

$$\text{Startup Time} = X_{FC} / 12 \overline{Y}_{FC} \text{ years} \qquad (8)$$

(6) A distribution of Startup Time was compiled, and the mean, median, and range reported.

(7) Lost Capacity in years was calculated for each point, according to the following formula:

$$\text{LOST CAPACITY} = b\, X_{FC} \,/\, (\, 1 - b\,)\, Y_{FC} \qquad (9)$$

(8) A distribution of Lost Capacity in months was compiled, and the mean, median, and range reported.

(9) The startup characteristic values 'a', 'b', M.P., startup time, and lost capacity were arranged in chronological order, and tested non-parametrically by the Spearman Rank Correlation Coefficient, to discover whether there is a trend, or order in these values, as the technology becomes established. Where a trend is evident by this test, its level of significance has been reported.

(10) Hypothesis 5 has been tested by examining the predictions of the startup characteristics which can be obtained with the parameter formula, distributions of lost capacity and startup time, and trends in the five startup characteristics, to find whether these predictions are increasingly accurate as the technology becomes established.

Discussion of Methodology for Hypothesis 5:

Several relationships between the startup characteristics from different plants, which can be utilized for prediction, are anticipated by the analysis for Hypothesis 5, which has been detailed above. This contrasts with the prediction method utilized in the analysis for hypothesis 2, where early data from each plant were used independently to predict the final outcome of the startup. One of the interplant relationships sought in this analysis was the parameter model connection between intercept and Manufacturing Progress, slightly revised from the model suggested by Baloff. Comparison of the distribution of two new measurement dimensions, startup time and lost capacity, was included as another possible guide to managers wishing to predict the length of their CONCAST startup, based upon earlier experience in the technology. Finally, an inspection of all five startup characteristics for chronological trend was anticipated to provide some guidance for predicting these values at later plants. The procedure used to test for relationships of these characteristics between CONCAST plants in the sequence may be clarified by the following comments:

The parameter model, here, has been revised to calculate M.P., whose values range from 1.0 to a maximum possible of 2.0, rather than to calculate Baloff's P.I., whose values can be distributed from 1.0 to .50. Thus, two new parameters, 's' and 't' are used, and a negative sign falls in front of the second term in the equation. The purpose of both models is the same: to predict the complete startup based upon intercept 'a'. This could be done in the aircraft learning curve, where the number of labor hours to assemble the first aircraft was often known. It would be of equal value for prediction in machine intensive manufacture, if the value 'a', which is monthly productivity for the first unit, was not completely theoretical. This presents some difficulties which will have to be discussed along with the research results. The analysis to discover the parameter model relationship itself is the same linear regression procedure which was discussed for hypothesis 1, and [illegible]o requires no further comment here.

Contrasted with the relative sameness of the parameter model, startup time represents a new startup characteristic which will certainly give a new dimension to measurement, in addition to the hoped for improvement in prediction. The formulae shown for calculating it are obtained by integrating the area under the arithmetic startup curve, to find the average productivity, as developed by Conway and Schultz.[4] A slight inaccuracy exists in this integration, which is seriously compounded for short startup periods. The integration assumes a smooth curve, whereas the data

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[4] Conway and Schultz, p. 40.

produce a series of straight line chords between monthly productivities, and these chords represent a particularly large truncation in short startups. This calculation can be refined, but it is accepted as adequate for the purpose here. A distribution of startup times, for a number of plants in the same technology, readily provides the range, median, and mean of startup times, which it seems will guide managers in predicting this characteristic, at least for this one technology.

Lost capacity is the other new startup characteristic which supplies an added dimension to measurement. Its calculation contains nearly the same inaccuracies as noted for startup time, but it, too, is felt to be calculated accurately enough at this time. Prediction of the magnitude of this startup characteristic, at least within the range reported for the CONCAST technology, is expected to be an aid to managers, and of particular significance to financial men.

A rank order in the chronological sequence of each of the five startup characteristics was the final relationship which was sought. The search for this rank order might not be very meaningful within the sequence of the first three characteristics, 'a', 'b', and 'I.P.'; however, a strong intuitive feeling arose, that startup time and lost capacity really ought to decrease in magnitude, as the technology becomes better known and established. The non-parametric statistical test provided by the Spearman Rank Correlation Coefficient was used to qualify the significance of those chronological trends which did exist. Proof of such a trend was expected to assist in prediction, although it does not give an interval scaling relationship by which probable values of later characteristics could be calculated.

Just which of these four relationships between startup characteristics, from the sequence of plants in the CONCAST technology, would provide the greatest assistance to prediction, could not be clear in advance. It did seem that one or more of them could more nearly show a manager what the final startup measurements would be, at an early date in the startup.

Analysis to test Hypothesis 6:

(1) Each plant was classified into one of two classes for each of four variables, as follows:

1. Degree of Advance of Technology:

TECHADV 0 = Identical

TECHADV 1 = Advance in technology

2. Management Experience:

MGMTEXP 0 = 2nd or more machines

MGMTEXP 1 = No prior machine

3. Product Quality Sophistication:

PRODQUA 0 = Low carbon steels

PRODQUA 1 = alloy and/or stainless steel

4. Materials and Energy:

MATENRG 0 = adequate liquid steel and power

MATENRG 1 = constrained liquid steel and power

(2) The classifications of the four variables were defined as follows:

TECHADV 0 = The design of the CONCAST machine is identical, in terms of dimensional characteristics of its product, as defined in TECHADV 2, to a prior operating machine, which has completed 24 months of startup.

TECHADV 1 = One of the following:

(i) The design of the CONCAST machine is changed from previously installed machines. The design change imparts some desirable characteristics to the product, as described in the Concast AG Register of Machines Installed, dated July, 1972.[5] Dimensional characteristics are here defined as: (a) number of strands, (b) strand curvature, (c) perimeter dimensions, or strand cross section.

(ii) The design of the CONCAST machine is changed from any previously installed machine in which the first cast was made more than 24 months earlier than its own first cast. Design change is defined as in (i) above. This classification (ii) provides for machines with a recent technological advance, which must be started up without the benefit of learning from at least 24 months of startup of a similar machine.

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[5] Concast AG, *CONCAST, Continuous Casting Machines for Steel, 7/1972* (Zurich: Concast AG, Toedistrasse 7, Postfach, 1972), pp. 1-11.

A discussion of the development of the technology has been provided in Chapter VII in order to illustrate the significance of this variable, as a measure of the degree of advance of this particular technology.

MGMTEXP 0 - The company owning the machine for which data have been obtained has started up and operated one or more CONCAST machines previously.

MGMTEXP 1 - The machine for which data are reported is the first CONCAST machine which the company owning it has started up.

PRODQUA 0 - The machine is used for casting carbon steels only, as recorded in the Concast AG Register of Machines Installed, dated July, 1972.

PRODQUA 1 - The machine is used to cast alloy and/or stainless steels, as recorded in the Concast AG Register of Machines Installed, dated July, 1972.

MATENRG 0 - Installed steel melting capacity, and uninterruptable power supply, provided exclusively for the CONCAST machine, were adequate throughout the startup period, to supply liquid steel, as required, up to the steady-state productivity level.

MATENRG 1 - The company contributing data reported that installed steel melting capacity and/or uninterruptable power supply, provided exclusively for the CONCAST machine were inadequate for some significant portion of the startup period, to supply liquid steel as required, up to the steady state productivity level.

(3) Linear hypotheses[6] that the four plant variables

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[6] Chi-Yuan Lin and William L. White, "Four Procedures for Testing Linear Hypotheses," Industrial Management Review, Vol. 10, No. 1, pp. 13-30.

tend to have an effect upon each of the five plant startup characteristics were formulated as follows:

$$Y_{1n} = k_1 + c_1\,\text{TECHADV0} + c_{11}\,\text{TECHADV1} + c_2\,\text{MGMTEXP0} + c_{12}\,\text{MGMTEXP1} + c_3\,\text{PRODQUA0} + c_{13}\,\text{PRODQUA} + c_4\,\text{MATLNRG0} + c_{14}\,\text{MATLNRG1} \qquad (10)$$

where: Y_{1n} = 'a', intercept, for plant 'n', where 'n' = 1 to 50 Concast plants, and c_1, c_{11}, c_2, c_{12}, c_3, c_{13}, c_4, c_{14} are regression coefficients.

However, since the plant variables are nominal, or classificatory only, and do not have interval scale values, they can be given only '0' and '1' values, as dummy variables.[7] The '0' value dummy variables can have no effect on Y_1, and will not have real coefficients, so the equation can be reduced as follows:

$$Y_{1n} = k_1 + c_{11}\,\text{TECHADV1} + c_{12}\,\text{MGMTEXP1} + c_{13}\,\text{PRODQUA1} + c_{14}\,\text{MATLNRG1} \qquad (11)$$

Similarly, linear hypotheses for the other startup characteristics were formulated as follows:

$$Y_{2n} = k_2 + c_{21}\,\text{TECHADV1} + c_{22}\,\text{MGMTEXP1} + c_{23}\,\text{PRODQUA1} + c_{24}\,\text{MATLNRG1} \qquad (12)$$

$$Y_{3n} = k_3 + c_{31}\,\text{TECHADV1} + c_{32}\,\text{MGMTEXP1} + c_{33}\,\text{PRODQUA1} + c_{34}\,\text{MATLNRG1} \qquad (13)$$

$$Y_{4n} = k_4 + c_{41}\,\text{TECHADV1} + c_{42}\,\text{MGMTEXP1} + c_{43}\,\text{PRODQUA1} + c_{44}\,\text{MATLNRG1} \qquad (14)$$

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[7] Wonnacott and Wonnacott, pp. 68 [illegible]

$$Y_{5n} = K_5 + c_{51}\,\mathrm{TECHADV1} + c_{52}\,\mathrm{MGMTEXP1} + c_{53}\,\mathrm{PRODQUA1} + c_{54}\,\mathrm{MATENRG1} \qquad (15)$$

where:

Y_{2n} = 'b', slope for plant 'n'
Y_{3n} = L.P., for plant 'n'
Y_{4n} = Startup time, for plant 'n'
Y_{5n} = Lost capacity, for plant 'n'

(4) These formulae were regressed by stepwise multiple regression using dummy variables. The startup characteristic values used for 'a' and 'b' were those calculated in the test for hypothesis 1, section (1) and L.P. was calculated from the 'b' in (8). Values for startup time and lost capacity were those calculated in the test for hypothesis 5, sections (5) and (7) respectively. Dummy variables were given '0' or '1' values according to their classification by definitions in section (2) above. These values were inserted into the SPSS (Statistical Package for the Social Sciences) Stepwise Multiple Regression program, on the University of Manitoba IBM 360/65 computer.[8] This program calculated regression coefficient values for

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[8] Norman Nie, Dale H. Bent and C. Hadlai Hull, SPSS: Statistical Package for the Social Sciences (New York: McGraw-Hill Book Co., 1970), pp. 174-195.

all the 'c' parameters in the formulae above,
'F' ratios for each.

(5) Regression proceeded by omitting one dummy vari
at a time in order to avoid the problem
multi-collinearity.[9,10] After estimates of
coefficients had been obtained, by omitting each
the variables in turn, then it was intende
obtain the true values of the coefficients
principal components analysis, but this refinem
subsequently proved unnecessary.

(6) The level of significance of these dummy variab
has been reported according to the F-ratio achie
for each. It was these levels of significance wh
determined whether the plant variables have
effect on the plant startup characteristics
hypothesized.

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[9] Daniel B. Suits, "Use of Dummy Variables
Regression Equations," Journal of the Americ
Statistical Association, Vol. 52, No. 280
1957), pp. 548-551.

[10] Lucy Chao Lee, "On Dummy Variables,"
Working Paper (Urbana, Illinois: Unive
Illinois, May 1973), pp. 1-15.

Discussion of Methodology for Testing Hypothesis 6:

Since the four plant variables have been introduced rather abruptly into this hypothesis and the methodology for testing it, some continuation of the discussion begun in the last chapter, about Buffa's general model for production systems, and these variables in relation to his six model flows, may make this introduction less precipitous. Such a discussion can show that the flows of the general model can be utilized to represent comprehensiely the difference between plants. The four variables chosen to act as proxies for the differences in four of these flows can be inspected to discover why they act as good substitutes. The propriety of using linear hypotheses, and the scaling limitation leading to dummy variables, are then worth commenting upon. Finally, some brief remarks about the statistical properties of the multiple regression procedure will be in order. Although the technical intricacies of the procedure will thus be dealt with rather summarily, this is thought to be preferable to the tediousness of a complete statastical exposition.

The whole procedure of analysis is based upon Buffa's general model for production systems, which sets a comprehensive representation of the production area into context of the total organization. This model was chosen because it is thoroughly comprehensive, and because it has received wide circulation and acceptance as a cornerstone concept of Buffa's successful test.[11] The six flows from the model are selected for analysis, because at a new CONCAST plant, everything related to the production system must enter the system through one of these flows, either just before, or else during, startup. The objective in observing these flows was to isolate the key differences between plants, of each of the flows, and select a variable in each case which adequately represents just this isolated difference. Two flows, cash and information, have been deleted from the list, because no simplified way for defining proxies and gathering data could be devised. The four variables defined in the foregoing procedure for analysis were selected as proxies for the other four flows, as follows:

FLOW	PLANT VARIABLE
Capital Equipment Flow	Degree of Advance of Technology
Population Flow	Management Experience
Orders Flow	Product Quality Sophistication
Materials or Energy Flow	Materials and Energy Supply

These variables are thought to provide sufficient scope for an initial investigation, if they do in fact represent the essential differences between the flows at different plants.

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[11] Elwood S. Buffa, *Basic Production Management* (New York: John Wiley & Sons, 1971), p. 29.

A discussion of each, in turn, will develop the argument for using them as proxies for the differences, so that when combined with the comprehensive qualities of the model, they can be expected broadly to represent plant differences.

There is no doubt that the degree of technological advance outlines one of the differences in capital equipment. Yet many other differences exist. Physical size, arrangement of components, extent of instrumentation and control, and type of product, whether billet, slab, or bloom, all constitute differences in the capital equipment. However, these other differences are generally known factors, which do not raise questions, and so extend startup. It may be that some untried components, such as electronic instruments, are introduced with the capital equipment, and these may create unknown difficulties, but such items are coincidental. The real changes consist of those configurations which are introduced into the CONCAST machines to provide more desirable dimensional characteristics to the cast steel, and so improve the performance of that task which is done uniquely by the machine. It is these changes which create unknowns, that lie at the center of the system, and are difficult to solve. These are the capital equipment differences which affect startup rates from plant to plant. The present Hypothesis 6 is really based upon the belief that the degree of technological advance, as defined, does represent the major difference in capital equipment which affects startup, as reasoned above.

The second variable, management experience, has been selected as the proxy to represent the major differences in population flow to the CONCAST plant, with somewhat similar reasoning, as follows: Management decides which problems will be solved during startup, and how; the problem solutions create productivity increases; the particular decisions made by one management, accompanied by their speed of implementation, may have a significant effect upon the rate and duration of startup. It might be noted here that unknowns and uncertainties can be divided into two sets. One set is due to unknown factors at each step in the sequence of technological advance. This set was taken into account by the plant variable, degree of technological advance. The other set is due to lack of knowledge about the machine, also about the process, by people at the site. A management without experience with a CONCAST machine is subject to the second set of unknowns and uncertainties. A management which has started up at least one other CONCAST machine has management experience, and is not subject to this second set of uncertainties. It can be argued that it is just as necessary for the hourly crew to have experience. Doubtless, this argument possesses some validity. Experience of hourly men differs, however, because an experienced management can specifically instruct an inexperienced crew, and teach the men in it the necessary operating actions. Frequently, the reverse is much more difficult, if not impossible. Likewise, experience by either group, in other technologies, may help, but will not substitute for CONCAST experience. Similarly, education, culture, attitudes, artisan and administrative skills can cause differences in the people. But none of these seem to create the difference of population flow into a new plant, as does management experience in starting up an earlier CONCAST machine.

The third variable, product quality sophistication, the proxy for orders flow, presents an easier selection to justify. Since steel is made in batches which are homogeneous within each batch, but vary primarily in chemical analysis between batches, chemical analysis can be chosen as the difference. The only difficulty arises in reducing the number of variable classifications from the many analyses of steel cast at any plant, down to only two. The choice of carbon steel as one classification, with alloy and/or stainless as the other, oversimplifies, but it relies on the relative properties of these two classifications which affect continuous casting. Carbon steel tends to have fairly equal melting point and heat conductivity values for all grades, whereas there are wider differences in these properties in alloy and/or stainless steel, from grade to grade. Although this choice of two classifications vastly oversimplifies, as was noted, and in addition does not provide for a count of the variety of analyses cast, nevertheless, product quality sophistication is very likely the best two-classification proxy available for the differences in orders flow.

The choice of the materials and energy supply variable can be dismissed even more briefly. Lack of liquid steel due to power shortage, or due to lack of capacity where there is enough power to melt it, will clearly delay CONCAST startup. It could be questioned whether the quality of steel, or the schedule of its delivery to the CONCAST machine will have a serious effect. Both could, but liquid steel quality tends to be well controlled in the mature melting technology, and, while scheduling individual heat deliveries poses a problem, this usually improves at all plants as time proceeds. If there is not enough liquid steel capacity, however, productivity simply does not progess, so the choice of the materials and energy supply variable appears to be valid.

Thus, the four plant difference variables are defined and justified. They have been selected as proxies for the differences in four of the six flows in Buffa's comprehensive model of the production system. It is therefore believed that they represent at least some of the significant differences between plants during startup. Discussion of each of these variables in Chapter VII will provide further evidence of their validity, in light of actual data, and other information gathered from CONCAST plants. Now, some remarks must be made about the analytic procedure through which these variables are applied.

The analysis is based upon five linear hypotheses, with one for each startup characteristic. No evidence has been submitted to show that these should have a linear relationship, but then no evidence is available to indicate a quadractic, cubic, or more complex relationship, either. Relying upon the principle of parsimony, Occam's razor, the linear hypotheses were proposed as the simplest form by which to investigate whether these plant variables are a significant cause of the different startup characteristic values from plant to plant.

The dummy variables, too, which are used for these plant variables in the linear hypotheses, are a creation of scaling necessity, rather than a choice of virtue. Since this classification is truly the highest degree of scaling which can be achieved for these variables, with the information available, then the dummy variables are an accurate presentation of that knowledge.

Finally, the choice of the multiple regression procedure, for analysing the linear hypotheses with dummy variables, along with its ramifications and technicalities, will bear some remarks. Lin and White indicate that this is the right analytic method for the type and extent of data available. The procedure goes forward, much like linear regression, with the first variable creating a line, the second a plane area, the third a three-dimensional body, and so on, into the unimaginable multi-dimensions. Although the mathematics become extensive, they are similar to linear regression using least squares fit, and are fortunately carried out on computers by standard programs. In this case, the Statistical Package for the Social Sciences was used. Some of the hazards and difficulties in ascertaining the true significance and coefficient values have been pointed out and foot-noted in the procedure for analysis, so nothing more will be said about them here. Multiple regression with dummy variables was an available procedure which could do the necessary analytic job.

This analytic procedure was used in an initial attempt to show the differences between plants during startup. The intent to make the plant variables comprehensive has been shown. Although there are many open avenues remaining in the reasoning, this methodology appeared to hold promise for disclosing the significant effects by one or more of the chosen variables.

The foregoing pages in this chapter have described the selection of research alternatives, the selection of CONCAST technology, the six hypotheses, and the analysis to test these hypotheses in very considerable detail. This exposition of the methodology is now complete, and the descriptive research findings, written as vignettes, follow immediately in Chapter IV.

CHAPTER IV

CONCAST STARTUP IN ACTION

Smoke, sound, steam, and white hot steel sear an image into the melt shop superintendent's senses. A hundred solved problems lurk in his memory. A paler shadow of these vivid scenes silhouettes the following pages, to flesh out the bare numbers of productivity growth, with startup action. A brief history, a description of the continuous steel casting process, and of the CONCAST machine begin this chapter. These descriptions are followed by eight vignettes, which portray action-packed modifications that solve startup problems, and increase productivity. A short analytic examination of these modifications, according to the conjectural problem-solving framework which was advanced in Chapter III, summarizes these verbal pictures of CONCAST startup in action.

The Concast Process and Machine

Endless streams of solid cast steel flow from a continuous steel casting machine, when startup has been completed. The first cast, on the first day, is more likely to show liquid steel spilling all over the machines from a breakout. Producing a solid slab or billet by pouring steel into the bottomless continuous casting mold, is much more difficult than by pouring steel into the traditional ingot mold which has a bottom. But that is the essence of the continuous steel casting process. A brief history of this steelmaking process, followed by a description of its major features, and of the CONCAST machine, may facilitate a mental picture of the ensuing startup scenes.

The history commences when Sir Henry Bessemer reasoned during the 1850's that if steel could be cast, or frozen, in its finished continuous sheet form, much advantage could be gained. He obtained a patent for such a process in 1857. He described to the Iron and Steel Institute in 1891, how he had poured the molten steel between two chilled horizontal rolls, to produce steel 1/10 of an inch thick. Sir Henry pointed out that due to the rapid cooling, the crystal size was small. Therefore the steel was tough and malleable. For the same reason, no scale had formed. Having pointed out the many advantages of casting the steel continuously in its final form, so that no hot rolling was required, he left it to the judgement and discretion of others, how they resolved the remaining difficulties.[1] So the ultimate goal

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[1] Sir Henry Bessemer, "On the Manufacture of Continuous Sheets of Malleable Iron and Steel,

of continuous casting was demonstrated; to cast in finished, hot rolled size.

Many steps have been taken since, to advance the technology in the direction advocated by Sir Henry. Continuous casting of copper and aluminum, with their higher thermal conductivities, was achieved by Siegfried Junghans in the 1920's. He was able to continuously cast steel with a relatively crude model machine during the 1930's.[2] Irving Rossi acquired the patent rights, outside of Germany, from Junghans in 1937. He motivated many improvements in continuous casting during the succeeding thirty-five years.[3] By 1950, pilot plants for continuous casting of steel had been built in several countries. The oldest production machine in continuous operation was installed in 1952, at Atlas Steel Ltd., Welland, Ontario. This step heralded a fast expansion in commercial use of the new process.

The 1950's and 1960's saw continuous casting grow from pilot plant experimentation to 12% of world raw steel

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Direct from Fluid Metal," *Proceedings of the 1891 Autumn Meeting of the Iron and Steel Institute*, (London: 1891). Reprint, The Iron and Steel Institute, "Continuous Casting of Steel, Special Report Eighty-Nine," Proceedings of the Autumn General Meeting, November, 1964, (London: Percy, Lund, Humphries and Co. Ltd. for the Iron and Steel Institute, 1965), Frontispiece.

[2] Concast, Inc., "*Familiarization Manual*" (New York, Concast, Inc. 1968), p. 1.

[3] "Rossi Re-enters Continuous Casting Ring, Armed With A New Product -- Rocast," *33 Magazine*, Vol. 11, No. 7, July 1973, p. 26.

production.[4] The technology advanced rapidly in versatility, reliability, and number of installations during that time. Several suppliers of continuous steel casting machines, such as Koppers, Inc. of Pittsburgh and Demag of Germany, participated in supplying machines for these installations. But Concast, AG of Zurich, and its subsidiary, Concast, Inc. of New York, the companies developed by Rossi, sold the most machines (over 200 by 1973) and have been in the forefront of advancing the technology. The characteristics of the steps in this advance will be discussed more fully in Chapter VII. But here, it will be sufficient to include a description of the CONCAST machine as it operates currently.

A heat of 10 to 300 tons of liquid steel is poured from the furnace into a large brick lined pot called a ladle. An overhead crane carries the ladle to the CONCAST machine. The ladle is placed so that the heat of steel can be poured gradually, typically during a one hour period, into a shallow container called a tundish. Usually, the liquid stream comes from a hole at the bottom of the ladle which can be controlled, or shut off, by a slidegate or stopper rod. The tundish contains a hole or nozzle, for each mold or strand of the CONCAST machine. The depth of steel in the tundish, usually coupled with a stopper rod at each nozzle,

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[4] Concast Brochure, (Zurich: Concast AG, 1972), p. 4.

controls the flow of steel to each mold.

The bottomless, reciprocating molds are the
the concast process. A machine may have from one
molds, which are vertical or curved copper tubes,
internal cross section, identical to the billet or
be cast. A dummy bar, plugging the bottom of the mo
the first liquid steel is poured, is gradually withd
solid skin is formed on the liquid steel in the
contact with the cool copper. The copper mold, in t
cooled by water running through the mold casing,
moves up and down many times a minute, in what is
sine motion. This sine motion continuously varies
from slow at top and bottom to much faster at the mi
the stroke. This mold speed is thus different
nearly constant billet or slab speed. The stroke usu
between 3/8 inch and 3/4 of an inch. Accompanied
lubricant such as rapeseed, this oscillation preve
hot steel skin from sticking to the mold. The endles
stream comes from the bottom of the mold, which is
curved slightly in recent machines, from vertical
horizontal, with a solid skin and liquid core. It is
and solidified by water sprays below the mold
supported and guided by a series of rollers as it
in the curve set by the mold, from vertical to the
horizontal level of the cooling bed. Torches or shear
desired lengths from the solid end of the strand.

without capacitors, and with the resulting undesirable power factor, if the extra charge is paid. The capacitor supplier indicated that operation could have continued in this case.

He inspected the damaged capacitors himself immediately upon his arrival at the plant in the evening, and ordered replacement parts to be carried, by a colleague, from his home city, by plane. His own hastily assembled crew installed the parts, and repaired the damaged capacitors. They were ready for operation after the weekend, a few hours before the relined furnace. Liquid steel was again available from the furnace. Steel was poured into the CONCAST molds, two and a half hours after the relined furnace was ready for charging. This delay to early CONCAST productivity growth was over.

It appears here that capacitor damage was due to incorrect furnace operation while learning. Deviations of procedure while learning can be expected during startup. The seeming effort to obscure the cause of downtime is more interesting. It is simple to institute inaccurate communications, with a large crew, working two or more shifts, who are just getting to know each other and the plant. It could happen spontaneously. The motivation to veil procedural deviations while learning, through inaccurate communications, could subsequently lead to solution of the wrong problems. It may be that the promptness, and accuracy of communications has an important horizontal cooling bed level. The continuous steel casting process is complete.

The process just described is the single technology being studied in this thesis. Additionally, the productivity data in this study have been limited to machines designed by one supplier, CONCAST, in order to study only that one sequence of technological advance. Most of the installations containing these machines cost between one million and fifty million dollars. The CONCAST machines represent an important portion of this cost. They have been installed during the last twenty years. The thirty machines for which productivity data have been gathered are situated on four continents. Thus the one sequence of technological advance which is being studied, is extensive in time, intensive in investment size, and broad-spread geographically.

The descriptive data in this chapter have not been limited entirely to CONCAST machines. Continuous steel casting machine installations designed by other suppliers provide the setting for more than one of the stories. The descriptive color of startup has been increased in this way without affecting the rigor of the quantitative analysis, which is firmly based upon the one sequence of technology.

Startup of the CONCAST machines contains one set of uncertainties due to unknown factors, at each step of this technological advance. Another set of uncertainties arises from lack of knowledge about the continuous steel casting machine and the process, by people on the site of a particular machine. Because of these unknowns and uncertainties, full capacity production is not achieved for many months. Many problems have to be solved to achieve the desired productivity. These problems are all different. The rest of this chapter consists of a series of vignettes, portraying the identification and solution of some typical problems, which then result in productivity growth. The vignettes are arranged in order of length of time they occurred after the first cast, with the earliest first. These are the activities of startup.

VIGNETTE 'A'

The infectious enthusiasm and prodigious energy exerted at the very beginning of an extremely successful startup has been recorded[5] in the following portrayal of the scene.

"The first sod was turned in November. Seven months later, the melt shop was preparing for the first heat. The overhead crane, which could carry the ladles from the furnace to the continuous steel casting machine, had just been placed on its track. High winds made it necessary to

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[5] University of Western Ontario, School of Business Administration, "Lasco Steel" A Case Study, (London, Ont.: 1972), p. 3.

lash the crane's wheels to the track with steel cable. The casting machine was directly below, and had the 80 ton crane fallen, the project would have been delayed for weeks. The winds strained the cables to the breaking point, and a welder was tied to a crane hook and raised 115 feet in an effort to tack down the wheels. As the winds reached 105 miles per hour, the welder waved back and forth past the wheels, eventually welding the wheels to the frame. On May 19th, the first heat was tapped in the middle of a blinding storm. The cladding on the melt shop had not been completed."

Such is the fervor and tempo of an all-out push for a fast startup. This temporary modification of welding the crane wheels, illustrates the ad hoc solutions sometimes used in the first startup days. Aggressive, effective managers simply react with any tools or materials at hand, in order to get some production. Such action can hardly be formalized as consisting of a search, screen, decision, implementation procedure. Yet the decision is made, instant action taken, and production obtained. That is the flavor of the early stage of some vigorous startups.

VIGNETTE 'B'

The supply of liquid steel to the CONCAST machine was halted for several days after only three weeks of one startup. The situation appeared to have been caused by a routine furnace reline. The real cause was obscured. The several communications, and basis of decision, show an interesting facet of early startup.

The first evidence of the stoppage of steel supply, to the foremen, hourly workers, and technical men, was the appearance of a subcontract bricklayer's crew to reline the furnace. Only twenty-five heats had been poured, with an expectation of fifty heats from the electric furnace lining. No one on the floor was aware of any lining defect, nor could they see any by visual inspection. Orders had been given, and the bricklayers proceeded on an eight hour a day schedule. They had not been asked to work on the weekend, and four calendar days were forecast for the job.

Further investigation disclosed that a supplier had been summoned post haste from another city, at the same time, to inspect and replace damaged capacitors. These capacitors are used to correct the power factor. An undesirable power factor consists of alternating phases of electricity which lag or lead the desired timing in the public electric utility's lines. This condition is caused by characteristics of the heavy drain of power through the electrodes to the scrap in the electric furnace. If capacitors do not correct the power factor, the steel company is charged substantially more for its power. Frequently, it is possible to operate the electric furnace without capacitors, and with the resulting undesirable power factor, if the extra charge is paid. The capacitor supplier indicated that operation could have continued in this case.

He inspected the damaged capacitors himself immediately upon his arrival at the plant in the evening, and ordered replacement parts to be carried, by a colleague, from his home city, by plane. His own hastily assembled crew installed the parts, and repaired the damaged capacitors. They were ready for operation after the weekend, a few hours before the relined furnace. Liquid steel was again available from the furnace. Steel was poured into the CONCAST molds, two and a half hours after the relined furnace was ready for charging. This delay to early CONCAST productivity growth was over.

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VIGNETTE 'C'

The first weeks of startup of a technologically advanced CONCAST machine disclosed a serious breakout hazard, due to an apparent mold supply problem. The assiduous, well managed search for a solution has been well documented.[6] Nevertheless, the extremely simple modification to correct the condition was preceded by a number of false moves. Over four months, and many thousands of tons of CONCAST billets were lost, before the proper modification to the supply was made.

The first observation of this particular difficulty was of breakouts from over 10% of the hot steel strands. A breakout occurs when hot liquid steel bursts through the thin shell, just as the slowly moving billet emerges from the bottom of the mold. As the vertically reciprocating mold starts its upward stroke, a jet of liquid steel spouts out. Soon the liquid steel, at 2900 degrees Fahrenheit, is spilling right through the tundish nozzle, down the now empty, square cross-section of the mold, and covering the

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[6] J. E. McConnell, "Startup and Operation of Inland's No. 1 Electric Furnace and Billet Casting Shop", (Chicago: Inland Steel Co., 1972.)

equipment below with hard to remove rivulets and globules of steel. The cleanup is annoying, time consuming, and delays the next cast. The managers and technical men began to look for the cause of the breakouts.

They discovered that the four inside walls of the copper mold had bulged inwards. The bulge was located at the metal meniscus. Thus, a small billet was formed which was not supported by the 32 inch long mold, further down below the meniscus. The steel broke out before actually reaching the bottom of the mold. The next question was to determine the cause of mold distortion.

Three potential causes of distortion were investigated: mold copper quality, mold water flow and back pressure, and mold water quality. Hardness tests disclosed that the copper in the original molds was softer than the 68 Brinell Hardness Number which had been specified. The supplier agreed to change his cold drawing practice, to supply a mold tube of uniform hardness. This correction still did not seem to make molds of sufficient dimensional stability. Although it was felt by this time that another cause was paramount in the distortion, a second modification was made to the molds. They were fabricated from welded tube, rather than from extruded tube, and this finally gave the desired dimensional stability. It was not, however, the solution to the distortion problem.

Experiments had been proceeding meanwhile, with increased mold water flow and decreased back pressure. Despite a series of wide changes in these values, no improvement in the distortion, or breakouts, was achieved. It was concluded that this approach would not solve the problem.

The investigation of mold water quality was more fruitful, but more complicated. The three water quality problems which were found, in chronological order, were: calcium (hardness) deposits, zinc oxide deposits, and bacteria. The first problem of water hardness was quickly solved by replacing the zeolite in the water softener which had deteriorated due to a freezeup in cold weather. In addition, the emergency tank was repiped for, and filled with, soft water. The second problen took a little longer. After some investigation, it was concluded that the white zinc oxide had been noticed shortly after a zinc chromic inhibitor was added to the mold water, to prevent rust noticed on the mold jackets. This observed coincidence led to the substitution of a zinc free inhibitor. Shortly thereafter, the zinc deposits disappeared. The third water quality problem took longer to discover, and to solve.

At the end of the third month of operation, with both calcium and zinc deposits gone, and sufficiently rigid copper molds in place, distortion still was occurring, followed by breakouts. Careful examination of the molds disclosed a brown slime on the water cooled surface. After several conjectures and tests of the slime, microbiological samples were taken and tested, and slime-forming bacteria were found. An attempt was made to kill these with a biocide. The attempt was only partially successful. Next, a trial was made with 100% city water, which was successful. The slime cleared. Chlorine in the city water prevented bacteria. Mold service water was then chlorinated. The problem was solved.

The bacteria and slime deposits disappeared. Unretarded by slime, the mold water could contact the copper surface completely, and fully cool the mold. The cool mold had sufficient strength, and mold distortion did not occur any more. The breakouts decreased to 1% from over 10%. A mundane item of supply, cooling water free of bacteria, was available, and startup could progress.

The identification of the correct cause was difficult here. The breakouts were easy to see, and the mold distortion not so difficult. The search for alternatives to correct the distortion was lengthy and detailed. Because alternatives were relatively cheap in cost, many were tried without screening. The final solution was simple, and inexpensive. That is, implementation was quick.

The entire modification process required over four months. Lack of its solution may have reduced productivity by 20% - 25% of full capacity during much of this period. It was one of many problems. Its size in percent of productivity and duration likely was not perceived when first noticed. Such are the activities and uncertainties of startup.

VIGNETTE 'D'

The withdrawal of a technical advisor caused interruptions in the progress of productivity at one plant. This population flow, of a highly trained and experienced man, out of the startup site, before the local men were fully trained, in effect, removed needed procedures. Using the wrong procedures, the men made less steel of poorer quality.

Sustaining the correct depth of liquid steel in the tundish, and correct rate of flow from tundish to the molds, is a key job in operating a CONCAST machine. The two are interdependent. The technical advisor specified that depth of steel in the tundish be maintained at twelve inches. During the first six weeks of startup, while he was present, the supervisors and operators maintained this level. The casting process was operating well.

After the technical advisor returned to his home city, breakouts began to occur. At the same time, the quality of steel cast was found to be unacceptable. This condition persisted for three weeks, until the plant manager prevailed upon the technical adviser to return. He immediately observed that the liquid steel depth in the tundish was far too shallow.

The operating crews were maintaining a depth of three inches to seven inches of steel in the tundish. They had commenced using much hotter steel in order to prevent freezeups at the tundish nozzles. This hot steel was less viscous, and required less ferrostatic head for the same rate of flow through the nozzles. Therefore, the head, or depth in the tundish, was reduced in order to diminish the flow. The twelve inch depth specification was forgotten in the concentration of solving this problem. At the same time, the flow rate was still greater than before, even at the reduced rate. This meant a faster oscillation and casting speed was used, along with more cooling water. The skin of the billet was thinner, the liquid core extended down lower, and more breakouts tended to occur due to this condition.

Where breakouts did not occur, many inclusions of slag and refractory were found in the center of the billet. The shallow level of steel had permitted a vortex to form in the tundish, at each nozzle. Slag from the surface of the tundish, and bits of refractory from the walls, were pulled down the vortex with the rushing liquid steel. They formed deleterious inclusions in the cast center of the billet. Thus the incorrect level of steel in the tundish was causing breakouts and poor quality steel. As soon as the depth of steel was changed to twelve inches again, the problem was solved.

The technical adviser represented a population flow which originally provided the correct procedures at this site. He transmitted them accurately to the operating people involved, but could not transmit a complete understanding of the many variables involved. When the technical adviser was withdrawn, the operating crew forgot the procedure. The breakout and quality problem arose. They saw the effects of the problem, but had no idea of how to search for an alternative solution. It took three weeks to get the technical adviser back. He solved the problem within hours of his arrival, without any search for alternatives, or screening. He also showed how to pour lower temperature steel for the required duration, by using additional slag cover on the ladle and tundish for insulation. This time the implementation of the procedure was prompt and permanent. Thereafter, the twelve-inch steel depth was maintained in the mold.

VIGNETTE 'E'

Inaccurate information about water flow plagued one machine, built by a supplier from another country. Communications on the matter between the foreign machine builder, foreign startup crew, domestic operating men and domestic technical adviser, took some considerable time to correct. Meanwhile, poor quality steel was being made, in insufficient quantities, and rejected.

Many cracks were observed on the surface of billets early in the startup. Further careful inspection of the process in operation showed that the billet was turning black too soon after leaving the mold. Both conditions pointed to an excessive flow of cooling water.

The cooling water plumbing system was checked carefully, and the water flow meters were read constantly. Although both mold and spray water had been set at minimum calculated values, the spray water was cut by successive decrements, to about three-quarters of its original flow. This helped to some extent, but not enough. Then, with considerable misgivings, the mold water rate was reduced in small steps, a total of fifteen per cent. After this, the cherry-red billets existed for the correct distance, and the cracks did not appear. Practically, the problem was solved.

Theory, however, disagreed markedly with this practice. Therefore, the flow meters must be wrong. The technical adviser ran water through one of the meters for a measured time, and directed it into an empty drum. He then measured the water in pails. It measured exactly the amount indicated by the flow meter, for the time run -- but in imperial gallons. The technical adviser and operating crew had understood that the flow was in U.S. gallons. The flow meters were immediately marked as imperial gallons, and a conversion scale to U.S. gallons posted underneath. Later, the dials were changed to read in U.S. gallons. The difficulty was overcome.

The information flow had been initiated by the foreign machine builder and startup crew, in imperial gallons. This information had been misinterpreted as U.S. gallons by the operating crew and technical adviser. A language difference contributed to the prolongation of this misunderstanding. The observation of cracked and black steel did not lead to identification of the real problem of incorrect information, and excessive water flow for four or five weeks. After that identification, selection and implementation of a solution were trivial. It is not often understood that inaccurate information flows can be serious impediments to startup. A rigorous audit of each item of information is not common. Yet this factor substantially impeded productivity progress in the startup described.

VIGNETTE 'F'

An arresting anecdote springs from the early months of startup in a company formed solely to operate a CONCAST facility. The event involved modification of both people and cash flows. An extended time was required to resolve the situation and implement changes which would raise productivity as desired.

The company president was an energetic, persuasive, aggressive promoter. He had succeeded in forming a coalition of diverse institutions which provided the substantial financing of the plant. He used most of his sizeable personal funds for equity, to catalyse this coalition. The plant was built at rather more than normal cost. It seemed probable that rewards went to several members of the financing coalition via supply contracts. The president participated effectively in his normal ebullient manner during the construction period.

The first cast found the company short of working capital. Also, the president had never operated in a steel company. Since most of his key executives reflected his own promoting ability, which had been the needed characteristic for the earlier stage, the president's shortcomings as an operating manager were magnified. It can be said that there was a dirth of steel operating management experience in the company. In addition, hourly workers who were experienced in this industry were not available locally. A few workers who were experienced in open hearth furnaces tended to insist upon the wrong practices for the electric furnace-CONCAST operation. As a result of these conditions, productivity increased slowly indeed.

Slow startup and heavy finance charges influenced the president to rely on his vast persuasive ability to obtain some short term funds. He talked a scrap supplier into giving him a cheque for a quarter of a million dollars. The cheque was made out to the president personally, ostensibly so that he could cash it and meet the payroll, without other suppliers seizing the funds from a bank account.

During the long hours of work throughout the promoting, construction, and early startup periods, the president had found the companionship of his attractive and efficient secretary more and more desirable. This feeling was reciprocated. Conversely, his feelings were becoming cooler towards his wife of many years. These three conditions triggered the unexpected action. The president, his secretary, and a quarter of a million dollars in small bills received from the supplier's cheque, all disappeared.

Management and creditors were dumbfounded. It was clear to the major creditors that people in the form of management, and the cash flow, must be changed. A temporary additional loan, with severe restrictions, was provided. New management was sought, and after some delay, was obtained. The startup proceeded again. It was hindered by the persistent shortage of cash. Enough good people could not be hired at once. The inexperienced people on the job tended to cause undue wear and damage to the plant and equipment. Money for repairs was not available. The new, experienced managers struggled valiantly to overcome the shortages, and break through to profitable, full capacity operations.

The committee of creditors and directors was willing to change management. However, they were reluctant to solve adequately the cash problem. Searching for alternatives took months. Actually implementing changed management took many more months, while the new men became familiar with the situation. The total time span for these people and cash flow changes took several years. It is doubtful that the people with financial authority perceived in advance the time scale that would be required for these modifications. It is unlikely that they related the needed modifications to the pattern of productivity increases, and predicted the slower rate of growth. Yet these modifications of changed managers, and adequate cash flow, were eventually the largest contributors to productivity progress in this CONCAST startup.

Meanwhile, American Express credit card bills, showing the president's signature, began to filter in to the creditors for payment. Torn between their reluctance to pay, and their desire to find him by this one cold trail, they paid luxurious expense accounts, month by month. The president had flown, with his secretary, and the cash, to Europe. There he proceeded to relax and enjoy life, far from the worries of home. Creditors, wife, and the exigencies of CONCAST startup were forgotten amid the pleasures of his secretary, and of the watering holes of the continent. Startup holds many surprises!

VIGNETTE 'G'

Managers at a recent technologically advanced CONCAST installation increased the quality level of their product mix after ten months of operation. As previously planned, they learned on simple rebar, then switched to sophisticated, special bar quality. Many modifications were required to achieve this quality. Only those changes necessary to overcome transverse corner cracks, which spoiled surface quality, will be recounted here.[7] They alone present a picture of extensive effort and time, to obtain one dimension of quality required for the new product mix.

The problem observed was cracks at the corners of the steel billet, perpendicular to the axis or direction of motion of the billet. These transverse cracks presented a defective surface. The surface was all right for rebar, but not acceptable for special bar quality, after further rolling. The cracks had appeared to a small extent during the first ten months of rebar production, but became more frequent and severe with the introduction of special bar quality.

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[7] Ibid.

Ceramic shrouds, or tubes, were attached to the tundish so that liquid steel could flow down these tubes, into the mold, without being touched by air, and oxidized. This is called submerged casting. A finely ground flux was placed on top of the liquid steel in the mold. This acted as an artificial slag, and it protected the steel on the surface of the mold from re-oxidation. Additionally, it worked as a lubricant between the steel and the mold, so that rapeseed oil was not necessary. These changes provided the required chemistry and internal physical structure for special bar quality by their prevention of oxidation, but, unfortunately, they also led to some further complications.

Transverse cracks increased in frequency and severity after these changes to submerged casting. They appeared after an in-line rolling station, in this advanced machine, reduced the cross-sectional area of the hot cast billet by up to 50%. This problem had to be solved so that the change in product mix could be accomplished.

A sequence of investigations explored changes in mold surface, secondary water cooling, aluminum content, and manganese-sulphur ratios. First, the mold surface was studied when copper-rich phases were found on the surface of the cracked areas. After some research, it was found that this occurred especially when the molds were brand new. A very thin, hard chrome plating was applied on the inside of the molds. This did prevent copper abrasion by the hot billet, and reduced the frequency of cracks. Yet far too many cracks still appeared.

A black strand of steel coming out of the water spray cooling Zone 2, instead of cherry-red steel, pointed to excessive cooling rates in submerged casting. This happened with the same water flow rates as had been used for open stream casting. The mold slag apparently allowed faster cooling in the mold than the rapeseed oil lubricant. The open stream casting flow rates were 8 gallons per minute (gpm) at the spray ring, 75 gpm. in Zone 1, and 25 gpm. in Zone 2. Water flow was eliminated in Zone 2 to correct the black strand condition, but it was noted that water ran down the inner radius of the curved billet, creating non-uniform cooling. A water flow model was constructed in a laboratory to demonstrate how the water flow could be equalized. As a result of experiments with this model, water flow in Zone 1 was reduced to 25 - 30 gpm. through the top three sprays, with the bottom spray blocked off. Flow in the spray ring remained at 8 gpm. Wipers were installed to divert excess water from the strand, and the problem of water running down the inner radius was solved. These changes produced uniformity in strand temperature, and markedly reduced cracks. Many cracks still remained, however, and the search continued.

It was noticed that a 500,000 BTU furnace, which reheated the corners, after the spray cooling and before in-line rolling, was not performing consistently. Sometimes, corners were reheated to a higher temperature than other times. Careful adjustment, and maintenance of this furnace made a further decrease in the number of transverse cracks. It did not solve the whole problem, however, and so end the search.

Metallurgists combed the heat records, looking for some correlation between cracks and some variables in the steel. They finally discovered that when the aluminum level was high, and the ratio of manganese to sulphur was low, the cracking condition was much worse. Heat chemistry was changed within the required specifications to avoid the undesired proportions of these particular elements, and finally the transverse cracks disappeared.

The hard chrome-plated molds, reduced flow of secondary cooling water, with wipers, carefully adjusted corner reheat furnace, along with the correct aluminum level and manganese-sulphur ratio, eliminated the transverse cracks. Billets without transverse corner cracks could be rolled subsequently to produce the surface quality specified for special bars. The change of product mix from re-bar to special bar quality could now be effective.

Most of these changes did not begin until after ten months of operating on simpler quality. They subsequently required three or four months to carry out. Good quality production was upped 10 - 15% of total capacity by this accomplishment. The searching and screening of alternative solutions was much more extensive than the successful changes outlined here. Implementation was prompt and effective. It required changed supplies in the molds, and changed operating procedures for water spray, reheat furnace maintenance, and steel chemistry. The wise decision in the first three days of startup to delay submerged casting, special bar practice, until operations stabilized with re-bar, can be recognized. Superimposing all the changes described here on early startup might triple the calendar length of this modification to a year or more. The managers of this advanced machine seem to reflect a realistic perception of the extended sequence and time scale of startup modifications.

VIGNETTE 'H'

Rhomboid rather than square cross-sections, coupled with longitudinal cracks at the billet corners, were noticed part way through one consistently managed CONCAST startup. A sequence of three alternative equipment modifications was made. Experimental results were collected from each in turn, and assessed. The third equipment modification, combined with a procedural change, finally solved this condition. A picture of this methodical solution process portrays one kind of startup activity very well.[8]

Longitudinal cracks on opposite corners of a billet were the first evidence of this problem which was observed. Further inspection showed that the 4 inch by 4 inch billet cross-section was not square. Opposite angles varied from 1 1/2 degrees to 4 degrees above or below 90 degrees, but the sides were equal, so a rhomboid was formed. It was also observed that the greater the variation from 90 degrees, that is the greater degree of rhomboidity, the more extensive were the cracks. It was concluded that the rhomboid shape, itself undesirable, caused the unacceptable longitudinal cracks.

Steel chemistry, mold geometry, steel temperature, and mechanical shaping were considered as factors causing this condition. Analysis of heat records showed that the rhomboid condition increasd with increased carbon content. Product mix could not be changed, so the higher carbon steels had to be accommodated. Mold geometry, such as corner radius, wall thickness, and dimensional accuracy, were not modified. These geometry items, whether rightfully or wrongfully, were considered as possible sources for minor improvement only, of the rhomboid condition. High steel temperatures entering the mold, with correspondingly higher

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[8] G. F. Newton, "Discussion", Continuous Casting, Open Hearth Proceedings, 1968, (New York: AIST, 1968), p. 129.

cooling rates, also resulted in more rhomboidity, and more cracks. Evidently, the higher cooling rates showed more variation from side to side of the billet. This condition could not be avoided without freezeup of steel at the tundish nozzles; therefore mechanical features of shaping the billets were explored for a solution.

First the curved molds were reversed, or turned upside down. The mold had been worn at the bottom end, where it was rubbed by the solid steel. Turning it upside down gave strong support at the now smaller bottom end. Cooling was more uniform, and cracks disappeared temporarily. The result was short lived, lasting only a few heats, until the mold wore again. A further solution was sought.

Careful observation disclosed worn guide rolls just below the mold. It was reasoned that the billet could move closer to one side of the mold than the other, because these worn rolls did not hold it exactly in the middle. The movement was possible because the billet cross-section at the bottom of the mold is always slightly smaller than the mold cross-section. The difference is due to shrinkage from cooling. This is in addition to the small difference caused by the thin film of lubrication between the steel and mold. Thus, the steel cooled more quickly where it was close to the cold mold, and less quickly where it was far from the mold; and the unsquare, cracked corner rhomboid resulted. The worn rolls were replaced to prevent this movement within the mold. The rhomboidity and cracking were reduced by this modification, but not enough to solve the problem. A search for other methods to control the position of the billet even more precisely was carried out.

Rolls were designed and attached to the bottom of the mold jacket. These were always positioned in precise dimensional relationship to the mold, since they were rigidly attached to it, and oscillated up and down with it. The rhomboid stopped appearing. The problem seemed solved; but then rhomboids and cracks appeared again. The bearings for the rollers had worn out in just a few days. Something else must be tried.

Corner foot guides, the shape of angle iron, were attached to the bottom, or foot, of the mold jacket in place of the rollers. They provided a surface guide contact for the billet, instead of the line contact of the rolls. They were just as precisely positioned in rigid attachment to the mold. They oscillated with the mold. They were set to thirty thousandths of an inch less across the billet cross-section, than at the liquid meniscus level of the mold. The problem was solved. Rhomboidity and cracks disappeared.

The billet which was precisely positioned in the mold by these guides, cooled equally on all sides. Its cross-section was square. No corners were stretched beyond 90 degrees, and so no corners cracked. The molds were reversed, and the foot guides reset, every twenty-five heats, to maintain this condition. The billets were rolled into finished rod and bar without folds and discontinuities in the surface. Good steel came from CONCAST.

This was one of many unforeseen operating problems which were solved in this startup. The three alternative equipment modifications were searched for, decided upon, and implemented. It is not known how many other alternatives were considered, and discarded or screened out, instead of being implemented. The potential value of other alternatives is highlighted by the fact that subsequently, most other plants used foot rolls with improved bearings, not foot guides. In any case, it required four to six months to progress through this problem-solving sequence. Productivity growth probably amounted to 3 - 5% of full capacity as a result of its solution. Such methodically gained solutions characterize the second year of a CONCAST startup.

Analytical Examination of Vignettes:

A classification of the preceding vignettes according to the conjectural, problem-solving framework described in Chapter II, is shown in Exhibit 4-1. The entries in this classification tend to indicate greater accuracy than is warranted by the inexact nature of the stories.

EXHIBIT 4-1

CLASSIFICATION OF VIGNETTES USING THE CONJECTURAL, PROBLEM SOLVING FRAMEWORK

	TYPE OF MODIFICATION	SECTOR OF FEEDBACK LOOP REQUIRING MOST TIME & EFFORT	TIME SPAN OF MODIFICATION	APPARENT MANAGER'S PERCEPTION OF TIME FOR MODIFICATION	POSITION IN STARTUP
A	Equipment	Implementation	1 hour	15 minutes	1st day
B	Population Flow - Procedures	Implementation	4 days	4 days	3rd week
C	Supply	Search	4 months	1 month	1st month
D	Population Flow Change People	Search	3 weeks	1 week	2nd month
E	Information Flow	Search	4-5 weeks	2 weeks	2nd month
F	Cash and Population Flow - People	Implementation	2-3 years	6 months	4th month
G	Orders Flow	Search & Screen	3-4 months	1-2 months	10th month
H	Equipment	Screen	4-6 months	1-2 months	13th month

Nevertheless, some generalizations may be cautiously stated from these observations.

Modifications do occur. Modifications do create productivity growth. Modifications may create the major portion of productivity growth. The evidence clinches this conclusion. It is so obvious as to be trite, but often the most obvious facts are missed, even though they are most important. Here, the obvious is important enough to bear repetition: Modifications increase productivity!

The most notable feature of these modifications seems to be the calendar time span to execute them. Most required weeks or months to complete. Although percent productivity gains are not detailed, each one provides only a small portion of the 100% productivity gains required during startup. Adding the time needed for all modifications determines the duration of startup. If the time scale for these modifications had been hours, instead of weeks or months, startup might be completed in a month. Inexact as these time measurements in the vignettes are, they indicate the nature, sequence, and duration of the activity which is the major determinant of the length of startup.

The third general observation about these vignettes is that the sectors of the problem-solving, feedback loop are not distinctly separated. Search, screen, and implementation proceed in parallel. An alternative often cannot be understood until its implementation is successful, or unsuccessful. The unknown causes the problem in the first place, and a search for its solution often requires implementation of an apparent alternative, to pierce the veil of the unknown. Thus, the clean cut procedure of generating alternatives; evaluating them, and implementing the best one, has not been followed in the vignettes related here. This seems characteristic of startup.

A fourth observation might be that regardless of the original classification of a modification, the ultimate solution tends to revert to an equipment or procedural modification. Order flow, information flow, population flow by people changes, and cash flow modifications in the foregoing vignettes, all ultimately required either equipment or procedural changes. The corollary might be that if these flows are effectively established at the beginning of startup, fewer equipment and procedural modifications will be necessary, and startup may be faster.

Such generalizations as these might better be presented only as ideas, to be used in further cogitation about startup. Problems are solved by modifications of the production system. The properties of these modifications are not revealed with great clarity, but only in misty outline form, by the little stories told here. Yet it is hoped that these vignettes have given the reader both a picture and flavor of CONCAST startup, and have also let him begin to think about its nature.

CHAPTER V

MEASUREMENT

Measurement of startup productivity progress on a linear, ratio scale would describe this phenomenon in the most comprehensible form. The human mind understands linear measure most easily. Unfortunately, startup is more complicated. It has a number of dimensions. Accurate portrayal requires that several be included.

Nominal measure seems to be the highest degree of scaling startup achieved in many situations. Two classifications are used: not started, and started. Sometimes a third classification is added: in the startup process. These measures are naive and create difficulties.

Ordinal measurement of startup, using a sequence of activities, is sometimes attempted. The difficulty, duration, cost, or failure to identify certain activities of startup causes this type of measurement to be ineffective. It assists in getting the startup job done, but does little to measure the actual dimensions involved.

Interval or ratio scaling is required to be explicit and accurate. The key dimension to be measured is output, that is, production in physical units, at any point during the startup. Productivity, which is the production during a standard number of hours from a single machine, can be conveniently used to express this dimension. The next desired dimension would measure the rate of increase of this productivity during startup, as a single consistent value. Total cumulative production during the startup, while this consistent rate of productivity increase is taking place, would be a third dimension. A fourth dimension, which should be measured, is the duration of startup in calendar months. Finally, it would be desirable to have a measure of the capacity which is lost from the time the first unit is produced until the plant is operating at full capacity. If all these dimensions could be accurately expressed on a single scale, or on related, linear, ratio scales, the measurement of startup would be explicit and easy to comprehend.

Accuracy in measurement is always a matter of degree. Absolute precision, except in the count of discrete units, is impossible. It is necessary then to state the degree of accuracy of measurement for each dimension of the startup.

The methodology described in Chapter III was designed to measure the startup of thirty CONCAST machines. The method used was to fit startup productivity data from the machines to the Manufacturing Progress Function. This process was carried out and the results are available.

These results will now be examined to find how well the Manufacturing Progress Function measures the several dimensions of startup.

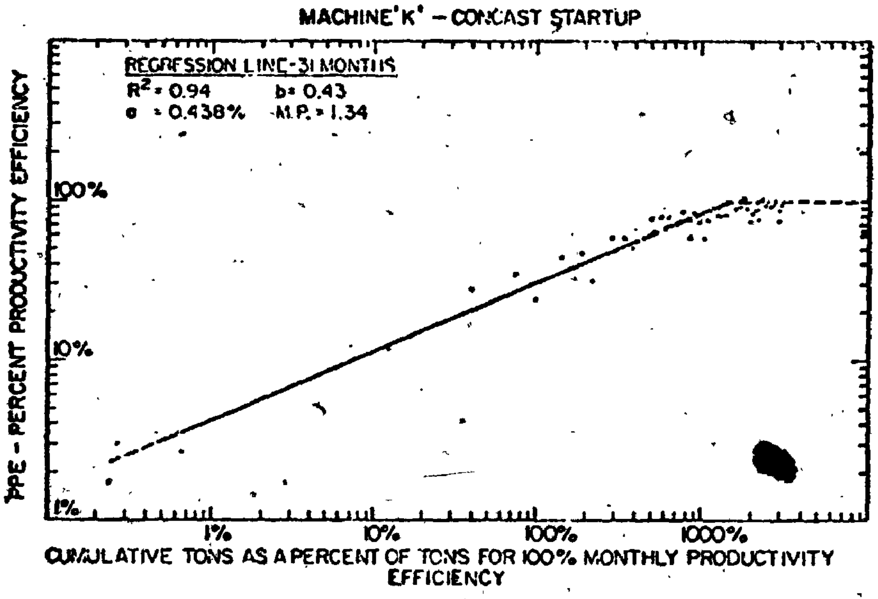
This examination will consist of four parts. First the graphical analysis will be inspected to find what measures of startup can be observed visually. Second, the statistical results of the regressions will be reviewed to determine how well the productivity data fit the Manufacturing Progress Function. Third, the level of scaling and degree of accuracy of measurement which was achieved for each of the dimensions of startup productivity will be set forth. Finally, the magnitude and variability of the startup dimensions for different CONCAST machines will be discussed.

Graphical Analysis of the Startup

Graphical analysis was used to make an initial examination of the startup productivity data from the thirty CONCAST machines. The number of actual tons produced each month were standardized for operating hours and plotted against cumulative actual tons on Log-Log graph paper. Exhibit 5-1 shows the graph of Machine 'K' as an example. A pronounced linear trend can be seen in the data points. This upward trend stops after many months and the data points vary around a steady state productivity level. Machine 'K' required thirty-one months to complete the productivity growth. A further sixteen months of data are shown, distributed around the steady state level.

The startup period can be seen in these graphical data points. Graphs for each of the thirty startups are shown in Appendix I. It commences with the first cast of steel, which is included in productivity for the first month, as represented by the first data point on the left. Start-up continues throughout the upward trend of each of the subsequent thirty data points to the right. It ends with the thirty-first month where maximum productivity is achieved for the first time. The steady state level was chosen from this graphical analysis, in accordance with the specifications for the end of startup, described in the methodology of Chapter III. Both the end of startup and the

EXHIBIT 5-1

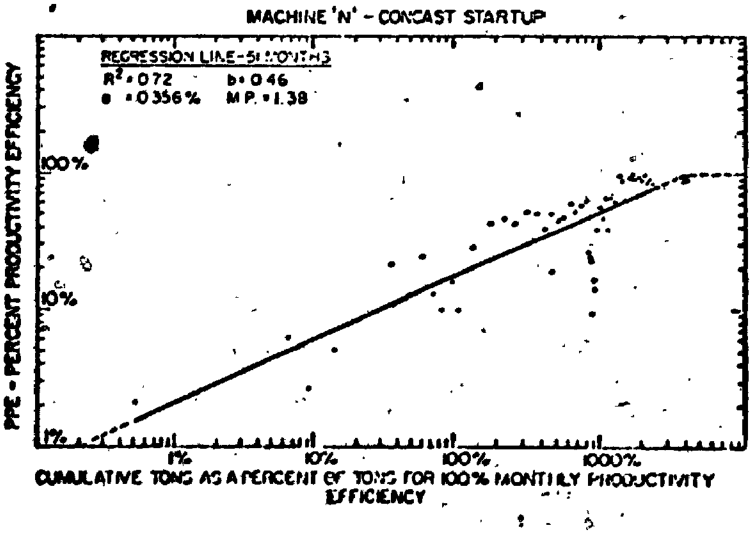


ensuing steady state are virtually evident in this graph. Thus, this initial graphical analysis simplifies the selection of the startup period for further analysis.

It should be noted that Exhibit 5-1 uses percent productivity efficiency (PPE) for coordinate scales in order to disguise the data. The original plot used tons on both coordinates, and these tons were divided by the monthly steady state tonnage chosen subsequent to the first graphical analysis, in order to establish PPE.

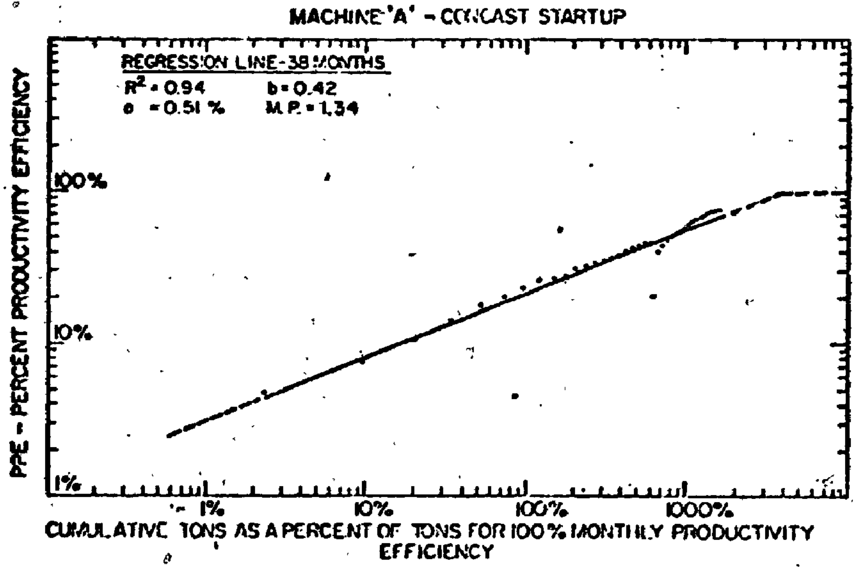
The data from some CONCAST machines do not form such a prominent linear trend as Machine 'K' when they are plotted. Exhibit 5-2 illustrates the sizeable deviations from linear Log-Log productivity growth which was experienced in the startup of Machine 'N'. Even after nine months of startup, the productivity dropped below 10% PPE. The total startup extended well beyond the fifty-one months of data shown. Yet even this startup does have a visible linear trend which defines the duration and termination of startup.

EXHIBIT 5-2



Some other machines show an even more consistent linear Log-Log relationship than Machine 'K'. Exhibit 5-3 displays the nearly exact linear sequence of productivity progress in Machine 'A'. This trend appears so pronounced that the startup is nearly defined at a glance. This particular machine did take so long to reach 100% PPE, that the steady state level was determined by subsequent average production data which are not included in the plotted points.

EXHIBIT 5-3



The graphical analysis does not prove any hypothesis nor provide a method for measuring productivity progress by itself. It does provide a quick and easily understandable arrangement of the data which suggests that every one of the thirty CONCAST startups may follow the Manufacturing Progress Function. Therefore, simple linear regression of the log transformed data was carried out.

Statistical Results of the Startup Regressions

Productivity data gathered from the startup period from thirty CONCAST machines, located on four continents, and spread over fifteen years, were regressed against the Manufacturing Progress Function as described in the methodology of Chapter III. The summary statistics for these regressions are shown in Exhibits 5-4 and 5-5. The data fit the Manufacturing Progress Function very well as evidenced by a median Coefficient of Determination, R^2 of .92. This indicates that in half the cases the Manufacturing Progress Function explains 92% or more of the total variance about the mean value. The R^2 values vary from a low of .52 to three cases with the high figure of .98. The lowest R^2 of .52 for Machine 'S' is explained primarily by a very flat slope. One exceptional point in each case has caused R^2 values for Machines 'H' and 'R'. Considering the R^2 measure for the group of thirty startups, it can be stated that the Manufacturing Progress Function describes the progress of productivity very well.

This description of productivity progress is substantially determined by the slope 'b' of the regression line, given that any such line will pass through $\overline{X}$ and $\overline{Y}$. The accuracy of this slope will be a primary factor in deciding the other dimensions of startup. The standard deviation, S_b, of the slope varies from .0166 to .0945, with a median of .0336 (Exhibit 5-5). This deviation is not

EXHIBIT 5-4

SUMMARY STATISTICS: THIRTY CONCAST STARTUPS

MACHINE	R^2	'b'	'a'*	M.P.	Mos. in Regression	Complete Startup X	Data Mos. Beyond Regression	Total Mos. of Data
'A'	.94	.42	0.51	1.34	38			
'B'	.96	.74	.029	1.67	9	X	16	25
'C'	.92	.58	0.13	1.49	17			
'D'	.85	.55	0.16	1.46	13			
'E'	.92	.50	0.32	1.41	12	X	2	14
'F'	.92	.58	.074	1.49	28			
'G'	.90	.46	0.36	1.38	28	X	9	37
'H'	.68	.32	1.83	1.25	22		23	45
'I'	.81	.21	6.47	1.15	16	Inter.	21	37
'J'	.95	.61	.091	1.53	18	X	14	32
'K'	.94	.43	0.438	1.34	31	X	16	47
'L'	.62	.36	1.0	1.28	36	X		
'M'	.92	.45	0.50	1.36	13	X	20	33
'N'	.72	.46	0.36	1.38	51			
'O'	.91	.38	0.53	1.30	39			
'P'	.89	.51	0.47	1.42	8	Inter.	30	38
'Q'	.96	.73	.038	1.66	11	Inter.	21	32
'R'	.67	.49	0.39	1.40	18	X		
'S'	.52	.12	20.2	1.09	32	X		
'T'	.89	.33	1.74	1.25	31	X	6	37
'U'	.98	.45	0.67	1.37	8	X	33	41
'V'	.87	.40	0.97	1.32	15			
'W'	.93	.55	0.17	1.46	21	X	10	31
'X'	.98	.50	0.23	1.41	20	X	3	23
'Y'	.98	.57	.06	1.48	19	X	5	24
'Z'	.87	.41	0.57	1.33	37			
'AA'	.74	.33	1.17	1.26	20	X		
'BB'	.96	.48	0.12	1.[illegible]9	24			
'CC'	.77	.33	0.92	1.26	31	X	12	43
'DD'	.94	.48	0.28	1.39	17	X	7	24

N.B. Inter. = interrupted startup
Machine 'CC' has 26 months of data spread over the first 31 months of operation, with 5 months missing. Machine 'BB' has 12 months of missing data in the middle of the 24, and has only 12 months of data used in the regression.

*These thirty Concast machines are located on four different continents.

EXHIBIT 5-5

SUMMARY STATISTICS - THIRTY CONCAST STARTUPS - ADDENDUM

MACHINE	t-Ratio b/S_b	S_b	St. Error of the Estimate
A	25.14	.0166	.0658
B	14.85	.0500	.1273
C	12.74	.0456	.1566
D	7.78	.0704	.1920
E	10.80	.0465	.0941
F	17.74	.0329	.1549
G	16.27	.0280	.0934
H	6.48	.0489	.1030
I	7.69	.0269	.0507
J	17.53	.0350	.1292
K	22.08	.0194	.0775
L	7.51	.0476	.1205
M	11.53	.0394	.1061
N	11.11	.0418	.2223
O	19.84	.0190	.0696
P	7.05	.0720	.1067
Q	13.24	.0552	.1304
R	5.22	.0945	.2014
S	9.52	.0208	.0466
T	15.30	.0214	.0777
U	17.52	.0256	.0494
V	8.82	.0454	.0980
W	16.40	.0335	.1386
X	25.51	.0197	.0572
Y	24.37	.0235	.0977
Z	15.63	.0264	.0815
AA	7.04	.0463	.1094
BB	17.51	.0272	.0802
CC	9.85	.0336	.1069
DD	14.75	.0326	.0784

large when compared to slopes with a median value of .46. It might be better expressed in terms of 't-ratio' of the slope, which is the slope, 'b', divided by its standard deviation, S_b. The t-ratios for the thirty startups range from 5.22 to 25.51, with a median of 14 (Exhibit 5-5). This means that the median standard deviation of the slope is less than 10%, since one fourteenth equals about .07. It is as high as 20% in one case, but only 4% in another. Thus the slope, as established by the regression, represents a stable value, which describes the rate of productivity progress with considerable accuracy.

The intercept 'a' fortunately has much less impact in determining the measurement of productivity progress in the regression because its values are subject to a broad deviation. 'a' represents productivity per month for the first ton of production. One ton is not produced by itself; therefore it is a theoretical value. It is difficult to generalize about the size of the standard deviation of 'a' due to its generation in logarithms and value near 1% PPE. However, using Machine 'O' as an example, one standard deviation above 'a' in arithmetic value is approximately ten times the size of one standard deviation below 'a'. This wide swing is caused by the long leverage of the regression line on the position of 'a', as the line rotates around $\overline{X}$ and $\overline{Y}$, due to even a small standard deviation of 'b'. The lack of symmetry results from the original definition of 'a' in logarithmic terms. The description of the startup by the Manufacturing Progress Function is not affected by this instability of the 'a' value around its nominal position.

Duration of startup is another dimension for which the statistical implications should be discussed. The slope controls this dimension. Since the slope, 'b', is relatively stable, the line does not rotate very much due to alternate and less probable estimates within the standard deviation of 'b'. The duration of startup, which is determined by the top right-hand end of the line, does not move nearly as much as 'a', because the fulcrum of $\overline{X}$ and $\overline{Y}$ is very near the upper end of the line. Thus the leverage on the termination point of startup may be only one tenth of the leverage on 'a'. The probable inaccuracy in the startup duration, due to this effect, will be commented upon again, later.

The measure of productivity in any individual month is not expressed as accurately by the Manufacturing Progress Function. The standard error of the estimate for a given point, expressed in logarithms, varies from .0466 to .2223, with a median value of .10 (Exhibit 5-5). These values convert into deviations of: low +11%, -10%, high +67%, -40%, and median +26%,-21%. Approximately two thirds of all individual values lie within these limits above and below the value predicted by the Manufacturing Progress line. Obviously this is not a close measure for individual values. However, the natural fluctuation in productivity, at the steady state condition, appears to be about +15%. This natural fluctuation has apparently been magnified by the uncertainties of startup. Therefore, although the Manufacturing Progress Function may not measure individual values very accurately, this inaccuracy appears to be due at least as much to the natural characteristics of the process as to inadequacies of the measure.

Another statistical characteristic which must be reviewed is auto-correlation. This occurs where the error term is correlated with the previous error. Thus a whole sequence of data points appear on one side of the regression line, followed by a sequence of points on the other side. Such auto-correlation indicates that the line is not a good least squares fit to the data.

The Durbin-Watson statistic is the traditional measure of auto-correlation, and this statistic was calculated for each of the startup regressions. The results are shown in Exhibit 5-6. Sixteen of the startups show auto-correlation at the .05 level of significance. Such results indicate the distinct possibility that the Manufacturing Progress Function may not be the very best representative of productivity progress, in spite of the high R^2 and t-ratio values.

Some tests were made to find whether the startup data showing the most significant auto-correlation might be better described by the Levy or Pegel functions. These

EXHIBIT 5-6

DURBIN-WATSON MEASURE OF AUTO-CORRELATION IN CONCAST STARTUP REGRESSIONS

MACHINE	DURBIN-WATSON STATISTIC	'N' in REGRESSION	NO AUTO-CORRELATION	SIGNIF. AUTO-CORR AT .05	INDECISIVE TEST AT .05 LEVEL
A	1.39601	38		X	
B	1.41943	9	X		
C	0.62423	17		X	
D	0.98807	13		X	
E	0.64505	12		X	
F	0.48144	28		X	
G	0.68765	28		X	
H	2.59177	22	X		
I	1.11138	16			X
J	0.51741	18		X	
K	1.68655	31	X		
L	1.06804	36		X	
M	2.32573	13	X		
N	0.82400	51		X	
O	1.49916	39			X
P	1.27990	8			X
Q	2.75525	11	X		
R	2.34067	18	X		
S	1.69964	32	X		
T	0.62048	31		X	
U	2.70048	8	X		
V	2.61992	15	X		
W	2.07308	21	X		
X	0.74305	20		X	
Y	1.04751	19		X	
Z	0.81716	37		X	
AA	1.05044	20		X	
BB	1.63184	24	X		
CC	1.14271	31		X	
DD	0.82972	17		X	
			11	16	3

NOTE: No Auto-Correlation means that the null hypothesis that there is no auto-correlation cannot be rejected at the .05 level of significance. Significant auto-correlation means that the null hypothesis that there is no auto-correlation, can be rejected at the .05 level of significance.

Test values of the statistics have been taken from Wonnacott and Wonnacott, "Econometrics", P. 428.

See also P. 427 for indecisive test.

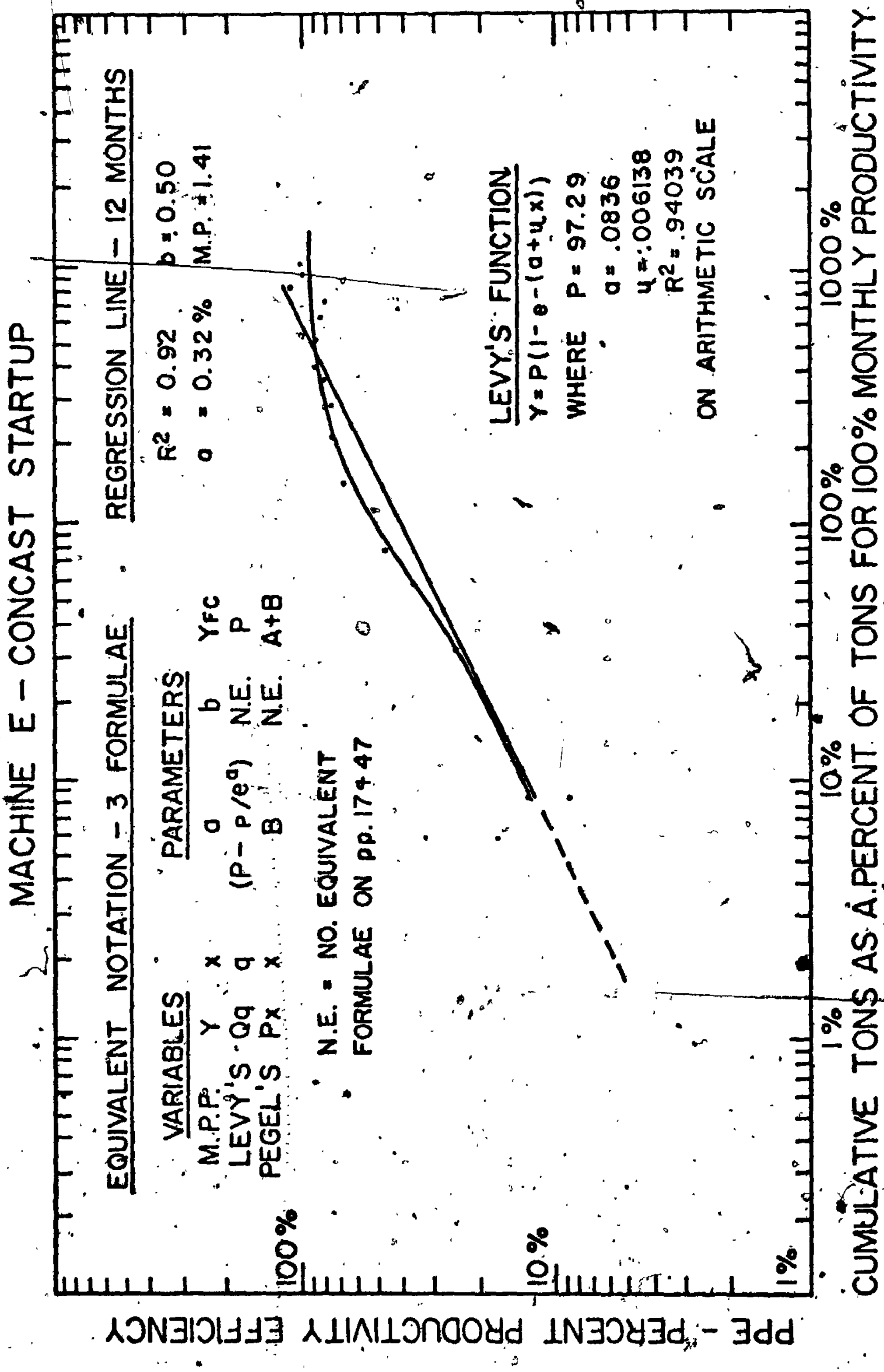
functions both have the property of asymptotically approaching a horizontal line, which would be 100% PPE in this situation. They are both exponential functions. The regressions of the data were made iteratively to convergence, after a manual estimation of three parameters had been hand calculated. The results showed that Machine 'E' fitted these functions well. Machine 'F' looked like a good fit on the arithmetic scale, but poor on the Log-Log scale. The comparison of fits is shown in Exhibit 5-7 for Machine 'E'.

This evidence argues that these, or other exponential functions, may possibly fit some sets of startup data more closely than the Manufacturing Progress Function. However, fitting these curves to data is difficult. More important, they do not possess the conceptual simplicity of the straight line which represents the Manufacturing Progress Function. This straight line can be described by the verbal statement: productivity increases by a fixed percent each time cumulative production is doubled. Therefore, these functions will not be pursued further in this thesis, although further investigation could show that they represent productivity progress more accurately.

Level of Scaling and Accuracy of Measurement

Ratio measurement has been achieved for all the startup

EXHIBIT 5-7


MACHINE E – CONCAST STARTUP
EQUIVALENT NOTATION – 3 FORMULAE
VARIABLES
PARAMETERS
M.P.P. Y x a b Yfc
LEVY'S Qq q (P – P/e^a) N.E. P
PEGEL'S Px x B N.E. A+B
N.E. = NO. EQUIVALENT
FORMULAE ON pp. 17 + 47
REGRESSION LINE – 12 MONTHS
R² = 0.92 b = 0.50
a = 0.32% M.P. = 1.41
LEVY'S FUNCTION
Y = P(1 – e^-(a+μx))
WHERE P = 97.29
a = .0836
μ = .006138
R² = .94039
ON ARITHMETIC SCALE
100%
10%
1%
1%
10%
100%
1000%
PPE – PERCENT PRODUCTIVITY EFFICIENCY
CUMULATIVE TONS AS A PERCENT OF TONS FOR 100% MONTHLY PRODUCTIVITY EFFICIENCY

dimensions, based upon the Manufacturing Progress Function regressions and statistical analysis discussed above. Although they are controlled by the Manufacturing Progress Function, with its constant exponent 'b', the measurements themselves are linear in each case. The degree of accuracy varies from one CONCAST machine to another, and from dimension to dimension. Each dimension will be discussed in turn to reveal the measure and its apparent accuracy.

The monthly productivity at any point during the startup is expressed by the regression line. It can be read from the graph, or calculated from the formula: $Y_x = aX^b$, for any desired value of cumulative production, 'X'. Y_x is expressed as a percent of steady state productivity, PPE. The linear scale goes from 0.00 to 100.00 PPE, with the lowest value being the intercept 'a', which is small and positive. The accuracy of 'Y' is determined by the standard error of the estimate as discussed earlier. Therefore, it can be as inaccurate as +67%, -40%, but in more cases has an accuracy of about +25%, -20%, with half the cases even more precise than this. Such precision is reasonable when compared to steady state fluctuations of +10% to 15%. It is more accurate than the nominal or ordinal measurement described earlier. It is better than an eyeball extrapolation of productivities plotted on an arithmetic scale. Greater accuracy is desirable. Nevertheless, this appears accurate enough to be used.

The second dimension of startup for which a measure was obtained is M.P., the rate of increase of productivity. It expresses the percent by which monthly productivity increased each time cumulative production doubled. The values range from 1.09 to 1.67, with a median of 1.38 (Exhibit 5-4). Zero rate of increase would be represented by a horizontal line with M.P. equal 1.00, so the scale begins at this value. The values of M.P. are based directly on 'b', and equal 2^b. These M.P. values, therefore, have the same median standard deviation of +7%. They may be even more stable than this, because twenty-five out of the thirty machines have M.P. values between 1.25 and 1.49. This measure of manufacturing progress, M.P., may be the most accurate and useful of all the measurements obtained.

The third dimension, cumulative production, is easily determined directly from the 'X' coordinate of the graph. It can also be calculated from the Manufacturing Progress Function formula. It is dependent upon the slope 'b' of the regression line, as are startup duration and lost capacity. A slight change in slope of a very flat line will change the cumulative production substantially. A steep startup slope shows cumulative production with great stability. It can be noted that the accuracy of cumulative tons produced during startup is reinforced by its near coincidence with the cumulative tons for the final month included in the regression. Therefore, it would appear that this dimension has an accuracy as close as +10%.

Startup duration, the fourth dimension, has also been calculated from the regression line, using the foregoing cumulative tons of production, and average monthly productivity from integration of the arithmetic curve. The calculated values range from 7.5 to 98 months (Exhibits 5-8 and 5-9). The calculated values for very short startups had to be adjusted due to an estimation in the integration procedure. The very longest time is likely overestimated due to the flat slope of the line. However, the results are measured on the linear, ratio scale of calendar months. Calculation of the accuracy depends upon several factors, but primarily upon the slope 'b'. Because the regression line is on Log-Log coordinates, a 10% standard deviation of 'b' seems to make a very large change in the startup time. This is the more sensitive because of the very small angle the regression line makes with the 100% PPE line to determine startup time. However, it must be remembered that the standard error of the estimate which is largely a natural fluctuation in the production process, as discussed, determines the deviation of 'b'. If this natural process error was removed, then the deviation of slope 'b' would be very much smaller. The actual results of calculated startup time appear to be much more accurate than this potential, total deviation would indicate. The results seem to measure the actual startup time within +10% to 15%, although this

EXHIBIT 5-8

STARTUP TIME and LOST CAPACITY for THIRTY CONCAST MACHINES

MACHINE	STARTUP TIME MONTHS	LOST CAPACITY MONTHS	CUMULATIVE TONS $ P.P.E.
A	69.4	28.9	4052
B	7.5	4.1	336
C	20.8	12.1	873
D	32.7	17.9	1476
E	9.1	3.1	595
F	26.2	14.5	1175
G	28.0	12.8	1526
H	29.6	9.4	2022
I	46.8	9.7	3711
J	18.7	11.5	722
K	28.3	12.1	1617
L	75.9	27.1	4880
M	12.8	5.8	680
N	75.7	35.1	4058
O	58.4	22.0	3640
P	7.8	4.0	383
Q	12.5	7.7	477
R	18.8	7.2	1159
S	98.5	11.8	8674
T	27.0	8.8	1813
U	8.3	3.7	455
V	20.0	8.0	1201
W	24.5	13.5	1127
X	20.6	10.4	1026
Y	17.9	10.2	767
Z	53.4	22.0	3140
AA	20.8	6.8	1405
BB	32.8	12.7	2015
CC	43.4	14.4	2902
DD	16.2	7.8	841

These values are calculated from the Manufacturing Progress Function, regression line.

EXHIBIT 5-9

DISTRIBUTION OF STARTUP TIMES AND LOST CAPACITY - IN MONTHS: CONCAST MACHINES

STARTUP TIME IN MONTHS IN ORDER OF DURATION	LOST CAPACITY IN MONTHS IN ORDER OF DURATION
7.5	3.1
7.8	3.7
8.3	4.0
9.1	4.1
12.5	5.8
12.8	6.8
16.2	7.2
17.9	7.7
18.7	7.8
18.8	8.0
20.0	8.8
20.6	9.4
20.8	9.7
20.8	10.2
24.5	10.4
26.2	11.5
27.0	11.8
28.0	12.1
28.3	12.1
29.6	12.7
32.7	12.8
32.8	13.5
43.4	14.4
46.8	14.9
53.4	17.9
58.4	22.0
69.4	22.0
75.7	27.1
76.8	28.9
98.5[é]	35.1

Median Startup Time=24.5mos.	Median Lost Capacity=11.5 mos.
Mean Startup Time =29.9mos.	Mean Lost Capacity =12.5 mos.
Range of Startup =7.5 to 76.8 mos.	Range of Lost Capacity=3.1 to 35.1mos.

[é] This startup time of 96.8 months is excluded from mean and range.

Note: Machines are not in the same order for these two parameters which are listed in order of size.

cannot be exactly determined by the statistical analysis.

Lost capacity, the final dimension, is much more stable. It is measured in months of 100% PPE which were not produced during the startup. It ranges from 3.1 to 35.1 on the linear scale of months of 100% PPE (Exhibits 5-8 and 5-9). It could be expressed in tons of lost capacity, except that comparability between machines would be difficult and confidentiality would be spoiled. Accuracy is somewhat closer than startup duration due to some compensating factors in the calculation. This improved accuracy can be recognized by visualizing the inverted triangle of lost capacity above the regression line. This triangle might reduce in width if the slope were increased, but would increase in height. Therefore, a reduction in startup time would not have as large an accompanying reduction of lost capacity. It is believed that the median accuracy for calculated lost capacity may be about +10% to 15%. This final dimension may be the most useful of the five for measuring the cost of startup.

Magnitude and Variability of CONCAST Startups

The most significant fact that emerges from all these forays into the statistical wilderness is that CONCAST startup takes a long time. A few machines reached capacity production in seven or eight months, but the median time was

24.5 months, or two years. The average time was two and a half years. Some machines required over six years to achieve full capacity production. Regardless of the possible statistical inaccuracies, it is clear that startup is a lengthy period.

The amount of lost capacity is significant too. The average machine lost a full year of capacity production during startup. Although some lost only three or four months, one lost three years of full capacity production (Exhibit 5-9). A tonnage measure can be used here without breaking confidentiality. The thirty machines together lost a total of 6,847,000 tons of capacity during startup. If each ton provides $20. contribution, this represents a potential, aggregate lost contribution of $137 million. Of course this calculation, is based upon a comparison of measured production to the theoretical ideal of achieving 100% capacity from the first cast. Such performance is not possible. Nevertheless, it would seem that recognition of the size of this dimension may be useful to managers.

The records of cumulative production before startup is completed do not seem as useful. They vary from 3.3 to 86 months of production at 100% PPE (Exhibit 5-8). The cumulative tonnages range from 50,000 to 1.5 million. Many of the machines had reached full productivity after cumulative production reached the equivalent of a year at this full rate. The range and variability of cumulative production is greater than for any other measure.

The manufacturing progress rate, M.P., is the most consistent, and possibly the most useful measure. As was stated earlier, although M.P. values range from 1.09 to 1.67, twenty-five of the thirty machines had M.P. values between 1.25 and 1.49. This argues for an expectation of M.P. not far from the median value of 1.38. Such an expectation may be a useful result of establishing this measure.

These measures of startup for a series of installations in a new technology are unique. The cost of not reaching full productivity immediately is large. The measures have accuracy enough to be useful. They have been made on separate, linear, ratio scales. Unfortunately, these scales are not co-linear, but have rather complicated inter-relationships based upon the Manufacturing Progress Function. The measures are more accurate than those which are now in use, as suggested at the beginning of the chapter. Since productivity growth follows the Manufacturing Progress Function closely during startup, as demonstrated by the high R^2 values, this provides a useful method for measuring startup. The measures of startup obtained here are expected to be helpful themselves in aiding the management of a startup.

CHAPTER VI

PREDICTION

The exact measurements of startup, stated before startup, would be perfect prediction. This would be desirable. Such perfection is not possible. A less accurate, but practical compromise was sought.

Prediction of five startup characteristics was the goal. The characteristics are: the intercept 'a', slope 'b', manufacturing progress, M.P., startup duration, and lost capacity. Preferred would be the ability to predict these characteristics several months before the first cast is made. Such preference seemed a bit ambitious. More feasible appeared the possibility that the final value of these characteristics might be predicted with some accuracy based upon productivity during the first few months of startup. This idea of predicting the parameters of the Manufacturing Progress Function, from the values of the first few months has been stated as Hypothesis 2 of this thesis. The accuracy of predictions achieved by the sequential regression methodology for testing this hypothesis, as set out in Chapter III, will be reported first in this chapter.

A further possibility discerned was that predictions of the startup characteristics could be made with increasing accuracy at each subsequent plant using a specific new technology, CONCAST. This supposition has been stated as Hypothesis 5 of this thesis. These predictions, based upon the results at earlier CONCAST plants, were made in two ways. First, the parameter model, which is reputed to show the relationship between the intercept 'a' and manufacturing progress, M.P., for all plants with a similar technology, was used to predict M.P. for later plants in the sequence. Second, the rank order of magnitude of each of the startup characteristics, for the whole series of thirty CONCAST plants, was tested for correlation with their chronological order, to find whether a trend in values correlated with this chronological order of machines could help to predict the characteristics. The accuracy of predictions achieved through using data from earlier machines which utilize the new technology of CONCAST, to forecast the startup characteristics of later machines, will be reported second in this chapter.

A discussion of both methods of forecasting startup characteristics will follow this reporting. Some combinations will be explored to achieve the best method of prediction. One particular possibility which will be discussed is the combination of the early values of productivity in PPL with an estimated value of M.P. to estimate startup. This discussion will conclude the chapter on prediction.

Predicting with Sequential Regressions Using Data from Early Months of Startup

Linear regressions were run for the first 3 months, 4, 5, 6, etcetera, up to 'N' months in the startup period, as previously defined, for each of the thirty CONCAST machines. The statistical results of these regressions are shown in Appendix II, Tables 1 to 30. These statistical values will be examined to find how closely the early regressions for a machine predict the final values of startup.

Prediction of the final value of the slope 'b' would be most useful, and so this will be looked at first. A partial summary of the statistical results for the sequential linear regressions of data from the thirty machines is shown in Exhibit 6-1. This exhibit shows that the final startup value for 'b' is contained within the 95% confidence level estimate for 'b' (i.e. $b \pm 2 \ S_b$), for regression of the first three months of data in twenty-five out of the thirty machines. Three other machines require only four months and the other two, ten months, to include the final 'b' within this estimate. Unfortunately, these estimates of 'b' from these three months of data have confidence limits that are far too wide to be of any use. Many have limits of well

EXHIBIT 6-1

SEQUENTIAL REGRESSIONS

Partial Summary Statistical Results

	No. of Months for Final 'b' to Lie Within 'b_3' $\pm$ $2S_b$.	Confidence Limits of 'b_3-% at 95% Con.Lv.	'b_3' Slope at 3 Mos.	'b_f' Final Slope	b_3-b_f arithm. error	$\frac{b_3-b_f}{b_f}$ % err.	$\overline{Y}_F$
A	3	108%	.3702	.4174	-.0472	-11%	1.5563
B	3	55	.8725	.7426	.0999	13	1.5022
C	3	62	.8409	.5808	.2601	45	1.5553
D	9	23	.8116	.5477	.2639	48	1.2703
E	4	14	.7659	.5024	.2635	52	1.7795
F	3	39	.8205	.5839	.2366	40	1.6309
G	3	79	.6573	.4556	.2017	44	1.7168
H	3	13	.2783	.3171	-.0388	-12	1.7907
I	3	60	.2550	.2070	.0480	23	1.7699
J	3	25	.6938	.6140	.0798	13	1.5852
K	3	54	.5606	.4285	.1321	30	1.7404
L	10	747	.1741	.3575	-.1834	-51	1.6822
M	3	149	.5360	.4545	.0815	18	1.7154
N	3	1160	.2037	.4644	-.2607	-56	1.5516
O	3	289	.4852	.3771	.1082	29	1.6782
P	4	45	.7780	.5080	.2700	53	1.8463
Q	3	123	.9101	.7309	.1792	25	1.3151
R	3	454	.2888	.4934	-.2046	-41	1.6644
S	3	800	.0912	.1198	-.0286	-24	1.9232
T	3	116	.4886	.3272	.1614	49	1.8398
U	3	62	.4022	.4486	-.0464	-10	1.6887
V	3	108	.4787	.4004	.0783	19	1.6969
W	3	16	.5911	.5497	.0414	8	1.5243
X	4	21	.4670	.5027	-.0357	- 7	1.6733
Y	3	12	.6728	.5728	.1000	17	1.6328
Z	3	313	.5312	.4126	.1186	29	1.6551
AA	3	84	.7469	.3262	.4207	129	1.8439
BB	3	58	.5548	.4763	.0785	16	1.4941
CC	3	75	.7339	.3312	.4027	121	1.7549
DD	3	75	.6917	.4810	.2107	44	1.7472

beyond ± 100%, while only six are closer than ± 25%. For example, Machine 'V', the sequential regression for which is shown in Exhibit 6-2, shows an estimate of 'b' as .4787 ± 108%. These very wide confidence limits improve as more months of data are included in the regression. However, as discussed in the previous chapter, they are still very wide in the final startup regression. Using the final regression of the same example, Machine 'V', 'b' equals .4004, and S_b equals .0454, so that b ± 2 S_b would be ± 23%. A few of the machines show closer confidence limits in the early stages. But estimation for most of the group, by this method, would be too inaccurate to be useful, and so this procedure was not followed further.

The same situation, only worse, prevailed in using the same procedure to predict 'a'. Logarithmic confidence limits of 'a' at the 95% confidence level, for early months, are plus or minus 100% or more. Converted to arithmetic values, these limits become many times larger. Even in the final startup regression, $2S_a$ may be equal to 2,000% of 'a' on the arithmetic scale. Therefore this approach was not followed further in an effort to predict 'a'.

Further examination of the sequential regressions revealed the interesting fact that twenty-two of the thirty machines showed a high value for 'b' in the original three month regression, and this declined consistently with each added month, down to the final regression value (Exhibit

EXHIBIT 6-2

```
DATA
   2.78    3.41    3.91    3.35    4.10    4.25    4.31    4.40    4.49    4.57    4.66    4.70    4.74    4.82    4.87
   1.16    1.35    1.65    1.44    1.66    1.78    1.44    1.76    1.78    1.85    1.39    1.92    1.93    1.93    1.96

    RHO   A-2SA   INTERC   A+2SA   B-2SB   SLOPE   B+2SB   XBAR    YBAR     SA      SB    STD ERR    SQ Y SQ Y
MANUFACTURING PROGRESS SEQUENTIAL REGRESSIONS              MACHINE LVL

  0.9441 -2.4681 -0.2169  2.0345 -0.0421  0.4787  0.9995  3.3353  1.3799  1.1257  0.2604  0.0949  0.5229  0.2571
  0.7472 -2.1319  0.1760  2.5610 -0.2071  0.3491  0.9054  3.4809  1.3951  1.1925  0.2781  0.1297  0.5253  0.2127
  0.9174 -1.5541  0.1769  1.9226  0.0171  0.3675  0.7179  3.6119  1.4461  0.9648  0.1752  0.1275  0.5314  0.2149
  0.7036 -1.4355  0.2265  1.6795  0.1364  0.3797  0.6231  3.7195  1.4995  0.7249  0.1217  0.1316  0.5437  0.2147
  0.8115 -1.3364  0.2970  1.9302 -0.0301  0.3151  0.6603  3.9128  1.4912  0.9167  0.1726  0.1412  0.5631  0.2154
  0.8358 -1.1906  0.2256  1.6593  0.0915  0.3351  0.5886  3.5779  1.5247  0.7174  0.1240  0.1327  0.5450  0.2219
  0.8764 -1.0912  0.1957  1.8514  0.1389  0.3467  0.5545  3.9453  1.5531  0.6332  0.1039  0.1260  0.5402  0.2235
  0.7495 -1.0457  0.1247  1.2955  0.1971  0.3639  0.5307  4.1073  1.5931  0.5853  0.0834  0.1129  0.5537  0.2312
  0.7991 -0.9947  0.0236  1.1720  0.2239  0.3755  0.5270  4.0666  1.4776  0.5442  0.0758  0.1144  0.5585  0.2362
  0.8137 -0.9333  0.0659  1.0701  0.2651  0.3875  0.5099  4.1177  1.6354  0.5151  0.0612  0.1107  0.5634  0.2426
  0.8202 -0.8525  0.0154  0.9033  0.2824  0.3962  0.5101  4.1673  1.6592  0.4875  0.0570  0.1262  0.5605  0.2441
  0.8419 -0.8107  0.0055  0.8306  0.2949  0.3960  0.4990  4.2186  1.6779  0.4496  0.0519  0.1018  0.5739  0.2488
  0.8547 -0.8834 -0.0376  0.8782  0.3096  0.4004  0.4912  4.2571  1.6969  0.4429  0.0454  0.0990  0.5773  0.2633
```

6-1). The original slope was too high by a slope value of .04 to .42. Observing further, it was seen that all three-month slope values of .48 or more declined in the final regression. The thirteen above .60 all declined substantially. Although these original 'b' values above .60 decline substantially by the final startup regression, they still showed higher than median values. Since three quarters of the machines followed this pattern of declining slope as the startup progressed, some further thought might be given to its use for prediction.

Another observation should be made about the changing of slope 'b' as the startup progresses. This configuration is exactly the progress of the slope which might be expected from the Levy and Pegel functions. They tend to commence with a steeper slope than the Manufacturing Progress Function, and then gradually flatten out to the horizontal. The evidence discussed here would suggest that more research into these functions as descriptors of startup might be fruitful.

Returning to the prediction of 'a', the same kind of reasoning ~~might be followed for prediction as was done~~ with 'b'. The intercept values themselves do not vary as much as the two standard deviations of the intercept. The trend, with each further sequential regression, for many of the 'a's is to start with a low value, which gradually increases. This follows the gradual rotation of 'b' towards a more horizontal position as the startup proceeds. The intercept rises with each slight clockwise rotation of the line. The values for 'a' are too scattered to be specific about the amount by which they might be increased for prediction. However, it might be possible to determine a procedure for the prediction of 'a' with a revised value of 'b' and with a review of the attached data.

One further item should be noted in the final regression for each machine. The value of $\overline{Y}$ for three quarters of the machines lies between 1.55 and 1.80 (Exhibit 6-1). This amounts to only 12% of the Y-scale in use, from 0 to 2.0. The result is that many of the statistics from the regressions are comparable in value, and it is easier to draw conclusions from the comparisons. The spread on the arithmetic scale is much higher of course, ranging from 35% to 60%. Nevertheless, this is a feature of standardized data which has simplified the analysis.

The result of this sequential regression analysis must be that early 'a' and 'b' values are not very good predictors of the final regressions. An understanding of the bias which may be present in the early values does permit some predictions of both parameters that may be of use. This tentative suggestion does not have the solid, statistical support which would make such predictions very dependable. Nevertheless, utilizing the bias of early values may be of some aid in place of the linear trend projections hoped for, as implied by the wording in the original hypothesis. Further discussion on prediction may show how this can be fitted in with some forecasts arrived at from another quarter.

Predictions with the Parameter Model

The values calculated for M.P. and Log 'a' for each of the thirty startups were regressed against the linear parameter model formula:

$$M.P. = s - t \text{ Log } a$$

The data fitted this model closely, with an R^2 of .91 for the thirty machines (Exhibit 6-3). The t-ratio of the slope was 17.1. Both these statistical measures indicate that the parameters of the Manufacturing Progress Function fit the parameter model closely.

This model establishes a consistent relationship between the intercept 'a' and the rate of progress, M.P., of a startup. The lower the intercept is located, the greater the rate ~~of progress~~, or M.P., that is achieved. If the intercept 'a' could be obtained or estimated from a regression of a few early months, then it appears that M.P. could be predicted from this formula. First, though, 's' and 't', the parameters of the parameter model, would have to be established with data from the first machines in the sequence of the CONCAST technology.

EXHIBIT 6-3

PARAMETER MODEL PARAMETERS

WHERE MACHINES ARE ADDED TO THE REGRESSION IN CHRONOLOGICAL ORDER

Machines in the Regression	Number of Machines	Y-Intercept 's'	Slope 't'	R^2	Standard Deviation of Slope
'A' 'B' 'N'	3	1.26243	-.2650	.9999	.0004
+ 'C'	4	1.2612	-.2643	.9994	.0046
+ 'V'	5	1.28764	-.2400	.9802	.0197
+ 'D'	6	1.28568	-.2383	.9768	.0183
+ 'W'	7	1.28477	-.2377	.9761	.0166
+ 'K'	8	1.27756	-.2431	.9707	.0172
+ 'G'	9	1.27659	-.2437	.9711	.0158
+ 'X'	10	1.27454	-.2434	.9666	.0159
+ 'P'	11	1.28671	-.2330	.9279	.0216
+ 'Q'	12	1.28091	-.2471	.9447	.0188
+ 'Y'	13	1.2876	-.2263	.8868	.0243
+ 'BB'	14	1.2859	-.2182	.8213	.0294
+ 'H'	15	1.2909	-.2126	.8529	.0245
+ 'O'	16	1.2848	-.2174	.8534	.0240
+ 'L'	17	1.2841	-.2182	.8659	.0221
+ 'CC'	18	1.2805	-.2218	.8751	.0209
+ 'R'	19	1.2826	-.2207	.8716	.0205
+ 'U'	20	1.2872	-.2168	.8632	.0203
+ 'Z'	21	1.2864	-.2174	.8656	.0196
+ 'I'	22	1.2919	-.2093	.8879	.0166
+ 'J'	23	1.2920	-.2110	.8933	.0159
+ 'F'	24	1.2921	-.2074	.8917	.0154
+ 'M'	25	1.2924	-.2073	.8920	.0150
+ 'S'	26	1.3001	-.1956	.9076	.0127
+ 'T'	27	1.2999	-.1958	.9112	.0122
+ 'AA'	28	1.2985	-.1969	.9124	.0119
+ 'DD'	29	1.2980	-.1967	.9119	.0117
+ 'E'	30	1.2984	-.1968	.9117	.0115

The Parameter Model is: M.P. = s - t Log a

Where: M.P. = Manufacturing Progress, the rate of increase of productivity in the startup.

'a' = the intercept of the regression line of the Manufacturing Progress Function with the Y-axis, for a startup
It is the productivity for the first ton.

's' & 't' = are parameters of the Parameter Model.

Sequential estimates of 's' and 't' were made by regressing M.P. and Log 'a' from the first three CONCAST machines in the chronological order, then the first four machines, and so on until thirty machines were included. The results of these regressions of the parameter model are shown in Exhibit 6-3. It can be seen that 's' is estimated nearly correctly, at 1.26, with the first regression of three machines, as compared with the final value of 1.29. The slope 't' shows more change during the chronological sequence, dropping from the initial value of -.265 down to -.196. Still, the estimates of 's' an 't' are both good enough to be used at the earliest stages of the sequence.

Estimates of M.P. were calculated using the parameter model with the 's' and 't' values which would have been available for the eighth, sixteenth, twenty-third, and thirtieth machines. These estimates used the Log 'a' value from the regression of the first three, six, and nine months of data for each of these machines. The results of these calculations are shown in Exhibit 6-4. The M.P. value calculated from the Manufacturing Progress Function regression line from which the value of Log 'a' was taken, is also shown in each case in a parallel column. These corresponding values of M.P. can be compared to discover which might make the best predictor.

It can be seen that the estimate of M.P. from the early Manufacturing Progress Function regressions is more accurate

EXHIBIT 6-4

ESTIMATES OF 'M.P.'

From: 3, 6, & 9 Month Regressions
and From the Parameter Model

MACHINE 'K': Chronologically the 8th Machine, Using 5 Machines in the Model

No. of Months in Regression	Log.'a'	'a'	'b'	M.P. From Regression	M.P. From Para. Model
3	-.7808	.166%	.560	1.475	1.475
6	-.6363	.231%	.506	1.42	1.440
9	-.5666	.271%	.483	1.398	1.424
31	-.3582	.438%	.428	1.34	1.3736
					1.369^z

MACHINE 'O': Chronologically the 16th Machine, Using 11 Machines in the Model

3	-.7755	.167%	.489	1.40	1.467
6	-1.1331	.074%	.588	1.50	1.551
9	-.7855	.164%	.497	1.41	1.470
39	-.2760	.530%	.377	1.30	1.351
					1.352^z

MACHINE 'J': Chronologically the 23rd Machine, Using 19 Machines in the Model

3	-1.5509	.028%	.740	1.67	1.625
6	-1.8624	.014%	.868	1.82	1.694
9	-1.6441	.023%	.790	1.73	1.645
18	-1.0427	.091%	.610	1.53	1.513
					1.504^z

MACHINE 'E': Chronoligically the 30th Machine, Using 24 Machines in the Model

3	-1.4477	.036%	.766	1.70	1.592
6	-1.0142	.097%	.642	1.56	1.502
9	-.7156	.192%	.562	1.48	1.440
12	-.4855	.327%	.502	1.41	1.393
					1.393^z

---

z: This value of M.P. is calculated with the values of 's' and 't' obtained from the parameter model regression containing 30 machines.

for the first two machines: Machine 'K' (eighth) and Machine 'O' (sixteenth). The parameter model estimate is more accurate for the other two: Machine 'J' (twenty-third) and Machine 'E' (thirtieth). This result is apparently caused by the fact that 'K' and 'O' have below average final values for the slope 'b', while 'J' and 'E' have above average values. The parameter model tends to pull the M.P. to a figure based upon the average value of 'b'. Despite this averaging effect, early predictions of M.P. with the parameter model are not very close.

The reason for the poor estimation is that the calculated M.P. is based upon the early value of Log 'a'. But the Log 'a' values tend to be too low because, as noted earlier, slope 'b' is too high in the early months. Thus the calculated M.P. from the parameter formula is too high also. The parameter model predictions are unfortunately very close to being a tautology, although some centralizing tendency is provided to the M.P. values calculated from it. Therefore, although the prediction of M.P. and other startup characteristics may be slightly more accurate at each subsequent plant, with the aid of the parameter model, it does not provide close predictions of these characteristics.

Prediction with the Aid of Chronological Trends

Another method which was investigated to find whether it might predict "the startup characteristics with greater accuracy at each subsequent CONCAST plant was based upon the possibility of chronological trends in these characteristics. The five characteristics were arranged in chronological order, as shown in Exhibit 6-5, in order to test this idea. The characteristics for each machine were identified with the number for the machine in the chronological order. These data were then inserted into the pertinent SPSS program and the Spearman Rank Correlation Coefficients were calculated by the computer. These coefficients, with their level of significance, are shown in Exhibit 6-6.

It can be seen that rank correlation exists at the .05 significance level, or greater, between chronological order (TIMEORD 1) and all of the startup characteristics except startup time (STRTIME 1). The intercept 'a' increases with time. The slope, 'b', and manufacturing progress, M.P., decrease in size with time. Lost capacity decreases as the chronological order proceeds. That is, later machines in the sequence tend to have less lost capacity. Some rank correlation exists with startup time, which becomes shorter as the chronological order number increases, but this is significant only at the .27 level. It appears that some predictions can be made with the help of these rank correlations.

The most useful prediction might be that the lost

EXHIBIT 6-5

CHRONOLOGICAL ORDER OF CONCAST MACHINES WITH THEIR STARTUP CHARACTERISTICS

	MACHINE	INTERCEPT 'a' %	SLOPE 'b'	STARTUP TIME MONTHS	LOST CAPACITY MONTHS	MANUFACTURING PROGRESS M.P.
1.	A	.51	.42	69.4	28.9	1.34
2.	B	.029	.74	7.5	4.1	1.67
3.	N	.36	.46	75.7	35.1	1.38
4.	C	.13	.58	20.8	12.1	1.49
5.	V	.97	.40	20.0	8.0	1.32
6.	D	.16	.55	32.7	17.9	1.46
7.	W	.17	.55	24.5	13.5	1.46
8.	K	.438	.43	28.3	12.1	1.34
9.	G	.36	.46	28.0	12.8	1.38
10.	X	.23	.50	20.6	10.4	1.41
11.	P	.47	.51	7.8	4.0	1.42
12.	Q	.038	.73	12.5	7.7	1.66
13.	Y	.06	.57	17.9	10.2	1.48
14.	BB	.12	.48	32.8	12.7	1.39
15.	H	1.83	.32	29.6	9.4	1.25
16.	O	.53	.38	58.4	22.0	1.30
17.	L	1.0	.36	75.9	27.1	1.28
18.	CC	.92	.33	43.4	14.4	1.26
19.	R	.39	.49	18.8	7.2	1.40
20.	U	.67	.45	8.3	3.7	1.37
21.	Z	.57	.41	53.4	22.0	1.33
22.	I	6.47	.21	46.8	9.7	1.15
23.	J	.091	.61	18.7	11.5	1.53
24.	F	.074	.58	26.2	14.5	1.49
25.	M	.50	.45	12.8	5.8	1.36
26.	S	20.2	.12	--	11.8	1.09
27.	T	1.74	.33	27.0	8.8	1.25
28.	AA	1.17	.33	20.8	6.8	1.26
29.	DD	.28	.48	16.2	7.8	1.39
30.	E	.32	.50	9.1	3.1	1.41

The chronological order is based upon the date of the first cast.

EXHIBIT 6-6

```
RUN SPEARMAN CORRELATIONS WITH CHRONOLOGICAL ORDER                                    03/29/74        PAGE   2

FILE   NJNAME   (CREATION DATE = 03/29/74)

- - - - - - - - - - - - - - S P E A R M A N   C O R R E L A T I O N   C O E F F I C I E N T S - - - - - - - - - - - - - -

VARIABLE              VARIABLE              VARIABLE              VARIABLE              VARIABLE              VARIABLE
PAIR                  PAIR                  PAIR                  PAIR                  PAIR                  PAIR
--------              --------              --------              --------              --------              --------

TIMEORD1   0.3366     TIMEORD1  -0.3229     TIMEORD1  -0.3300     TIMEORD1  -0.1150     TIMEORD1  -0.3551     INTRCPT1  -0.9504
WITH       N(   30)   WITH       N(   30)   WITH       N(   30)   WITH       N(   30)   WITH       N(   30)   WITH       N(   30)
INTRCPT1 SIG .034     SLOPEUP1 SIG .041     MFGPROG1 SIG .037     STARTIM1 SIG .272     LOSTCPC1 SIG .027     SLOPEUP1 SIG .001

INTRCPT1  -0.9496     INTRCPT1   0.4477     INTRCPT1  -0.0018     SLOPEUP1   0.9991     SLOPEUP1  -0.5904     SLOPEUP1  -0.1445
WITH       N(   30)   WITH       N(   30)   WITH       N(   30)   WITH       N(   30)   WITH       N(   30)   WITH       N(   30)
MFGPROG1 SIG .001     STARTIM1 SIG .007     LOSTCPC1 SIG .496     MFGPROG1 SIG .001     STARTIM1 SIG .001     LOSTCPC1 SIG .223

MFGPROG1  -0.5877     MFGPROG1  -0.1410     STARTIM1   0.8360
WITH       N(   30)   WITH       N(   30)   WITH       N(   30)
STARTIM1 SIG .001     LOSTCPC1 SIG .229     LOSTCPC1 SIG .001

                      A VALUE OF 99.0000 IS PRINTED IF A COEFFICIENT CANNOT BE COMPUTED.
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capacity will tend to be less as each additional machine using the new technology becomes established. This reinforces an intuitive expectation. The other prediction would be that productivity starts at a higher rate (intercept), but progresses somewhat more slowly (M.P.), as each machine is added in the sequence. These are generalized predictions that cannot readily be applied to predict the startup characteristics of a specific machine. They might, however, be used with other data to modify and to make a specific prediction more accurate.

A Procedure for Predictions: Using Revised M.P. and Three Month Productivity

A further possibility for prediction might be based upon the relatively narrow range of M.P. values which was noted in the last chapter. Twenty-five of the thirty CONCAST machines had a final M.P. value between 1.25 and 1.49, with a median value of 1.38. It was also noted, earlier in this chapter; that three quarters of the machines followed a pattern of declining slope, 'b', as the startup progressed. These two facts may make it possible to predict suitably accurate M.P. values with three month data. If these predicted M.P. values are combined with productivity in PPE from the first three months of startup, then estimates of startup duration and lost capacity may be obtained.

First, a procedure for estimating the final slope, 'b', and final M.P. has been illustrated in Exhibit 6-7. The three month slope values have been arranged in rank order and compared with final slope values. It can be seen that the larger the initial slope, then the greater the amount by which it exceeds the final slope. Rules to estimate the final slope, 'b_f', can be generated from this bias of the early slope values, as follows:

If 'b_3' is .70 or greater, reduce it by .25.

If 'b_3' is .60 or greater, but less than .70, reduce it by .15.

If 'b_3' is .48 or greater, but less than .60, reduce it by .10.

If 'b_3' is .40 or less, then increase it by .05.

These arbitrary rules reflect the early bias, and the final small range, in the slope, 'b', and M.P. values. They have been used to estimate the final value of 'b' and to calculate M.P. These predicted values are shown in Exhibit 6-7, along with the actual values and error. It can be seen that nineteen out of thirty of the M.P. values have been estimated within ± .05 by this method. These values appear close enough for further use in predicting startup duration.

It must now be noted that cumulative production to the end of startup, startup time, and lost capacity can be calculated, based not only upon M.P., but upon the productivity in PPE achieved at the end of the third month.

EXHIBIT 6-7

ESTIMATES OF FINAL M.P. FROM THREE MONTH SLOPE

MACHINE	THREE MONTH SLOPES IN RANK ORDER	FINAL SLOPE b_f	b_3-b_f ERROR IN 3 MO. SLOPE	REDUCE b_3 by FACTOR FOR ESTIM.	ESTIMATED FINAL SLOPE	ESTIMATED M. P. (2^b)	ACTUAL M.P.	M.P. ERROR
Q	.9101	.7309	.1792	.25	.6601	1.58	1.66	-.08
B	.8725	.7426	.0999	"	.6225	1.54	1.67	-.13
C	.8409	.5808	.2601	"	.5909	1.51	1.49	.02
F	.8205	.5839	.2366	"	.5705	1.49	1.49	-
D	.8116	.5477	.2639	"	.5616	1.47	1.46	.01
P	.7780	.5080	.2700	"	.5280	1.44	1.42	.02
E	.7659	.5024	.2635	"	.5159	1.43	1.41	.02
AA	.7469	.3262	.4207	"	.4969	1.41	1.26	.15
CC	.7339	.3312	.4027	"	.4839	1.40	1.26	.14
J	.6938	.6140	.0798	.15	.5438	1.46	1.53	-.07
DD	.6917	.4810	.2107	"	.5417	1.46	1.39	.07
Y	.6728	.5728	.1000	"	.5228	1.43	1.48	-.05
G	.6573	.4556	.2017	"	.5073	1.42	1.38	.04
W	.5911	.5497	.0414	.10	.4911	1.41	1.46	-.05
K	.5606	.4285	.1321	"	.4606	1.38	1.34	.04
BB	.5548	.4763	.0785	"	.4548	1.37	1.39	-.02
M	.5360	.4545	.0815	"	.4360	1.35	1.36	-.01
Z	.5312	.4126	.1186	"	.4312	1.35	1.33	.02
T	.4886	.3272	.1614	"	.3886	1.31	1.25	.06
O	.4852	.3771	.1082	"	.3852	1.31	1.30	.01
V	.4787	.4004	.0783	"	.3787	1.30	1.32	-.02
X	.4670	.5027	-.0357	0	.4670	1.38	1.41	-.03
U	.4022	.4486	-.0464	+.05	.4522	1.36	1.37	-.01
A	.3702	.4174	-.0472	"	.4202	1.34	1.34	-
R	.2888	.4934	-.2046	"	.3388	1.26	1.40	-.14
H	.2783	.3171	-.0388	"	.3233	1.25	1.25	-
I	.2550	.2070	.0480	"	.3050	1.24	1.15	.09
N	.2037	.4644	-.2607	"	.2537	1.19	1.38	-.19
L	.1741	.3575	-.1834	"	.2241	1.17	1.28	-.11
S	.0912	.1198	-.0286	"	.1412	1.10	1.09	.01

The cumulative production will vary widely, depending partly upon M.P., but more importantly upon the PPE achieved at this point. Startup time and lost capacity will be proportionately smaller variations due to this factor.

A conceptual understanding of this point may assist in visualizing its usefulness in prediction. If the final M.P. is 1.40 and productivity at month three is 10 PPE, then cumulative production must be doubled 6.84 times, a multiple of 114 times cumulative production at the end of month three. If productivity at month three has reached 50 PPE however, then cumulative production need only be doubled 2.06 times, a multiple of 4.17 times cumulative production at month three. This is based upon the calculation that:

$$10 \text{ X } 1.40^{6.84} = 100 \quad \text{and} \quad 50 \text{ X } 1.40^{2.06} = 100$$

The accompanying Exhibit 6-8 indicates how these multiples are quite sensitive to the productivity level attained, and not as sensitive to the M.P. value. However, the two values can be combined. Starting at the correct point of PPE, and progressing the prescribed distance along a line of approximately the right slope or rate of progress becomes a useful prediction procedure.

The wide range in three month PPE values points to the variation in total progress which can be identified through this procedure. A review of these three month PPE values in Exhibit 6-9 reveals that they range all the way from 2.6 to 76.7 PPE. Many of the low productivities at this stage

EXHIBIT 6-8

NUMBER OF DOUBLINGS OR MULTIPLES OF CUMULATIVE PRODUCTION REQUIRED TO ATTAIN 100 PPE FROM VARIOUS GIVEN PPE VALUES

At Various Rates of Manufacturing Progress, M.P.

PERCENT PRODUCTIVITY EFFICIENCY PPE	M.P.= 1.25 Log = .0969	M.P.= 1.30 Log = .1139	M.P.= 1.35 Log = .1303	M.P.= 1.40 Log = .1461	M.P.= 1.45 Log = .1614	M.P.= 1.50 Log = .1761
			CUMULATIVE DOUBLINGS			
Y_3 =10.0	10.31	8.77	7.67	6.84	6.19	5.67
Y_3 =20.0	7.20	6.13	5.36	4.78	4.32	3.96
Y_3 =30.0	5.39	4.59	4.01	3.58	3.24	2.97
Y_3 =40.0	4.10	3.48	3.05	2.72	2.46	2.25
Y_3 =50.0	3.10	2.64	2.31	2.06	1.86	1.71
			CUMULATIVE MULTIPLES			
Y_3 =10.0	1270	437	204	114	73	51
Y_3 =20.0	147	70	41	27	20	16
Y_3 =30.0	42	24	16	12	9.5	7.8
Y_3 =40.0	17	11.6	8.3	6.59	5.52	4.76
Y_4 =50.0	8.57	6.23	4.96	4.17	3.63	3.27

EXAMPLE CALCULATION OF NUMBER OF DOUBLINGS:

$Y_{FC} = Y_3 \times M.P.^Q$, Where $Y_{FC} = 100.0$ PPE, $Y_3 = 10.0$ PPE, and M.P.= 1.40

then: $\text{Log } 100.0 = \text{Log } 10.0 + Q \text{ Log } 1.40$

$$Q = (\text{Log } 100.0 - \text{Log } 10.0)/\text{Log } 1.40$$

$$= (2.0 - 1.0)/.1461 = 6.84$$

EXAMPLE CALCULATION OF NUMBER OF MULTIPLES:

Multiples of Cumulative Production = $2^Q = 2^{6.84} = 114$.

EXHIBIT 6-9

PRODUCTIVITY FOR THE FIRST THREE MONTHS

Expressed as Percent Productivity Efficiency - PPE

MACHINE	MONTH ONE	MONTH TWO	MONTH THREE
A	4.75	7.25	10.75
B	0.93	9.6	15.9
C	1.19	4.2	18.2
D	0.82	6.2	13.7
E	8.62	23.74	47.35
F	0.21	2.17	14.8
G	4.66	12.5	16.6
H	29.26	37.3	43.3
I	29.65	39.08	49.68
J	1.4	3.3	4.6
K	2.64	11.96	27.84
L	23.6	27.0	29.6
M	6.54	11.06	47.32
N	2.13	6.18	2.61
O	6.4	14.7	13.5
P	14.2	50.4	88.9
Q	2.1	2.3	12.8
R	11.86	24.1	17.0
S	67.9	64.8	76.7
T	6.92	18.3	43.3
U	11.43	23.1	43.5
V	13.8	22.3	44.8
W	4.6	9.6	11.6
X	6.2	10.9	14.9
Y	0.48	7.1	18.0
Z	8.7	17.1	16.1
AA	10.77	46.9	60.1
BB	4.37	9.1	11.1
CC	6.34	22.1	31.9
DD	8.52	14.1	31.2

resulted in longer than average startups, even although M.P. was not excessively lower. A couple of machines with high productivities in the third month already displayed flat slopes which predicated long startups, but most high, early PPE values preceded a short startup. The information in these early values can aid prediction.

The prediction procedure selected uses the mean PPE value of three months, located at mean cumulative production for that period. This position on the Manufacturing Progress Function is the best estimate of a point on the final regression line from the information available. These values, for each machine, were combined with the M.P. values estimated from the early slope in Exhibit 6-7. For some machines the average PPE figure of four or five months was used, rather than of three months. The consequent predictions from this procedure for startup time and lost capacity are shown in Exhibit 6-10. Eleven of the startup times and nineteen of the lost capacity values have been estimated within two months of the actual period by this procedure. This accuracy encourages the further use of the procedure which has been outlined.

Predictions Based Upon Early Months and Early Machines

This discussion and the figures displayed in Exhibit 6-10 testify that predictions can be made using a

EXHIBIT 6-10

PREDICTIONS OF STARTUP CHARACTERISTICS

Using Either Three, Four, or Five Months Regression
Compared with Actual Startup Characteristics

		M.P.			STARTUP TIME			LOST CAPACITY		
MACHINE	MONTHS	PREDICTION	ACTUAL	ERROR	PREDICTION	ACTUAL	ERROR	PREDICTION	ACTUAL	ERROR
A	3	1.34	1.34	0	68.4	69.4	-1.0	28.8	28.9	-0.1
B	3	1.54	1.67	-.13	19.4	7.5	11.9	11.9	4.1	7.8
C	3	1.51	1.49	.02	22.8	20.8	2.0	13.5	12.1	1.4
D	3	1.47	1.46	.01	31.6	32.7	-1.1	17.7	17.9	-0.4
E	4	1.43	1.41	.02	10.2	9.1	1.1	5.2	3.1	2.1
F	4	1.49	1.49	0	24.0	26.2	-2.2	13.7	11.8	1.9
G	3	1.42	1.38	.04	27.7	28.0	-0.3	14.1	12.8	1.3
H	5	1.25	1.25	0	25.2	29.6	-4.4	8.2	9.4	-1.2
I	5	1.24	1.15	.09	13.0	46.8		4.0	9.7	
J	5	1.46	1.53	-.0[illegible]	27.3	18.7	8.6	14.8	11.5	3.3
K	5	1.38	1.34	.04	21.2	28.3	-7.1	9.8	12.1	-2.3
L	5	1.17	1.28	-.11	341.	75.9		82.	27.1	
M	3	1.35	1.36	-.01	15.0	12.8	2.2	6.5	5.8	0.7
N	3	1.19	1.38	-.19	367.	75.7		93.	35.1	
O	5	1.31	1.30	.01	62.4	58.4	4.0	24.0	22.0	2.0
P	3	1.44	1.42	.02	6.3	7.8	-1.5	3.3	4.0	-0.7
Q	5	1.58	1.66	-.08	17.7	12.5	5.2	11.7	7.7	4.0
R	3	1.26	1.40	-.14	75.8	18.8	57.0	25.7	7.2	18.5
S	5	1.10	1.09	.01	22.4	98.5	-76.1	3.1	11.8	-8.7
T	3	1.31	1.25	.06	19.2	27.0	-7.2	7.5	8.8	-1.3
U	3	1.36	1.37	-.01	9.0	8.3	0.7	4.1	3.7	0.4
V	3	1.30	1.32	-.02	17.9	20.0	-2.1	6.8	8.0	-1.2
W	5	1.41	1.46	-.05	36.0	24.5	11.5	17.7	13.5	4.2
X	5	1.38	1.41	-.03	28.0	20.6	7.4	13.0	10.4	2.6
Y	5	1.43	1.48	-.05	23.8	17.9	5.9	12.5	10.2	2.3
Z	3	1.35	1.33	.02	48.3	53.4	-5.1	20.8	22.0	-1.2
AA	5	1.41	1.26	.15	8.9	20.8	-11.9	4.4	6.8	-2.4
BB	5	1.37	1.39	-.02	40.2	32.8	7.4	18.3	12.7	5.6
CC	5	1.40	1.26	.14	15.3	43.4	-28.1	7.4	14.4	-7.0
DD	3	1.46	1.39	.07	14.5	16.2	-1.7	7.8	7.8	0

combination of early data from a startup and startup characteristics from early machines in the sequence of the specific technology, CONCAST. The predictions given by the procedure described here are not unfailingly accurate. They do not predict the precise final measure of startup, which can be provided after startup is over, as described in the last chapter. However, these predictions are better than estimates which would be available without this procedure using the Manufacturing Progress Function.

CHAPTER VII

PLANT VARIABLES AFFECTING PRODUCTIVITY PROGRESS

All new CONCAST installations are not the same. The foregoing analysis, which fitted productivity data to the Manufacturing Progress Function, in order to measure and predict, has treated the thirty machines as if they were the same. In this chapter, four variables which are believed to represent the major startup affecting differences between CONCAST installations will be considered. These four plant variables are: degree of technological advance, management experience, product quality sophistication, and materials or energy supply. The definitions given for these variables in Chapter III will be restated. Following each definition, the validity of the variables will be discussed in light of the descriptive material uncovered in this research. This descriptive material must be debated in context of world wide, continuous steel casting, since reference to specific features of the plants under study would disclose their identity. Discussion will especially dwell on degree of advance of technology, so that development of this technology, as expressed by the variable, is thoroughly clarified. The thirty plants will be classified according to these four variables. The effects of these four plant variables upon five startup characteristics, as determined by the Manufacturing Progress Function analysis, will be investigated by multiple regression. The effect upon the rate and length of startup caused by differences from one CONCAST installation to another, as expressed by these variables, will then be discussed at the conclusion of the chapter.

Plant Variables

A conceptual scheme was used to select the few variables which represent the major differences between plants during startup out of the huge number of variables that are present. Buffa's general model for operational systems has been chosen as a concept which represents the total production system, and which is well known.[1] The variables have been selected to act as proxies for inequalities between plants in four of the six flows in that system. The four flows represented along with their respective variables are:

Capital Equipment Flow - Degree of Technological Advance

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[1] Elwood S. Buffa, Basic Production Management (New York: John Wiley & Sons, 1971), p. 29.

Population Flow - Management Experience

Orders Flow - Product Quality Sophistication

Materials or Energy Flow - Materials or Energy Supply

Information and cash flows are not represented by plant variables in this analysis. The rationale behind this selection has been more fully detailed in Chapter III. A discussion about the meaning and usefulness of each of these variables as a proxy for the disparities between a particular system flow at different plants, especially in relation to the CONCAST technology as it developed, along with the related definition for each, will be provided in the sections that follow.

Degree of Technological Advance

The following definition is excerpted from the full definition of TECHADV 1 which was stated in Chapter III.

> "A degree of technological advance is achieved, where a CONCAST machine has a design difference from earlier machines, such that the cast steel which it produces has more desirable dimensional characteristics, either (a) number of strands, (b) strand curvature, (c) perimeter dimensions, or (d) strand cross-section."

The pertinence of this definition will be aided by the discussion of the purpose of continuous steel casting and of its development which follows. The usefulness of this definition in disclosing startup differences between the thirteen plants, among the thirty studied here, which possessed a technological advance, and the seventeen which did not, can be considered subsequently.

Prior to the appearance of CONCAST, steelmakers traditionally poured liquid steel into ingot molds. A typical, large ingot measures 32 inches by 32 inches by 72 inches high and weighs ten tons. Smaller ingots are proportional in size. A 12 inch by 12 inch ingot, 28 inches high, weighs only half a ton. It generally is not economical to roll single pieces of steel smaller than this. Therefore, smaller ingots are not usually poured. But even the largest ingots present problems for further processing.

The problem faced by steelmakers in further processing of ingots is due to the discontinuous method of casting the steel. Frequently, the ingots are not as large as desired for economical rolling. However, their cross-section is too large for the center to cool quickly. When it does cool, and contract, a hollow, or pipe, is formed at the center top of the ingot. Up to 15% of the ingot has to be cropped off and scrapped to get rid of this pipe. The ingot then has to be reheated and rolled to a longer, thinner shape. This requires a furnace, fuel, and an expensive rolling mill. Scale forms on the ingot when it is reheated. An inventory of ingots is needed to sustain this intermediate rolling process. Processing time is extended to accomodate the operation. The discontinuous ingot casting operations present these many problems.

The purpose of continuous steel casting is to cast longer, thinner shapes and to avoid the cropping, reheating, scale, and rolling costs associated with such large cross-section ingots. Sir Henry Bessemer proposed the ultimate goal of casting in the finished, hot rolled size as described in Chapter IV. Some progress towards this goal had been attained by 1950, but development of the technology in the ensuing twenty years was more rapid.

The arduous steps to accomplish this development in the advance of the continuous steel casting technology tend to support the argument in favor of this plant variable, as it has been defined. Each installation with an advance disclosed certain new problems which had to be resolved during startup. The first commercial casting unit, at Atlas Steels Ltd., in Welland, Ontario, used a high head, vertical mold machine. Monitoring temperatures in the mold, so that neither freezeup nor breakout occurred, was one of the many difficult problems encountered. It finally abated when the right thermocouple became available. The experimental Barrow-in-Furness machine achieved several advances between 1952 and 1958, including the casting of very small 2 inch by 2 inch billets at over 500 inches per minute. The detailed log of 869 heats cast during these six years, indicates the hundreds of production system innovations and modifications necessary to accomplish the advance there.[2] The first vertical mold with bending to the horizontal, at Benteler Werke, Germany, in 1958, required a solution to breakouts just below the mold, due to stress imposed by bending at that weakest point. The first few curved mold machines, in 1964 and 1965, presented difficult strand alignment problems which had to be solved to prevent breakouts.[3] The introduction of 3, 4, 6 and 8 strand machines in 1965, 1966, and 1968, created metal flow problems in the tundish. The steel tended to be hotter and to flow faster at the tundish nozzles near the center, while the outboard nozzles had a tendency to freeze. Such problems required ingenuity and increased startup time to overcome. Wider, thinner shapes in slabs and dogbones had metal flow, homogeneous coolng, and mold development problems which needed resolving.[4] Each of these design innovations advanced the technology by casting longer, thinner steel. Each had special startup problems due to the innovations.

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[2] Iain M. D. Halliday, "Continuous Casting at Barrow," Journal of the Iron and Steel Institute, Vol. 191 (February 1959), pp. 121-63.

[3] B. Tarmann and W. Poppmeier, "Continuous Casting with Bow-type Machines," Continuous Casting of Steel: Special Report Eighty-Nine (London: Percy Lund, Humphries and Co. for the Iron and Steel Institute, 1965), p. 134.

[4] The Iron and Steel Institute, "Discussion One," Continuous Casting of Steel: Special Report Eighty-Nine, pp. 88-101.

The sequence of technological advance in continuous casting is not yet complete. Steel is not yet regularly cast in its final hot rolled form. Each of the steps described above did proceed a little farther towards Sir Henry Bessemer's ultimate goal. Each one appeared to have special problems during startup which were caused by the particular advance in the machine to cast longer, thinner steel. The special problems were related to the equipment, and its difference in design from predecessor machines. It does seem that the plant variable, degree of advance of technology as defined, represents a very important difference between machines or equipment flows. It seems that it can ~~be~~ used as a proxy for inequalities of equipment flow into the production system to isolate and measure the effect of this difference between plants upon the various startup characteristics.

We can now proceed to consider, and discuss, the usefulness of the second plant variable, management experience.

Management Experience

Management experience was defined in Chapter III as a nominal variable with two classifications as follows:

MGMTEXP 0 - The company owning the machine for which the data have been obtained has started up and operated one or more CONCAST machines previously.

MGMTEXP 1 - The machine for which data are reported is the first CONCAST machine which the company owning it has started up.

Analysis showed that management at nine of the thirty CONCAST plants had management experience by this definition MGMTEXP 0, while twenty-one did not have prior experience, as shown in Exhibit 7-1.

Intuitively it makes sense to most people that a group of managers who have started up and operated one CONCAST machine is likely to achieve a faster startup rate, and shorter startup duration, for a second or third machine. Men in the steel industry unfailingly stated that such experience was desirable. This desirability, is emphasized by some tales of inexperience which are both hair-raising and humorous, such as the tale which follows.

One company undertook to start up a continuous steel casting machine with only one manager who was extensively familiar with CONCAST startups. Three months into a slow startup, this man stopped in to the plant unexpectedly, after midnight, on his way home from a social engagement. A wild, motorcycle race was roaring around the plant yard at speeds up to 100 miles per hour. Amid the dust and the deafening whine and backfires of the motorcycles, bets were being made, and large amounts of money were changing hands. The whole steel plant crew was either participating or watching. Furious, the experienced, six foot six inch, three hundred pound manager slammed his heavy, luxury car across the race track, stopped the race, and demanded an explanation. The gang was subdued and apologetic. The larger size billets which they were making for the first time had broken out three times. It didn't seem worth while to try again. They had phoned everybody they could think of and had asked what to do. Were they running the large billets at the same number of inches per minute as the small billets? Yes, exactly! Had no one thought of running slower? Oh! They had been told to keep the speed absolutely constant. "Well," said the experienced manager, "Get to work now, and run this bigger billet at this specific lower speed, and you will not have breakouts." The solution, of course!

A hair-raising startup incident, due to inexperience! A month later, what could sound more humorous?

One experienced man was not enough in this case. Two or three would be better. Obviously the best transfer of experience will be provided by a complete management team, which has already worked together through an earlier startup.

Some evidence from other plants showed that untrained hourly workers retarded startup. They did not understand some basic functions. As a result, the manual learning curve started at a less efficient level and improved more slowly. Some startups in the group of thirty studied here were located in completely unindustrialized countries at near equatorial latitudes. These startups were longer in duration and had greater lost capacity than might otherwise be expected. The values were not deviant enough to conclude that lack of industrial skills in the hourly group significantly affected startup characteristics.

Supporting evidence for the use of the chosen measure of management experience was strong. One vigorous, cohesive group pushed through their fourth startup in record time with the elan of a veteran team. Difficulties due to power constraints, local labor traditions, a grounded supply boat and recalcitrant technicians were all smoothly surmounted, while technical CONCAST startup problems were being solved on an hourly or daily basis. Their sources of information from previous startups were so broad that the cause, and solution, of any problem was never in doubt for more than a few days. Accompanied by aggressive crash program spending where necessary, this experienced management so shortened the problem solving: identify, search, screen, implement cycle, that the sequence of all problems was quickly solved, and startup was complete. This and similar examples give strong evidence indeed that management experience as defined provides a good proxy for population flow in the total production system during startup.

Consideration of the third variable reveals some even more interesting differences in activities between the two classifications of the variable:

Product Quality Sophistication

DEFINITION: The definition given for Product Quality Sophistication was stated in Chapter III to cover two classifications of a nominal variable, as follows:

PRODQUA 0 - The machine is used for casting carbon steel only, as recorded in the CONCAST AG Register of Machines Installed, dated July 1972.

PRODQUA 1 - The machine is used to cast alloy and/or stainless steels, as recorded in the CONCAST AG Register of Machines Installed, dated July 1972.

This plant variable was chosen as a proxy to represent Orders Flow in the production system. To understand its usefulness, first, the exclusion of several other dimensions of orders flow from this definition will be discussed. Then, the relative simplicity of carbon steel orders will be examined in terms of a CONCAST startup. The complications to a startup caused by continuous casting alloy and stainless steel will next be contrasted with this simplicity. This contrast will be examined to show how the descriptive information gathered in this study tended to demonstrate that this variable, as defined, identified the major differences in orders flow between CONCAST plants during startup.

Orders flow in a raw steel plant may contain the dimensions of: number of orders, volume, quality constraints on any one analysis, and number of analyses. Since heat size was not changed in the plants studied, the number of orders, or conversely the size of items, had no effect. The order volume did cause a reduction in operating hours in a few plants. However, this variance was adjusted for previously in the standardization of monthly productivity. Thus, the quality constraints in any one steel specification and the number of specifications produced remain as the operative, orders flow variables in these CONCAST plants.

Carbon steel can be produced in many analyses, with many physical specifications. However, it does have virtually the same melting point and thermal conductivity for most kinds that are cast. Thus, the casting and cooling rates can be nearly the same for all carbon steels. Different practices are used for killing the steel to end the action of gases in the molten metal and so procure a fine grain. Other variations in procedure are used to obtain a particular surface or interior physical condition in the steel. But in many of the plants studied which made only carbon steel, one relatively simple procedure could suffice for all production. Often the objective was to produce just rebar and light angles. As one sales manager put it, "If it's black, rusts, and sinks when thrown in water, I can sell it." While this overstates the point, one, or a very few procedures, could make all the carbon steel in the plants studied. These procedures were repeated over and over again, so that learning and startup progressed promptly. That is the characteristic which justifies the segregation of carbon steel orders flow, as one class of plant variable.

Alloy and stainless are another matter entirely. Atlas Steels Ltd. managers listed fifteen analyses of stainless for which they standardized procedures in their original machine. Each one had a different combination of casting speed, water flow, and casting temperature. Each procedure had to be determined experimentally.[5] Alloys too have different melting points, different thermal conductivities, and require different casting combinations. Surface and internal quality specifications for both alloy and stainless tend to be more stringent than for carbon steels. One company spent two years developing a satisfactory procedure for a high quality alloy, before it produced even one good ton, and entered the startup phase. It is time consuming to establish a sound procedure for just one specification. Establishing the different procedures for many specifications is not only difficult for each one, but lack of repetition causes learning, and consequently productivity, to proceed more slowly. Examination of the descriptive information from these CONCAST startups disclosed that establishing these procedures was a difficult and time consuming activity indeed.

The variable under discussion, as it is defined, does

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[5] R. S. Wagstaff and G. E. Stock, "A Decade of Development in the Continuous Casting of Special Steels," *Continuous Casting of Steel: Special Report Eighty-Nine*, p. 117.

not fully disclose the number of procedures established, the relative difficulty of establishing them in light of prior knowledge, or the natural tolerance limits of the process. Some installations produced a number of different and difficult types of carbon steel. Some plants made many more specifications of alloy and stainless than other plants, including some specifications that demanded a very precise procedure for success. Yet it is clear that the choice of Product Quality Sophistication, as defined, represents the key difference in orders flow between plants studied. We shall find later that the results of this variable are truly significant.

Materials and Energy Supply

DEFINITION: The two classifications of this nominal variable, materials and energy supply, can be restated from the definitions in Chapter III, as follows:

> MATENRG 0 - Installed steel melting capacity and uninterruptable power supply, provided exclusively for the CONCAST machine, were adequate throughout the startup period, to supply liquid steel, as required, up to the steady state productivity level.
>
> MATENRG 1 - The company contributing the data reported that installed steel melting capacity, and/or uninterruptable power supply, provided exclusively for the CONCAST machine, were inadequate for some significant portion of the startup period, to supply liquid steel as required, up to the steady state level.

First, it is necessary to comment upon the efficacy of deleting an extensive list of other materials and energies not named here, so as to arrive at these simplified variables for the CONCAST plants studied. The function of this simplified material and energy flow in the startup can then be discussed. This discussion must be qualified for the uncertainty of classification of some of the plants, for this variable, due to its nature. Consequent to these factors, materials and energy supply flow turns out to be less indicative of differences between plants studied than some of the other plant variables.

Consideration of the first factor shows that many supplies of material and energy are required to make a CONCAST plant produce. Some can influence startup rates. For example, low levels in the rapeseed oil tank stopped production at one machine located in a non-industrialized country. Refills at the end of the day could not prevent it from emptying overnight and causing sticking and freezeups in the mold. When thefts of this lubricant were discovered for sale as a cooking oil, a laxative addition to the rapeseed ~~oil~~ promptly ended this supply shortage. The effect was short term and was not repeated. At another, large, sophisticated plant all the apron rollers broke within a short period. Unused components dismantled from other parts of the widespread plant quickly overcame this dilemma. Generally, the vast host of supplies, other than the essential liquid steel, are both cheaper and quicker to replace. They, therefore, have one time, short term effects on the startup, which can be neglected with reasonable confidence.

Molten steel and the power to produce it are not so easily procured if a plant has inadequate supplies. Most of these plants had electric furnaces that either were in operation previously or started up faster than the CONCAST machine. Electric furnace technology is well established. A number of plants did not have furnace capacity equal to the CONCAST machine capacity. Startup proceeded until it reached this capacity. It then plateaued or progressed very slowly while various stratagems were pursued to alter the furnace somewhat and get more steel. In a few locations, productivity plateaued until another furnace could be added. Some plants could not get enough electric power to melt continuously at peak capacity. Negotiations with a public electric utility sometimes took an extended time before this supply could be corrected. When activating the furnace caused lights in homes for several miles around to flicker and darken, the political reaction tended to make the delay even longer. These conditions limited or stopped the essential liquid steel supply to the CONCAST machine. Production could not proceed without it. Correction was expensive and took a long time. This sizeable and extended barrier to productivity progress caused a real difference between plants in the rate of startup, whereas other supplies did not seem to do so. On this basis, the simplification of the materials and energy supply flow, to include just the liquid steel, seems to be justified for the plants studied.

Unfortunately, even this simplification left difficulties of classification. Six contributing companies reported being short of steel or power. The effects on their productivity could be easily observed. Other companies were short to a more limited degree, and more may not have commented on shortages. Likely all plants were short for at least a week or two due to furnace contingencies. The impediments to gathering absolutely precise information have made classification difficult. Therefore, this variable has less value that might be desired. It is not as indicative as the other plant variables. Nevertheless, it has been successful enough to point out some of the real supply differences between plants which affect startup characteristics.

This descriptive evidence about the four plant variables, which was discovered during the research, tends to substantiate their selection as indicators of the differences between plants. The foregoing discussion was intended not only to substantiate the variables, but was also intended to give a practical picture of important differences between CONCAST plants during startup as a background for the report on multiple regression analysis which now follows.

Classification of Thirty Plants

The classification of each of these four variables, into which each of the thirty plants fell, is shown in Exhibit 7-1. Thirteen of the machines exhibited a degree of technological advance. This group includes many of the machines which initiated the most important improvements in continuous steel casting. The data in this study have been much enriched by the inclusion of such ground-breaking installations. Additionally, the near balance between thirteen machines with technological advance, and seventeen without, provides a sound basis for analysis.

The balance is not quite so equal for management experience, where only nine of the thirty companies had started up a prior machine. This lack is further compounded by the fact that some companies had started two, three, and even four machines. Thus, considerable difference in the depth of management practice existed within the group with experience. The range of management cultures, around the world, on four continents and in ten countries, is not expressed by this variable either. Nevertheless, a meaningful sample of machines has been obtained for each classification of this variable.

The same Exhibit 7-1 shows that nine of the thirty machines are classified in PRODQUA 1, indicating that they made alloy and/or stainless steels. Some of these companies are leading producers of alloy and stainless steels. Their

EXHIBIT 7-1

PLANT CLASSIFICATION FOR DUMMY VARIABLES MULTIPLE-REGRESSION

	TECHADV 1		MGMTEXP 1		PRODQUA 1		MATENRG 1	
MACHINE 'A'		1		1	0		0	
MACHINE 'B'		1	0		0		0	
MACHINE 'C'		1		1		1	0	
MACHINE 'D'		1		1	0		0	
MACHINE 'E'	0		0		0		0	
MACHINE 'F'	0			1		1		1
MACHINE 'G'		1		1		1	0	
MACHINE 'H'	0			1	0			1
MACHINE 'I'	0		0		0			1
MACHINE 'J'	0			1	0		0	
MACHINE 'K'		1		1	0		0	
MACHINE 'L'	0			1		1	0	
MACHINE 'M'	0			1		1	0	
MACHINE 'N'		1	0			1	0	
MACHINE 'O'		1		1		1	0	
MACHINE 'P'		1		1	0			1
MACHINE 'Q'		1	0		0			1
MACHINE 'R'	0			1	0		0	
MACHINE 'S'	0		0		0			1
MACHINE 'T'	0		0			1	0	
MACHINE 'U'	0			1	0		0	
MACHINE 'V'		1		1		1	0	
MACHINE 'W'		1		1	0		0	
MACHINE 'X'	0			1	0		0	
MACHINE 'Y'		1		1	0		0	
MACHINE 'Z'	0			1	0		0	
MACHINE 'AA'	0			1	0		0	
MACHINE 'BB'	0		0		0		0	
MACHINE 'CC'	0			1	0		0	
MACHINE 'DD'	0		0		0		0	
	17	13	9	21	21	9	24	6

*"0" = TECHADV 0 etc.
"1" = TECHADV 1 etc.

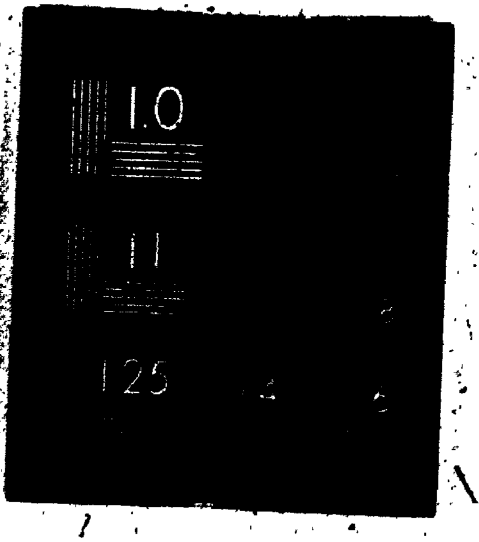
range and quality of product is outstanding. Many of the twenty-one carbon steel producers, on the other hand, concentrated on fast delivery of standard quality rebar and light structurals for the construction trade. Therefore, the split of machines between the two classifications of product quality sophistication also provides a suitable foundation for analysis.

The division between classifications in the fourth variable, material and energy supply, is not quite as suitable. Only six of the thirty plants are classified as having inadequate liquid steel or power. This inadequacy persisted throughout the startup period studied for five of the machines. Most of the other twenty-four plants are known to have had sufficient steel throughout CONCAST startup, although there may have been some brief shortages which were not identified. In any case, a firmer reference base would have been provided if more than six were classified as short of steel.

Multiple Regression Analysis

The four plant variables were multiple regressed against each of the five plant startup characteristics in turn. The five plant startup characteristics are: intercept 'a', slope 'b', Manufacturing Progress, M.P., startup duration, and lost capacity. It will be noted that the

3 OF/DE 4



nominal measurement of the plant variables puts them in dummy form rather than in continuous form. The plant variables are the independent variables. Each startup characteristic in turn is the dependent variable. The regression was carried out by computer using the multiple regression program of SPSS.[6] The regression progressed by omitting each plant variable in turn in order to investigate the effects of multi-collinearity. This whole process has been more fully detailed in Chapter III.

Multiple Regression Results

The summary results for these multiple regressions are given in Exhibit 7-2. The detailed results for each startup characteristic, with each plant variable omitted in turn, are shown in Exhibit 7-3 through Exhibit 7-7 respectively. These results indicate that each one of the startup characteristics is significantly affected by one or more of the plant variables.

The multiple R^2 indicates how well this prediction fits the actual values from the Manufacturing Progress Function. If the multiple R^2 values were 1.00, the fit would be exact, and the prediction perfect. The fact that multiple R^2

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[6] Norman Nie, Dale H. Bent, and C. Hadlai Hull, SPSS: Statistical Package for the Social Sciences (New York: McGraw-Hill Book Co., 1970), pp. 174-195.

EXHIBIT 7-2

EFFECT OF PLANT VARIABLES ON STARTUP CHARACTERISTICS

The Results of Multiple Regression with Dummy Variables

INTERCEPT = K_1 + C_{11}TECHADV1 + C_{12}MGMTEXP1 + C_{13}PRODQUA1 + C_{14}MATENRG1

INTERCEPT = 2.504 - 1.277 " - 1.843 " - .144 " + 3.714 "
(F = 1.028) (F = 1.788) (F = .011) (F = 5.527)
Overall: F = 2.853, Multiple R^2 = .313, Standard Error = 3.34

SLOPE = K_2 + C_{21}TECHADV1 + C_{22}MGMTEXP1 + C_{23}PRODQUA1 + C_{24}MATENRG1

= .439 + .116 " - .011 " - .045 " - .053 "
(F = 6.036) (F = .044) (F = .759) (F = .799)
Overall: F = 1.829, Multiple R^2 = .226, Standard Error = .126

M.P. = K_3 + C_{31}TECHADV1 + C_{32}MGMTEXP1 + C_{33}PRODQUA1 + C_{34}MATENRG1

= 1.363 + .114 " - .018 " - .046 " - .040 "
(F = 6.392) (F = .132) (F = .898) (F = .515)
Overall: F = 1.845, Multiple R^2 = .228, Standard Error = .119

STARTUP TIME = K_4 + C_{41}TECHADV1 + C_{42}MGMTEXP1 + C_{43}PRODQUA1 + C_{44}MATENRG1

= 30.69 - 1.41 " - 3.81 " + 11.05 " + 2.82 "
(F = .029) (F = .175) (F = 1.494) (F = .073)
Overall: F = .41320, Multiple R^2 = .062, Standard Error = 22.14

LOST CAPACITY = K_5 + C_{51}TECHADV1 + C_{52}MGMTEXP1 + C_{53}PRODQUA1 + C_{54}MATENRG1

= 10.18 + 2.56 " + .51 " + 4.51 " - 2.53 "
(F = .794) (F = .026) (F = 2.093) (F = .491)
Overall: F = 1.152, Multiple R^2 [illegible] .156, Standard Error = 7.65

EXHIBIT 7-3

REGRESSION OF INTERCEPT AGAINST PLANT VARIABLES

$$Y_{1n} = K_1 + C_{11}\text{TECHADV1} + C_{12}\text{MGMTEXP1} + C_{13}\text{PRODQUA1} + C_{14}\text{MATENRG1}$$

3 Variables

TECHADV1 Missing	= 2.0911		- -1.98609 (F = 2.097)	- 0.33988 (F = .063)	+ 3.80558 (F = 5.814)
PRODQUA1 Missing	= 2.47158	- 1.29606 (F = 1.123)	- 1.85241 (F = 1.887)		+ 3.73364 (F = 5.884)
MGMTEXP1 Missing	= 1.24149	- 1.45015 (F = 1.300)		- 0.26576 (F = .037)	+ 4.13319 (F = 6.914)
MATENRG1 Missing	= 3.88058	- 1.44595 (F = 1.126)	- 2.48492 (F = 2.883)	- 0.51524 (F = .123)	

All 4 Variables Included

Y_{1n}	= 2.50383	- 1.27725 (F = 1.028)	- 1.84273 (F = 1.788)	- 0.14439 (F = .011)	+ 3.71435 (F = 5.527)

Multiple Regression F = 2.85257 $(F_{.95}\ 4/25 = 2.78)$

Multiple R^2 = .31338

Standard Error = 3.34614

$(F_{.75}\ 1/24 = 1.39)$ $(F_{.95}\ 1/24 = 2.78)$

EXHIBIT 7-4

MULTIPLE REGRESSION OF SLOPE AGAINST PLANT VARIABLES

$$Y_{2n} = K_2 + C_{21}\text{TECHADV1} + C_{22}\text{MGMTEXP1} + C_{23}\text{PRODQUA1} + C_{24}\text{MATENRG1}$$

	K_2	C_{21} TECHADV1	C_{22} MGMTEXP1	C_{23} PRODQUA1	C_{24} MATENRG1
3 Variables					
TECHADV1 Missing	= .47646		+ .00224 (F = .002)	- .02694 (F = .235)	- .06143 (F = .898)
MGMTEXP1 Missing	= .43144	+ .11538 (F = 6.223)		- .04547 (F = .817)	- .05066 (F = .786)
PRODQUA1 Missing	= .42886	+ .11056 (F = 5.609)	- .01382 (F = .072)		- .04713 (F = .644)
MATENRG1 Missing	= .41916	+ .11881 (F = 6.358)	- .00164 (F = .001)	- .03945 (F = .603)	
All 4 Variables Included					
Y_{2n}	= .43885	+ .11639 (F = 6.036)	- .0108 (F = .044)	- .04475 (F = .759)	- .05311 (F = .799)

Multiple Regression F = 1.82966 $(F_{.75}\ 4/24 = 1.44)$

Multiple R^2 = .22645

Standard Error = .12583

$(F_{.975}\ 1/24 = 5.72)$

EXHIBIT 7-5

MULTIPLE REGRESSION OF M.P. AGAINST PLANT VARIABLES

$Y_{3n} = K_3 + C_{31}\text{TECHADV1} + C_{32}\text{MGMTEXP1} + C_{33}\text{PRODQUA1} + C_{34}\text{MATENRG1}$

3 Variables

TECHADV1 Missing	= 1.39925		- .00510 (F = .009)	- .02878 (F = 2.95)	- .04857 (F = .617)
MGMTEXP1 Missing	= 1.35029	+ .11198 (F = 6.488)		- .04735 (F = .981)	- .03639 (F = .449)
PRODQUA1 Missing	= 1.35221	+ .10764 (F = 5.873)	- .02096 (F = .183)		- .03428 (F = .376)
MATENRG1 Missing	= 1.34753	+ .11549 (F = 6.748)	- .01087 (F = .052)	- .04213 (F = .772)	

All 4 Variables Included

Y_{2n}	= 1.36253	+ .11365 (F = 6.392)	- .01786 (F = .132)	- .04617 (F = .898)	- .04045 (F = .515)

Multiple Regression F = 1.84498 $(F_{.75}\ 4/24 = 1.44)$

Multiple R^2 = .22792

Standard Error = .1194

$(F_{.975}\ 1/24 = 5.72)$

EXHIBIT 7-6

MULTIPLE REGRESSION OF STARTUP TIME AGAINST PLANT VARIABLES

$Y_{4n} = K_4 + C_{41}\text{TECHADV1} + C_{42}\text{MGMTEXP1} + C_{43}\text{PRODQUA1} + C_{44}\text{MATENRG1}$

3 Variables					
TECHADV1 Missing	= 30.24		- 3.96 (F = .199)	+ 10.83 (F = 1.523)	+ 2.92 (F = .081)
MGMTEXP1 Missing	= 28.09	- 1.76 (F = .047)		+ 10.79 (F = 1.480)	+ 3.69 (F = .134)
PRODQUA1 Missing	= 33.175	+ .049 (F = .000)	- 3.066 (F = .117)		+ 1.34 (F = .017)
MATENRG1 Missing	= 31.74	- 1.53 (F = .035)	- 4.29 (F = .240)	+ 10.76 (F = 1.491)	
All 4 Variables Included					
Y_{2n}	= 30.69	- 1.41 (F = .029)	- 3.81 (F = .175)	+ 11.05 (F = 1.494)	+ 2.82 (F = .073)

Multiple Regression F = .41320

Multiple R^2 = .062

Standard Error = 22.14

($F_{.75}$ 1/24 = 1.39)

EXHIBIT 7-7

MULTIPLE REGRESSION OF LOST CAPACITY AGAINST PLANT VARIABLES

$$Y_{5n} = K_5 + C_{51}\mathrm{TECHADV1} + C_{52}\mathrm{MGMTEXP1} + C_{53}\mathrm{PRODQUA1} + C_{54}\mathrm{MATENRG1}$$

3 Variables

TECHADV1 Missing	= 11.01		+ .80 (F = .066)	+ 4.91 (F = 2.543)	+ 2.71 (F = .571)
MGMTEXP1 Missing	= 10.53	+ 2.61 (F = .865)		+ 455 (F = 2.217)	- 2.64 (F = .581)
PRODQUA1 Missing	= 11.19	+ 3.155 (F = 1.175)	+ .81 (F = .064)		- 3.13 (F = .733)
MATENRG1 Missing	= 9.24	+ 2.68 (F = .887)	+ .94 (F = .096)	+ 4.77 (F = 2.413)	

All 4 Variables Included

Y_{2n}	= 10.18	+ 2.56 (F = .794)	+ .51 (F = .026)	+ 4.51 (F = 2.093)	- 2.53 (F = .491)

Multiple Regression F = 1.152 $(F_{.75}\ 4/24 = 1.44)$

Multiple R^2 = .15568

Standard Error = 7.65

$(F_{.75}\ 1/24 = 1.39)$

$(F_{.90}\ 1/24 = 2.93)$

values are well below 1.00, and the effect this has upon the predictors, must be discussed later.

Since the multiple R^2 values are relatively low, the possible multi-collinearity effect upon the coefficients in the linear equations have been disregarded. The highest multiple R^2 is .313, leaving 68.7% of the variance unexplained. Yet the coefficients of the variables in the linear equations are calculated to arithmetically encompass all of the variance. Added to this consideration, it can be observed in Exhibits 7-3 through 7-7 that the coefficient values are rather stable regardless of which variable is omitted from the regression. Thus the coefficients in Exhibit 7-2 appear to be accurate enough for the purpose here, and as accurate as the multiple R^2 values warrant. Therefore, no further attempt was made to calculate exact coefficient values by principal components analysis for the purpose of avoiding multi-collinearity. Values shown in Exhibit 7-2 were used without alteration.

The same exhibit also displays both the overall, and individual variable, F-ratios. Like the multiple R^2, a large F-ratio, too, indicates a better fit. The F-ratio expresses the ratio of variance explained by the regression to the residual variance. The F-ratios shown in Exhibit 7-2 are not strikingly high, but four out of five overall F's show considerable significance. Each equation contains one or more variables where the individual F-ratio expresses even more significance than the overall 'F' value. These warrant individual discussion.

Regression Results in Words

It may help if the general thrust of the regression findings is stated in words before commencing a more detailed discussion. This can be done by making one statement about each plant variable. First, a machine with a degree of technological advance is likely to have lower productivity in early months, but the slope and manufacturing progress will be much more rapid, so that startup duration will be no longer, although lost capacity may be slightly greater, than the average machine. A machine started without management experience is likely to have lower productivity in the early months, but other startup characteristics do not appear to be affected by this variable. A machine on which product quality sophistication, that is alloy and/or stainless, is produced is quite likely to experience a longer startup, with much more lost capacity. A machine which experiences material or energy supply shortages, that is not enough liquid steel or power, is likely to have started at a much higher level of productivity initially. Not all of these results are expected intuitively. A fuller discussion of each may be useful.

Effects of Individual Plant Variables

The most significant effect of technological advance is to increase the slope and manufacturing progress by about .11. This effect is significant at the .975 level, as evidenced by the F-ratios of 6.036 and 6.392, respectively.[7] The intercept, or initial productivity, tends to be lower with this variable, but the significance indicated by F = .028, is only at the .60 level. Lost capacity may be two and a half months greater with a technological advance, but the F of .794 can barely be called significant. These are not the results that might have been anticipated.

Intuitively, a technologically advanced machine might be expected to have startup progress more slowly, and so result in a longer startup, with more lost capacity. The result displayed here, may be due to a management willingness to work very rapidly, and to change almost anything, in an effort to overcome poor productivity in the first few months.

The second variable, management experience, shows a significant effect upon only one characteristic, the intercept. The regressions indicate that a lower intercept, or lower initial productivity, can be expected with significance at about the .80 level for F = 1.788, where

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[7] See, for example, Wilfred J. Dixon and Frank J. Massey Jr., Introduction to Statistical Analysis, Third Edition (New York: McGraw-Hill Book Co., 1969), pp. 472-85.

management experience was not available. The conclusion makes sense. It might also have been expected, however, from some of the descriptive information that this variable would have affected some of the other startup characteristics.

The effects of the plant variable, product quality sophistication, are much more in tune with the earlier discussion. Startup time is increased by 11.05 months, from the average of 30.69 months, when this variable is present, at a significance level above .75, since F is 1.49. Lost capacity increases by 4.51 months, from the constant of 10.18 months, with a significance of .90, for an 'F' value of 2.093. These levels of significance are not especially high. But the change in the values of these two startup characteristics is large. Also, the reality of this effect is supported by the descriptive evidence, which was discussed earlier, of the lengthy time required to establish successful procedures for making these steels of stringent quality. The statistical level of significance is likely lowered by the inclusion of several plants which undertook few grades, and simpler grades, of alloy and stainless. An important conclusion from this analysis appears to be that startup duration and lost capacity will be significantly extended where a CONCAST machine is started up to make a series of alloy and/or stainless steels.

The effect of the fourth variable, materials and energy supply, seems as logical, but not as important. A much higher intercept, or initial productivity, occurred where liquid steel or electric power were subsequently found to be inadequate during the startup. The F-ratio of 5.527 suggests a significance at the .97 level for this relationship. It may be that very rapid startup of the CONCAST machine quickly catches up with the limited steel and power supply at some plants, which then becomes the production bottleneck in such situations. The same steel and power limitations may have existed in other plants, but they never became operative, because of inability to cast the existing output. Also, it might be noted here that none of the machines with a materials or energy supply constraint were near the beginning of the chronological sequence. Most were recent machines. The situation of liquid steel and power shortages constraining startup nearly as frequently as the ability to operate the CONCAST machine may be evidence of the more normal situation which prevails when a technology matures.

Importance of Regression Analysis Disclosures

A further examination of the regression results shows that overall explanation of variance in the startup characteristics by the four variables in the linear equations is not nearly so significant as effects of the individual variables. The intercept equation is significant at the .95 level, and both slope and M.P. at the .75 level. Lost capacity and startup time significance is well below that. The multiple R values vary from .313 for the intercept down to .062 for startup time. This shows that between 6% and 31% of the total variance in the startup characteristics has been explained by the effects of the four plant variables, as discussed. It also points out that from 69% to 94% of the variance has not been explained by these relationships. The explanation of the effects of the individual plant variables is valid. But there is much more variance in the values of the startup characteristics which remains to be explained.

Other variables doubtless affect the rate and duration of startup. The four studied here are extremely simplified in definition. They have a significant effect upon startup characteristics, as hypothesized. It is encouraging that they have explained as much about startup as set forth in this discussion. Finer definition of these variables could produce further explanation. The earlier discussions about each supports their underlying importance. But new variables would likely have to be introduced for more complete explanation of the variance. One hint about a variable appeared in the analysis of vignettes. It appeared that some modifications were completed much more quickly at some installations than at others. This might be due to different management skills and attitudes. It is not necessarily related to management experience in starting up a prior CONCAST machine. Although this evidence is weak, it will be discussed at greater length in the concluding chapter. It appears to offer promise of a further explanation and, more important, of shortening startup. Pending the discovery of such a variable, the four plant variables studied here can be accepted as having significant effects on startup and as explaining some, but by no means all, of the variance in the startup characteristics.

CHAPTER VIII

CONCLUSIONS AND IMPLICATIONS

This chapter will commence with a summary of the research findings. These have been stated in detail in the preceding four chapters. Consolidation here is accompanied by additional emphasis and assessment which knits the results into a more cohesive body of startup knowledge.

This summary leads to a consideration of the theoretical implications of the research. The empirical data upon which the research conclusions have been based are a unique, broad-based, consistently assembled, and arranged set. It seems not unreasonable to induce from these facts some tentative generalizations. The implications of the relationships between these generalizations and current theory will then be discussed.

The practical implications of this research, to managers, can be developed from this discussion of generalization and theory. It is suggested that certain superior management startup actions can be deduced from the new generalizations. These will then be stated as recommendations to managers.

The recommendations are not nearly sufficient to solve all the problems of measurement, prediction, and expedition of startup. Some thoughts on the direction of future research which may help to remedy this insufficiency will conclude the thesis.

Summary of Research Findings

Productivity progress in CONCAST startups can be usefully measured by the Manufacturing Progress Function. Production in the early months of startup can be used to predict with reasonable accuracy the eventual startup duration and lost capacity, with the aid of this function. Although such measurement and prediction is possible, managers do not now use the Manufacturing Progress Function to forecast, plan, or control startup. Additional explanation of productivity progress is furnished by the four plant variables: degree of advance of technology, management experience, product quality sophistication, and materials and energy supply, which have an effect on startup characteristics. However, only a portion of the total startup variance between plants is explained by these four variables. These are the summary conclusions.

They can be more fully expressed by restating the six hypotheses proposed earlier with each followed by a statement of conclusions pertaining to it.

Measurement:

HYPOTHESIS 1: Productivity growth data from CONCAST installations will follow the Manufacturing Progress Function during startup, and regression lines will indicate high R^2 values.

Conclusions:

(1) Graphical analysis of standardized productivity data on Log-Log graph paper, for the thirty CONCAST machines, shows the clear linear trend of productivity progress. This growth phase is followed in a number of cases by productivity points distributed about a near horizontal line, which indicates a steady state phase.

(2) The monthly productivity data for the growth stage in each startup were regressed against the Manufacturing Progress Function, and high R^2 values were obtained. The median R^2 value was .92, with a range from .52 to .98. Only six R^2's were below .80. It is concluded from this test that Hypothesis 1 is true.

Some other useful measurements were disclosed by this linear regression procedure.

(3) The rate of manufacturing progress, M.P., which is the percent of productivity increase each time

cumulative production, is doubled, does not vary greatly from the median value of 1.38. Out of thirty machines studied, twenty-five had M.P. values within the range from 1.25 to 1.49.

(4) The duration of startup has been calculated from the startup regressions for these plants. The time taken is from 7.5 months to 76 months, with a median of 24.5 months.

(5) Lost capacity, as compared with a theoretical production at full capacity from the day of the first cast, has also been measured. It ranges from 3.1 months to 35.1 months, with a median of 11.5 months. The total lost capacity calculated in this way for the thirty plants amounted to 6,847,000 tons, which represents a theoretical lost contribution of $137 million, if that contribution is valued at $20 per ton.

These conclusions confirm that the Manufacturing Progress Function can be used to measure these characteristics of startup with useful accuracy.

Prediction:

HYPOTHESIS 2: The parameters 'a' and 'b' of the Manufacturing Progress Function can be forecast from productivity data during the early startup period, because of high R^2 values, and this prediction can be a basis for management planning of the remainder of the startup.

Conclusions:

(1) The final slope 'b' of the Manufacturing Progress Function can be predicted from the slope 'b' of the first few months of productivity data, but it is usually less than, not equal to, this early slope. The data from a sequence of machines is required to establish the basis for prediction, along with the early data.

(2) The early mean of productivity data, $\overline{X}$, $\overline{Y}$, provides an accurate point from which maufacturing progress can be projected, although the parameter 'a' of the Manufacturing Progress Function cannot be forecast from early productivity data.

HYPOTHESIS 3: Most managers do not forecast startup using the Manufacturing Progress Function.

Conclusion: True.

HYPOTHESIS 4: Those managers who do forecast startup using the Manufacturing Progress Function have difficulty predicting parameters 'a' and 'b' accurately.

Conclusion: One manager who did forecast startup using the Manufacturing Progress Function was not able to predict the parameters very accurately.

HYPOTHESIS 5: It should be possible to make increasingly more accurate predictions of the startup characteristics at each subsequent plant using a specific new technology. Startup characteristics are: parameters 'a' and 'b', M.P., startup time, and lost capacity.

Conclusions:

(1) It is possible to use the final Manufacturing Progress, M.P., values, from a sequence of plants in the new technology which have already completed startup, plus the early and final slope 'b' of these plants, to make increasingly more accurate predictions of M.P. at each subsequent plant.

(2) Lost capacity tends to be lower at later plants in the sequence, but although the correlation between these two trends is significant, it is not consistent enough from plant to plant to be used for prediction in an individual case.

(3) The parameter model expresses a consistent relationship between the intercept 'a' and the slope 'b' for a series of plants, but it cannot be used

for prediction because intercept 'a' is a theoretical value.

(4) Predictions of startup characteristics can be made by a calculation using the first three to five months of productivity data. The calculation also utilizes data from early plants in the sequence to determine the manufacturing progress rate, M.P. Many of these predictions of M.P., startup time, and lost capacity are serviceably accurate, as shown by Exhibit 6-10.

Plant Variables

HYPOTHESIS 6: Four plant variables tend to have a significant effect upon the startup characteristics. The four plant variables are: degree of advance in the specific new technology, management experience, product quality sophistication, and materials and energy supply.

Conclusions:

(1) A CONCAST machine with a technological advance tends to have a lower early productivity, faster productivity growth, and slightly more lost capacity than the average machine.

(2) The first CONCAST machine started up by a steel

company tends to show lower productivity in the early months than the second or third machine, but the lack of experience does not seem to affect the other startup characteristics.

(3) A CONCAST machine used to make alloy and/or stainless steels is very likely to have longer startup duration and much more lost capacity, than a machine making carbon steel.

(4) There is a greater probability that the shortages of liquid steel and power will retard startup where high initial productivity levels are attained with the casting machine.

Summarizing these statements, it can be concluded that productivity progress in CONCAST machines can be measured and predicted with helpful accuracy, using the Manufacturing Progress Function. Some plant variables which significantly affect startup characteristics have been identified. These conclusions have implications for existing theory, and can themselves assist managers to better forecast, plan, and control startup.

Theoretical Implications

The theory discussed in Chapter II does not include all of the relationships which are implied by the foregoing conclusons. Several startup characteristics have been added here to produce a more comprehensive description of the startup phase. Measurement of startup by the Manufacturing Progress Function has been applied to one, machine-intensive, new technology. Some variables which cause differences in this measure from plant to plant begin to explain the barriers to productivity progress. A rudimentary explanation of the cause of progress, through modifications, has been exposed by descriptions of startup. Generalizations of these discoveries imply some expansion to existing theory.

Measurement:

The startup characteristics, Manufacturing Progress, M.P., startup time, and lost capacity have not been proposed previously. Although M.P. is just the inverse of the learning curve percentage, its name and meaning seem to be more positive. Manufacturing Progress at a given percentage increase in productivity, each time cumulative production is doubled, is both meaningful and optimistic. Startup time, too, has meaning and substantial comparative value, based upon a precise mathematical calculation. Lost capacity, although based upon a theoretical ideal of full production from the first day, provides a mathematically calculated value which has meaning to both academics and managers. The addition of these measurement characteristics to startup theory should enrich the startup descriptions.

This enriched version of the Manufacturing Progress Function has proved to be a valid instrument for measuring one specific technology, CONCAST. Although the startup characteristic values are different from plant to plant, they still lie within a relatively small range. They show a consistency. Baloff has shown that several different machine-intensive technologies are adequately measured by the Manufacturing Progress Function. He does not present many examples from a single technology. However, the many examples of CONCAST startup, and Baloff's few examples from several technologies, show the same adequacy of measurement. It seems clear that productivity progress at plants using a machine-intensive technology can be usefully represented and measured by the Manufacturing Progress Function. This statement is a major generalization of the thesis.

This generalization is not intended to imply that a better measurement will not be discovered. Considerable evidence was uncovered in this research indicating that Levy's Function may describe productivity progress more accurately. Asher[1], too, showed some evidence that the

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[1] Asher, *Cost-Quantity Relationships in the Airframe Industry*, p. 82.

linear Log-Log relationship might not be the most accurate representative of the Aircraft Learning Curve. The mathematics of Levy's Function are currently too cumbersome for meaningful application. It is suggested here that the Manufacturing Progress Function is more useful than Levy's Function at the present time, and that it can be applied to measure startups in most machine intensive technologies.

Differences:

The differences between startups have not been determined as well as the similarities of measurement. If all startups were the same, then the startup characteristics, M.P., startup time, and lost capacity would be identical. It was noted that these values fall within a reasonably small range, but the differences are still significant. Some plant variables do explain part of this difference.

The plant variables: degree of technological advance, management experience, product quality sophistication, and materials and energy supply are recommended for future use. This research has indicated that they each have a significant effect. As noted in Chapter II, Feldman recommended a somewhat similar set of variables for predicting plant startup cost and duration. He did not show proof of their significant effect.[2] However, the evidence developed in this research, plus his endorsement, appear to validate the use of these variables.

Greater differences between plants remain unexplained by these variables. The practical man would say that the differences present such a long list that it is impossible to sort them out. Yet the essence of theory is the selection of just those variables, with their relationships, which consistently explain a large portion of the phenomenon under study. A look at prediction results in this research can assist in this selection.

Prediction:

The useful accuracy of the predictions has been noted. These predictions are based on data from the first three to five months of startup, plus a knowledge of the startup characteristics in the sequence of machines. Similarities of productivity progress are taken into account by the Manufacturing Progress Function measurements, and by the rate of progress based upon experience in the sequence. But the important differences are evident from the data themselves, usually in the first three months. These differences are sufficient to predict the final startup in

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[2] Feldman, Economics of Plant Startup, p. 90.

many cases. The plant variables did not explain enough of the variance to provide predictive power. Other variables must be involved, and their effect on progress throughout the startup must be closely related to the effect they have during the first few months.

Explanation of Manufacturing Progress:

A full theoretical explanation of the exceedingly consistent productivity progress, as expressed by the Manufacturing Progress Function, would clearly expose these other variables. Other investigators have disclaimed any attempt to explain the function. The consistency displayed by the measurements, and their ability to predict, seem to call out for an explanation. The descriptive evidence in this research will be culled to discover an explanatory relationship.

Eight vignettes described modifications to the production system. These modifications were shown to be the major activity during startup. Productivity increased when each modification was completed. Many modifications had to be completed to raise productivity to the final steady state level. The number, sequence, and duration of modifications was suggested as the major activity which determines the length of startup.

The number of modifications may be indicated by the plant variables which have been used, and recommended for future use. This number of modifications due to plant variables has a significant effect on startup characteristics. This effect is only a portion of the total variance.

The sequence of modifications is determined by the perception of the size of productivity increase which will result from a particular change. Welding the wheels of the crane was necessary to get any production at all at the time described in Vignette 'A'. Mold guides, in Vignette 'H', which were added after many months at another plant, improved good production by a few percent. The modifications with the big tonnage results are done first, and the ones with lesser results are done later. Weber's law of perception seems to operate in the selection of the sequence of modifications undertaken.

The remaining portion of the variance, not explained by the plant variables, seems to be due to two things. First, it is due to a willingness to change portions of the production system. Second, variance in startup rate and duration is due to the speed with which these changes or modifications are executed. Startups at initial high levels often proceed slowly. This appears to be due to an unwillingness to change original items in the production system that were good, but not good enough. Such a tendency was reported in a recent RAND Corp. paper, in relation to the initiation of air force production contracts.[3] Relative unwillingness to make changes has not been explicitly reported in the research done in this thesis. It is nevertheless suggested as a key variable.

The speed with which modifications are carried out has been identified as the other variable. Comparing and perceiving the discrepancy can be very time consuming, as shown by the analysis of vignettes. Search for alternatives was frequently carried out without knowing what exactly was the cause of the discrepancy in production. The hot, dirty, steamy environment of a CONCAST machine does not lend itself to observations of laboratory precision. Quick 'cut and try' solutions carried out on ten problems at a time often thinned the ranks of outstanding questions without precise definition of either question or answer. Yet such laboratory precision was often needed in order to contrive an alternative which would provide a successful modification. Screening did not seem to take a great deal of time in most of the vignettes described. Implementation, however, was a lengthy process in several of the situations. The result was that most of the modifications took weeks or months. It is postulated here, albeit on the basis of slim descriptive evidence, that the speed of making modifications determines the rate and length of startup to a great degree.

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[3] J. A. Marschak, The Role of Project Histories in the Study of R & D, P-2850 (Santa Monica, California: The RAND Corp., 1964), p. 118.

This speed seems to have some consistency within a single plant. That is the consistency which is believed to permit prediction on the basis of three to five months of data.

This attempted explanation of the cause of the Manufacturing Progress Function is admittedly tenuous. However, considerable thought and observation have been applied to arrive at it. It is an attempt to combine careful conjecture with extensive observation to provide a theoretical basis for the Manufacturing Progress Function. If this theoretical implication eventually proves to be near the truth, then its practical value may be greater than other contributions in this thesis. It is tendered here, in spite of the sketchy evidence supporting it, because of this great potential value.

Practical Implications and Recommendations to Managers

Managers can improve startup of plants incorporating a machine-intensive technology by taking certain actions deduced from the foregoing theoretical implications and research findings. These actions can certainly improve measurement and prediction. It is believed that they can accelerate productivity progress as well. Some recommendations for CONCAST managers can be more specific than for managers of other technologies. The startup recommendations for all machine-intensive technologies will be placed first.

RECOMMENDATIONS FOR STARTUP AT ANY MACHINE-INTENSIVE PLANT:

1. Obtain Log-Log graph paper, and plot on it monthly production in consistent units, against cumulative production to date. Standardize operating hours as explained in Chapter III, in order to compensate for sales or other fluctuations not related to the ability to produce.

2. Apply linear regression monthly, to the productivity data plotted on the graph, starting with the third month. Complete startup will be measured by the final regression, which is succeeded by twelve steady state months, as defined in Chapter III.

3. Calculate startup characteristics intercept 'a' and slope 'b', M.P., startup time, and lost capacity, from this final regression, as described in Chapter III. These characteristics provide a complete measurement of startup.

4. Gather startup productivity data from earlier plants using the same technology and obtain their startup measurements using the Manufacturing Progress

Function analysis, above. An industry association might execute this task with confidentiality and economy.

5. Predict the rate and duration of startup of the plant, by combining regression results from early months productivity data, with the early and final M.P. values from prior plants in the technological sequence.

6. Produce only one, or a very few product specifications during startup. Make products with broad tolerances and simple specifications, first. Gradually add more ~~products~~ with more difficult specifications, but only one at a time.

7. hire managers and operating crew men who are experienced in the particular technology, so as to achieve early high productivity levels.

8. Be willing to change anything in the production system. Provide substantial funds to pay for changes. (A suggestion to estimate "substantial" might be 20% to 40% of capital cost.)

9. Form a startup modification group to initiate,

monitor and expedite modifications. (Appendix III provides one suggested form that such a group might take.) The faster the modifications are completed, the faster the startup.

10. Take particular care to observe accurately the condition at the point of difficulty in the process, with laboratory precision, and do not spare expense for this purpose. Many of the modifications described in the vignettes were easily accomplished, once an accurate specification of the existing condition was procured.

RECOMMENDATIONS FOR CONCAST MANAGERS:

1. Make many heats as quickly as possible. Many small heats tend to provide a faster startup than the same tonnage in large heats. Learning occurs according to the number of times a procedure is repeated.

2. Cast only a few grades of carbon steel with simple specifications, at first. Add required alloys or stainless grades, one at a time, the simplest first. Repeat frequently, heats of each added analysis of steel, until the process for casting it is completely and successfully defined. The fewer and simpler the grades of steel cast, the faster

productivity will progress.

The recommendations above have been stated in point form for brevity. The reasoning behind each one, and the method of implementing each, are more fully detailed on earlier pages of the thesis. In a more general vein, this research implies that startup can be measured, predicted, and probably accelerated. It is a long period, measured not in days, weeks, or months, but in many months or several years. Research findings stated earlier display a scale of startup duration and lost capacity, which can alert managers to the size of the startup task. Measurement and prediction can increase the certainty of startup. Identifying and speeding modifications can shorten the task.

The Direction of Future Research on Startup

Further explorations of the startup phenomenon are suggested by the questions raised in this research. Additional measurements in other technologies, and refinement of the measuring instrument, present themselves as obvious candidates. The difference between plants might be clarified by a closer look at the variety and difficulty of product specifications. Motivating a startup crew with a Manufacturing Progress Function target could provoke some interesting research findings. However, more important than these appears to be the need for research into an explanation for the Manufacturing Progress Function, which has begun so tentatively here.

Measurement of productivity progress at a number of plants, in each of several new technologies, appears to be the most obvious next step in startup research. The Manufacturing Progress Function would be used to measure productivity progress by a method similar to the one used here. Typical technologies which come to mind for investigation are: the float glass process, computer controlled paper making machines, and color TV tube production lines. Many other technologies would be just as suitable. The central tendency and variance of startup rate, and startup duration for these various technologies could then be compared with each other and with CONCAST. The extension of results for several technologies, to an unresearched technology, would then be easier and more accurate.

Measurement might also be advanced by further research into Levy's Function. Currently data can be fitted to the function only by an iterative procedure which converges to a near optimum. The initial parameters for this procedure are difficult to estimate. Research might first fit a number of sets of data to the function to find whether it does describe startup better than the Manufacturing Progress Function. If so, then the mathematical procedures, and the meaning in terms of progress as a constant portion of the unachieved productivity, might be further refined. This research could be combined with the suggested investigation of startups in other technologies.

The differences between startup from plant to plant might be elucidated by careful observation of the number and difficulty of product specifications at various sites. The number of products which require different procedures during startup could be counted at each site. The relative difficulty of achieving the procedure for each product, in relation to the natural tolerances of the manufacturing process, could be classified into three or four categories, and ranked in order of difficulty. An investigation such as this might better define the product quality sophistication variable used in this research, and make it much more useful in explaining and managing startup.

Another area of research which holds promise for better startup management is the motivation of startup managers and crew with a growing productivity target. The Manufacturing Progress Function could be estimated in advance and a higher target production level set each month on this basis. A similar paired plant would use the final full production level as a target. Research results from a number of paired plants might show whether this motivation could increase the startup rate, if the many obstacles to such an enquiry could be overcome.

Investigation of the areas described above will undoubtedly aid the understanding of startup, but research into an explanation of the Manufacturing Progress Function is likely to yield the most valuable insights. It has been shown in the descriptive vignettes that production system modifications create productivity progress, but measurements of the specific gains were not available. Managers' perception of the potential productivity gain from a modification was identified as a probable determinant of the modification sequence, but perception and results were not compared. A modification group, designed to initiate, monitor, and expedite was recommended, and a specific structure suggested on the basis of theoretical considerations, but no empirical proof of its effectiveness was shown. The manual learning curve was postulated as a source of productivity progress, as operating and maintenance crews became more skilled at their jobs, but the extent of this factor was not determined. Each of these sources of productivity progress contains important possibilities for explanation of the cause of the Manufacturing Progress Function. It is believed that each would yield fruitful explanatory results with careful research.

The productivity progress from each modification could be gathered from a group of three or four similar plants, as a first effort. Each modification of equipment, people, procedures, materials and energy, orders and cash could be meticulously recorded and compared between plants. The productivity gain achieved by each could be ascertained with the aid of some rules for awarding the gain consistently between modifications. The time scale for comparing, searching, screening, and implementing can be recorded and compared between plants. The extent and timing of productivity gains from these modifications could then be qualified and assessed to find whether they explain the regularity of productivity growth.

A second research project could duplicate that suggested immediately above, but in addition managers' perception of the potential gains from each modification could be ascertained in advance. Using the same methodology as before to determine actual productivity gains for each modification, the actual and perceived gains could easily be compared. This research could then determine whether the sequence of modifications is determined by Weber's Law of perception, and the effect which that has on productivity progress.

Either one of these immediately preceding projects might encompass a modification group at one of the plants, organized in accordance with the modification group design suggested in Appendix III. Comparison of the time to complete modifications, by this group, with the time for modifications at other plants would indicate the efficacy of the described group structure. If it did not appear to be as effective as anticipated, alternate structures could be tested in subsequent research.

Finally, the portion of productivity progress explained by the manual learning curve might be discerned by future research. All procedures of hourly crew members and teams would be listed and timed. A count of repetitions of each procedure would be recorded as the startup progressed. At intervals, a time study would be carried out on each procedure. The manual learning curves for all procedures could then be plotted. The productivity gain from manual learning could be totalled, and its portion of total productivity progress could then be delimited. This would likely establish a satisfactory explanation for a portion of the progress which is represented by the Manufacturing Progress Function.

This research, which is suggested for the future, could vastly expand knowledge of startup. It would undoubtedly lead to improvements in the system of measurement. Understanding the effect of many product specifications and motivation by a moving progress target are likely to reveal ways to faster startup. An explanation of the cause of such regular progress, as evinced by the Manufacturing Progress Function, is likely to be the most useful research finding of all. With these potential values at the end of the trail, the above projects are recommended to future researchers.

It is hoped that this thesis has made its own contribution to the understanding of startup and that others will be encouraged to assist in the exploration of this fascinating period in the life of every plant.

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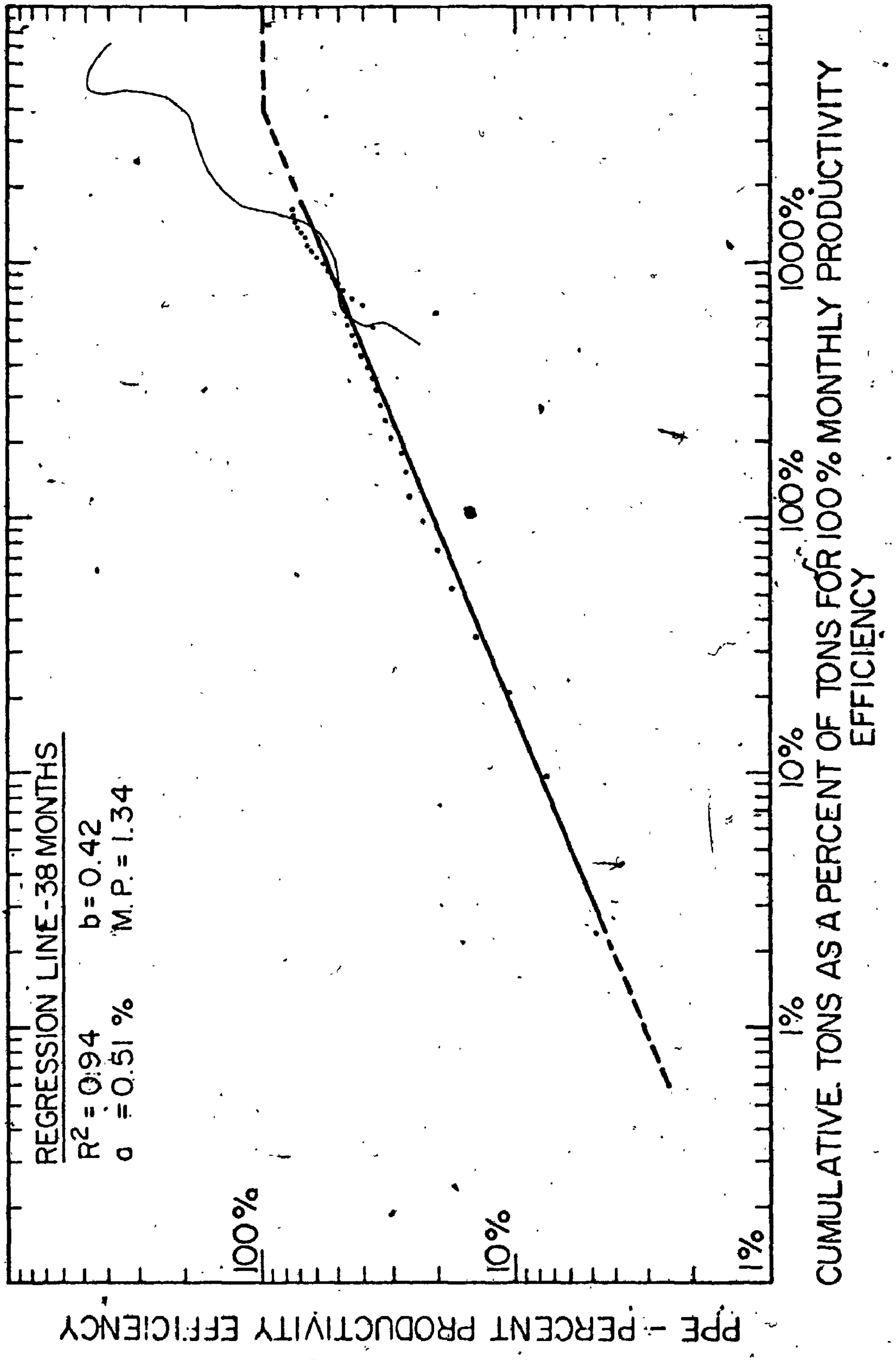
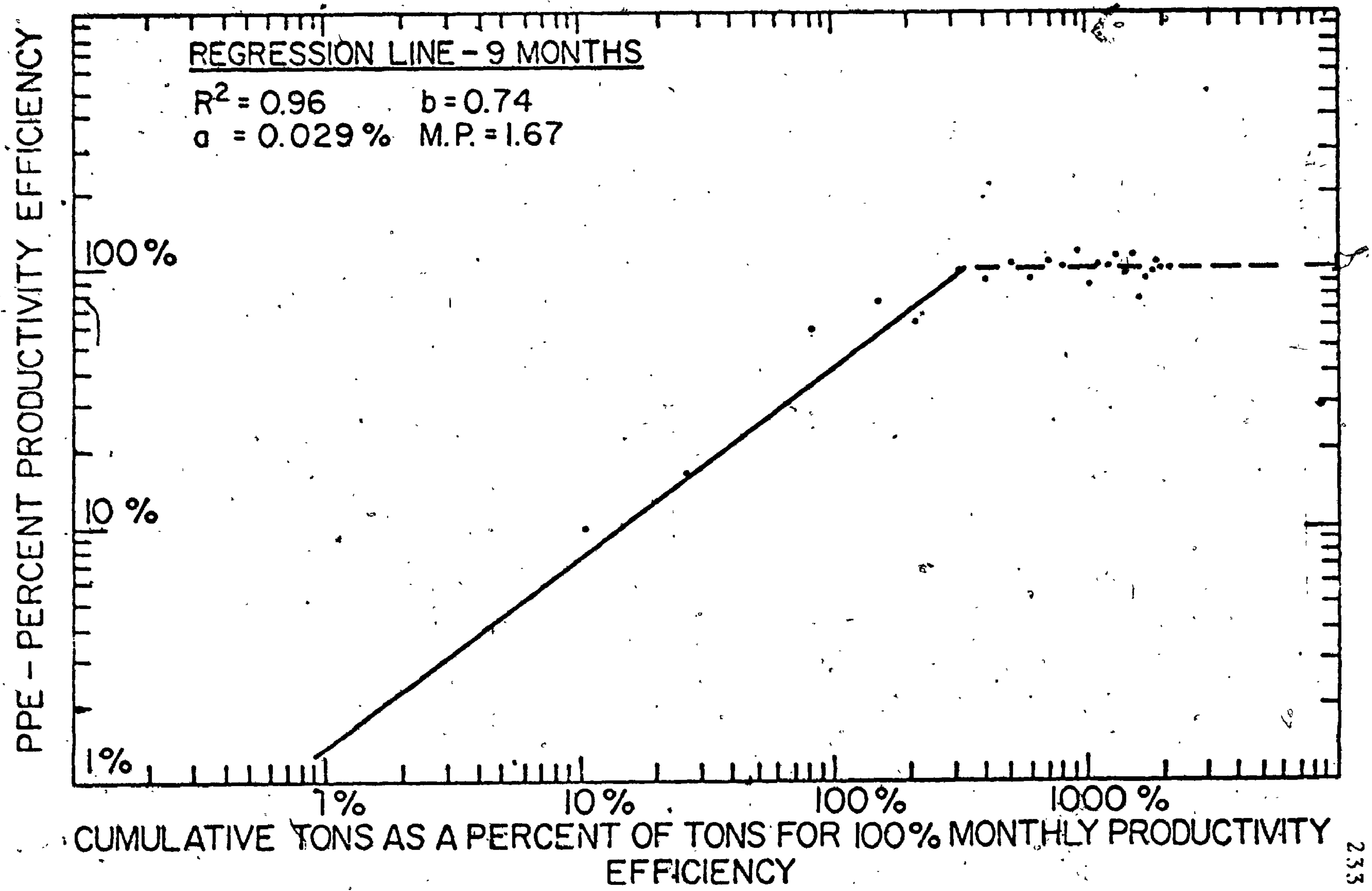
APPENDIX I

STARTUP GRAPHS WITH REGRESSION LINES FOR THIRTY CONCAST MACHINES

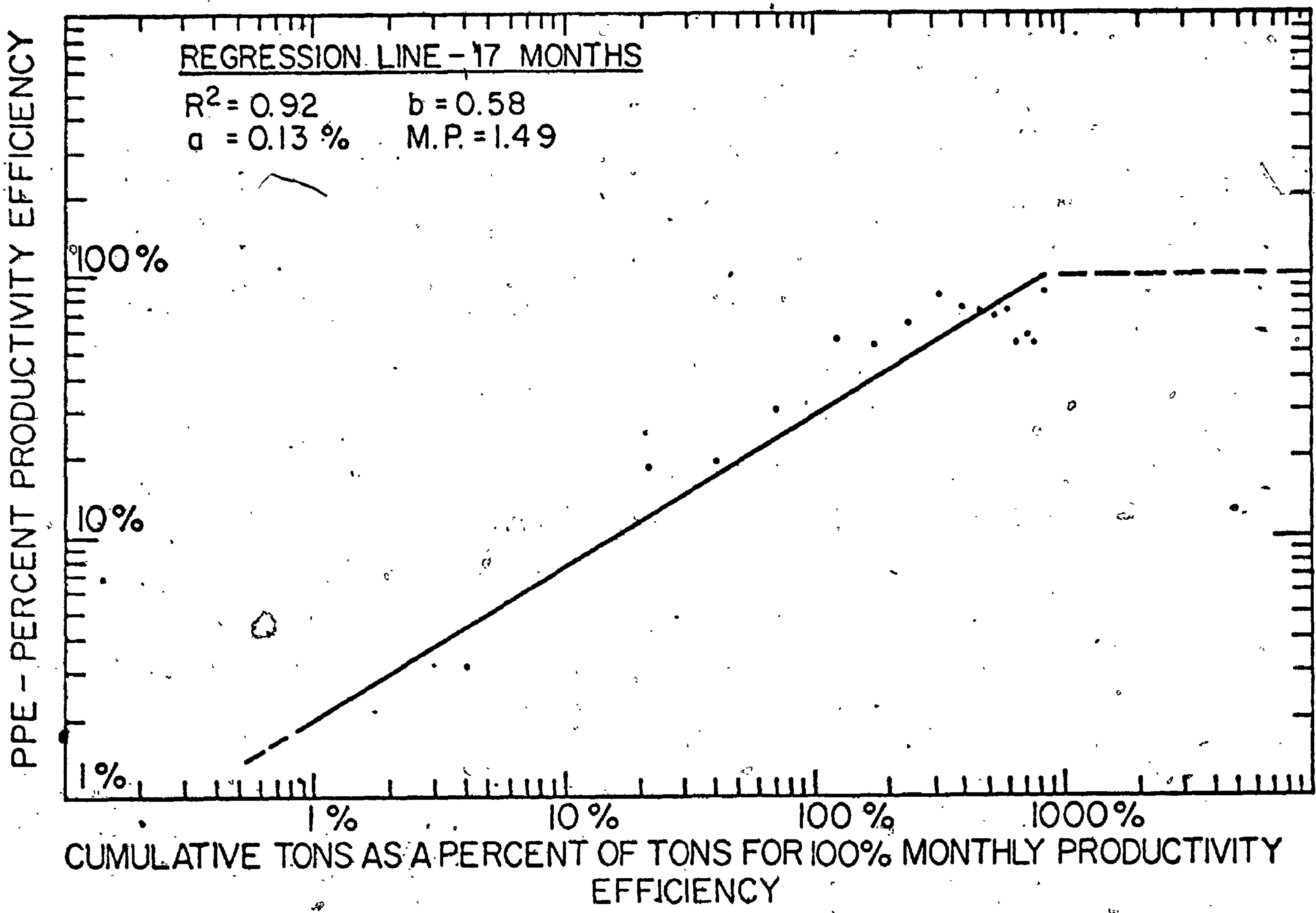
MACHINE 'A' - CONCAST STARTUP



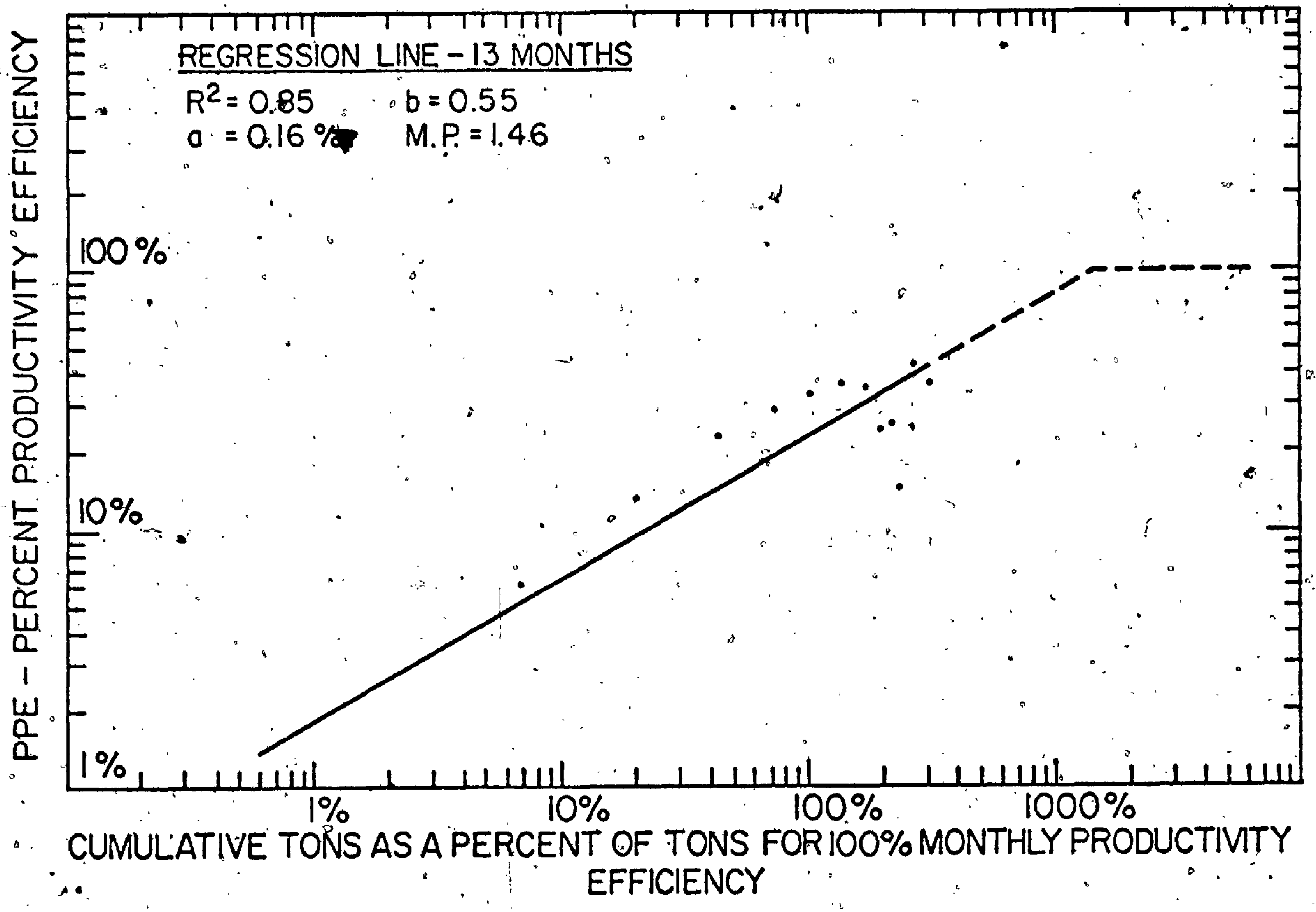
MACHINE 'B' - CONCAST STARTUP



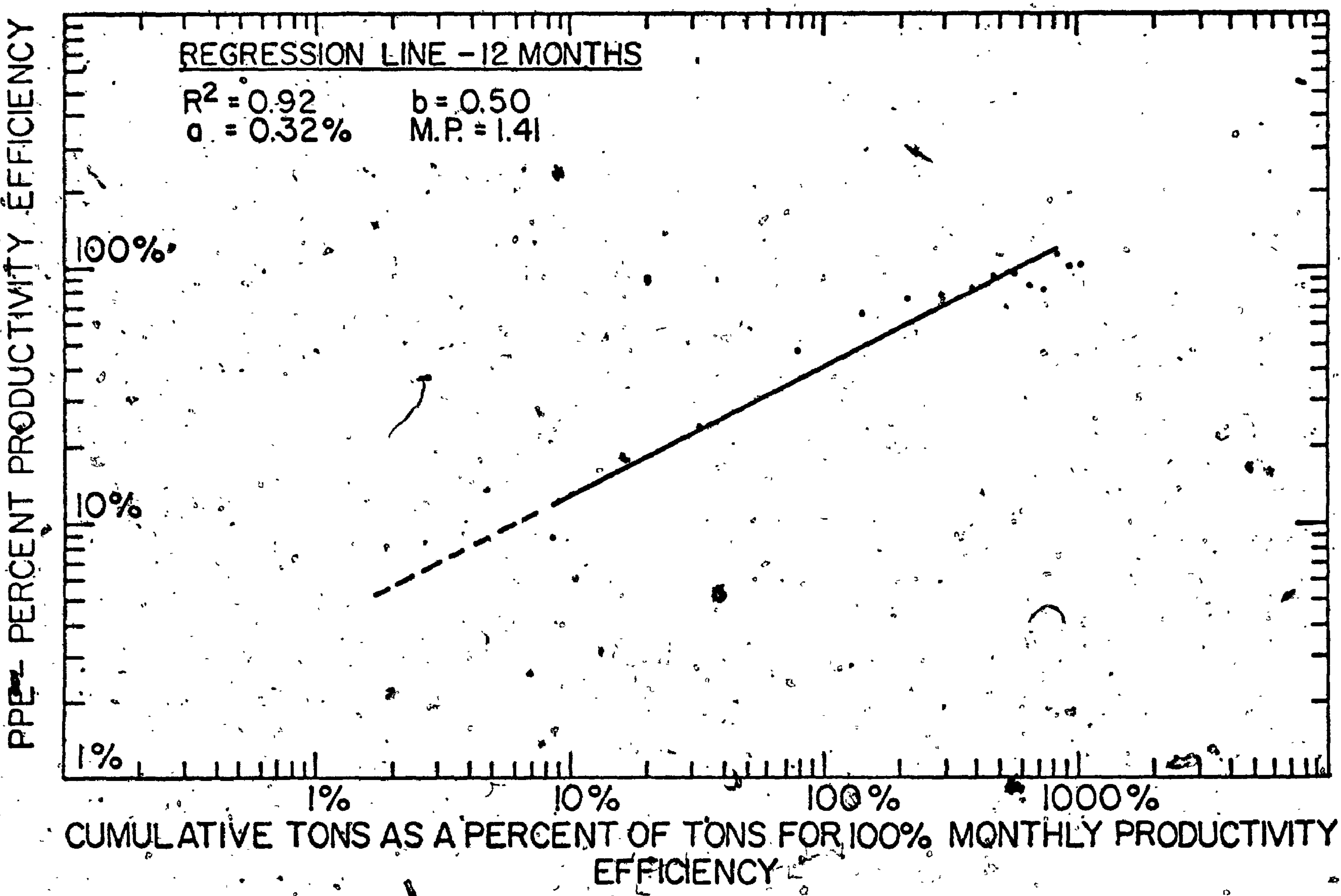
MACHINE 'C' - CONCAST STARTUP



MACHINE 'D' - CONCAST STARTUP



MACHINE 'E' - CONCAST STARTUP



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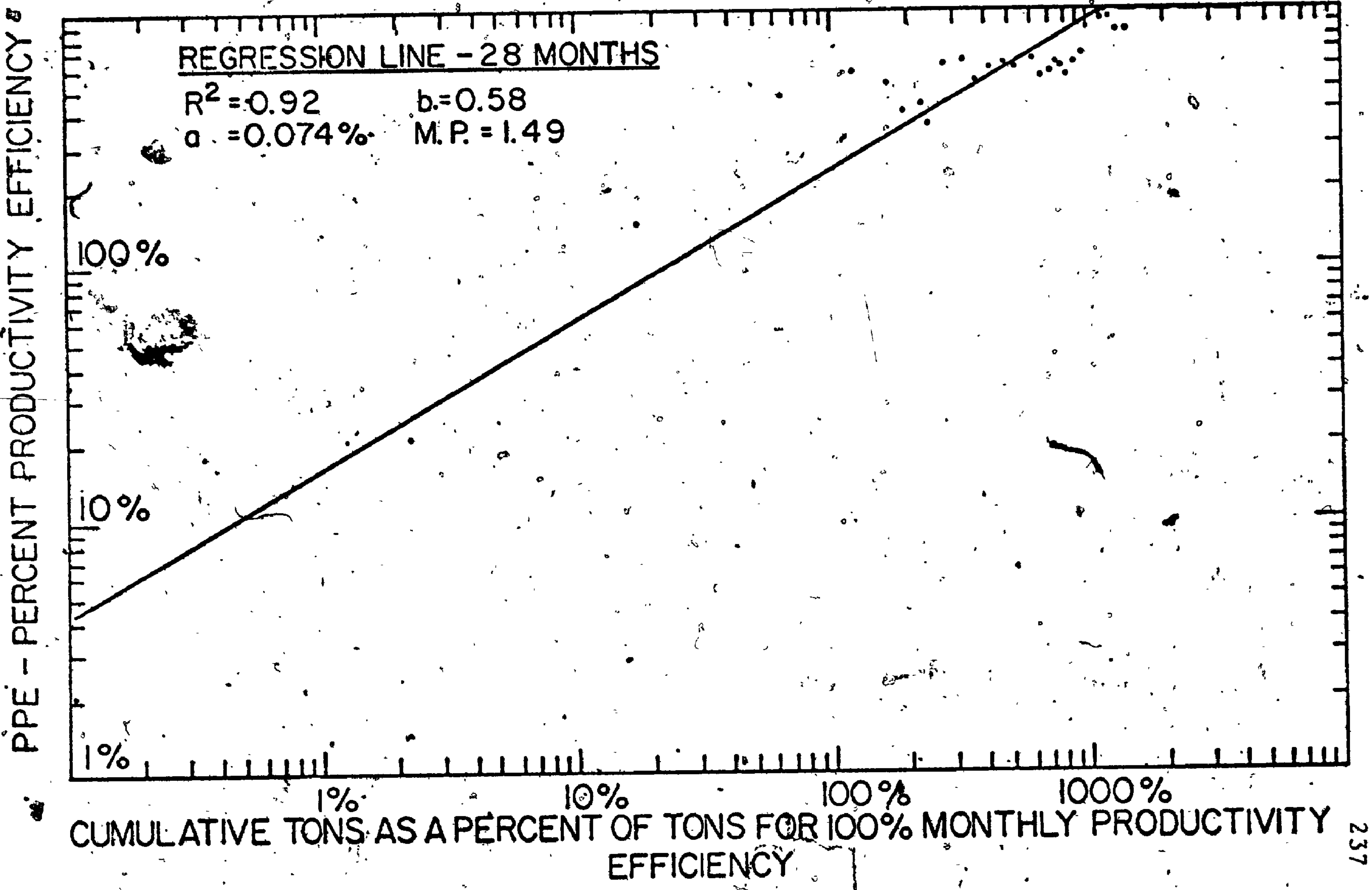
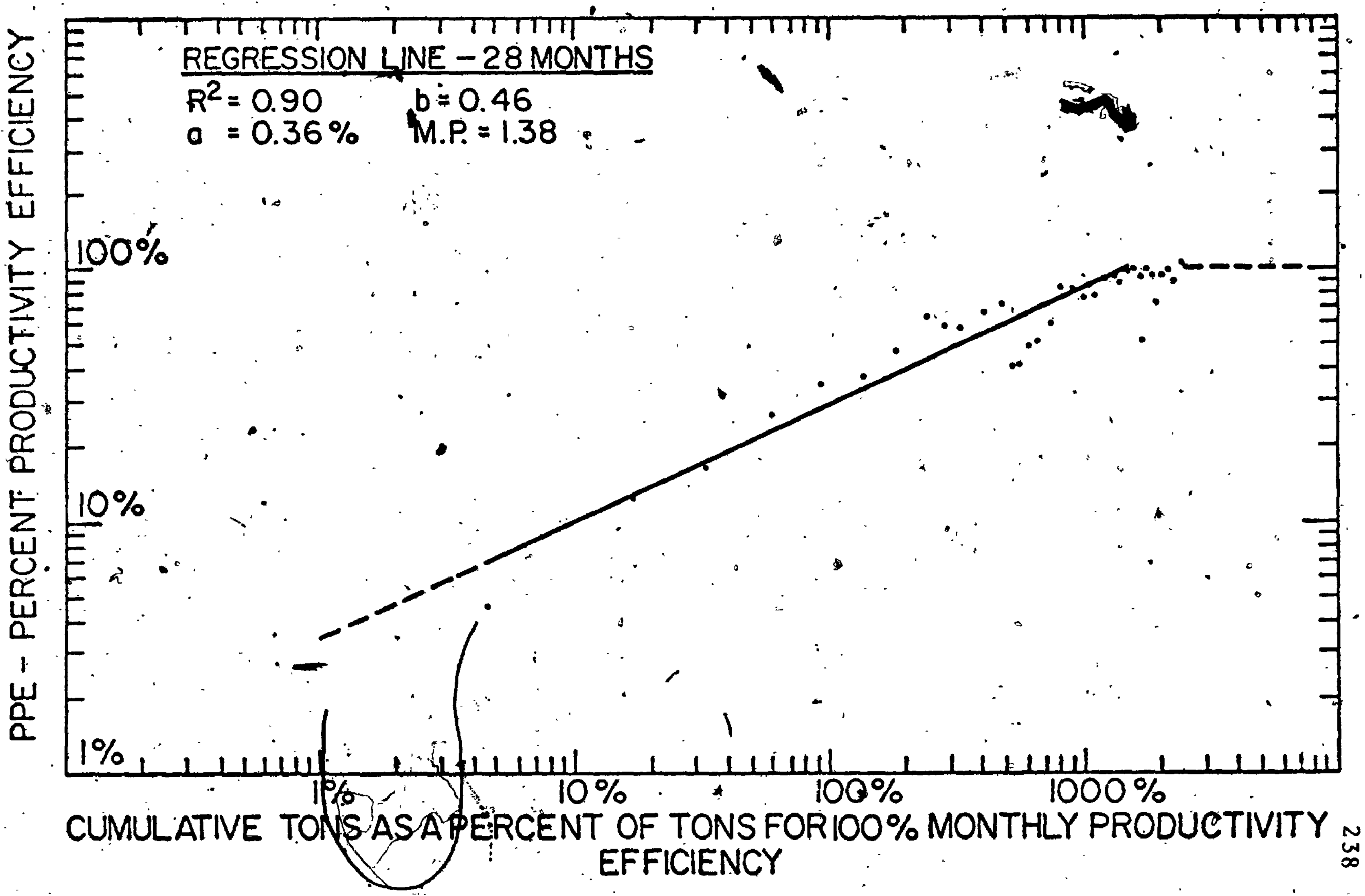
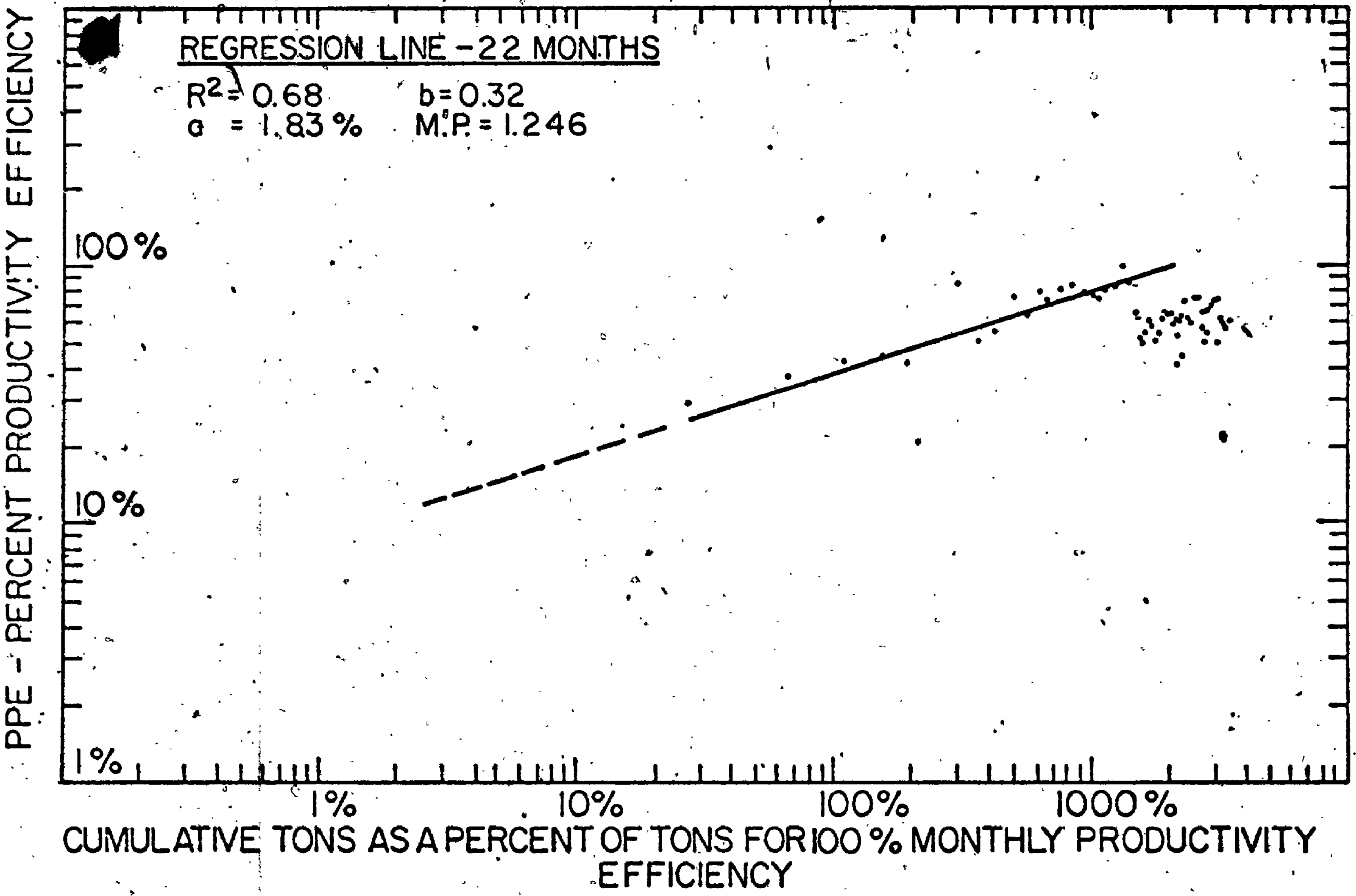


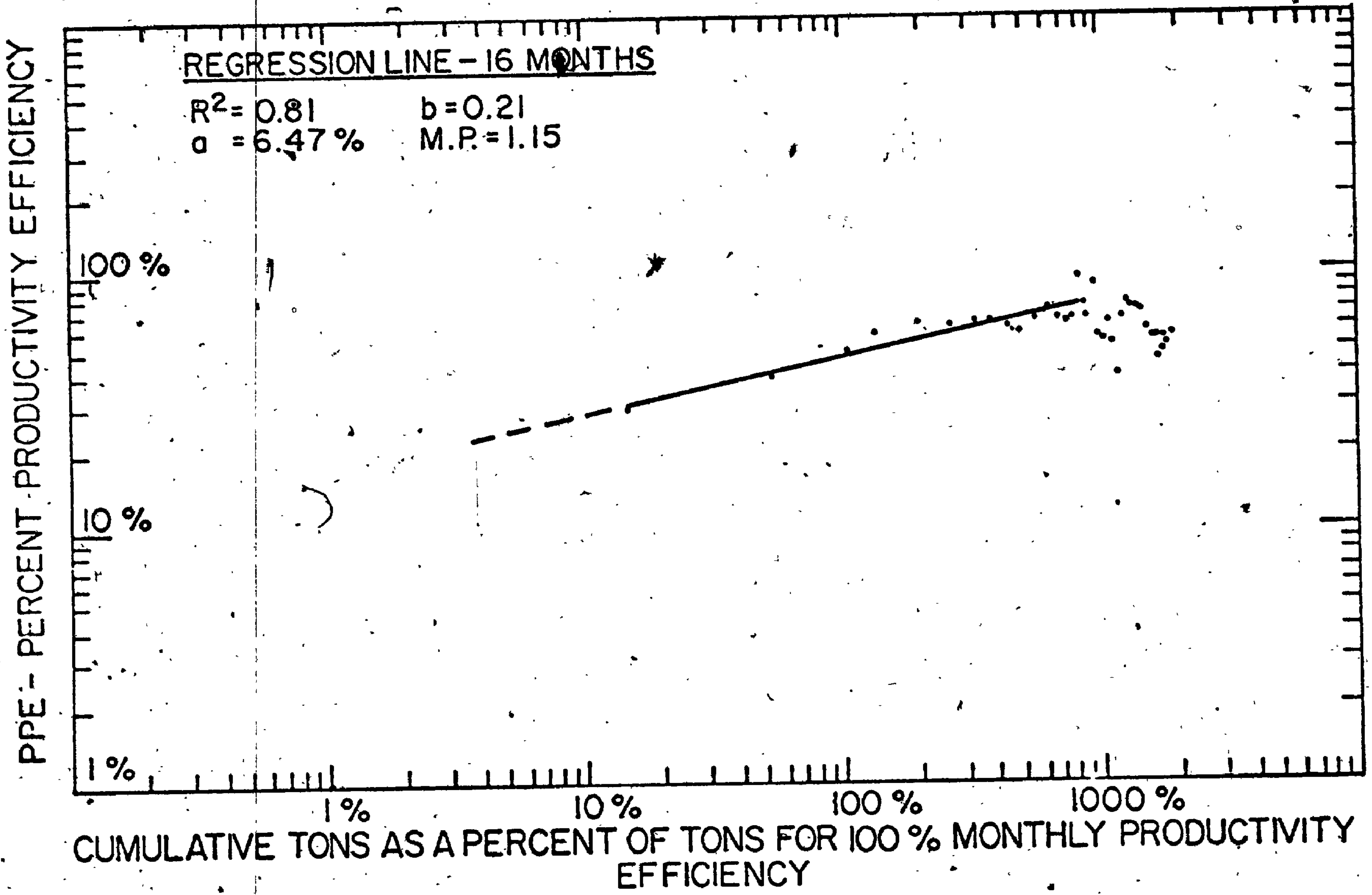


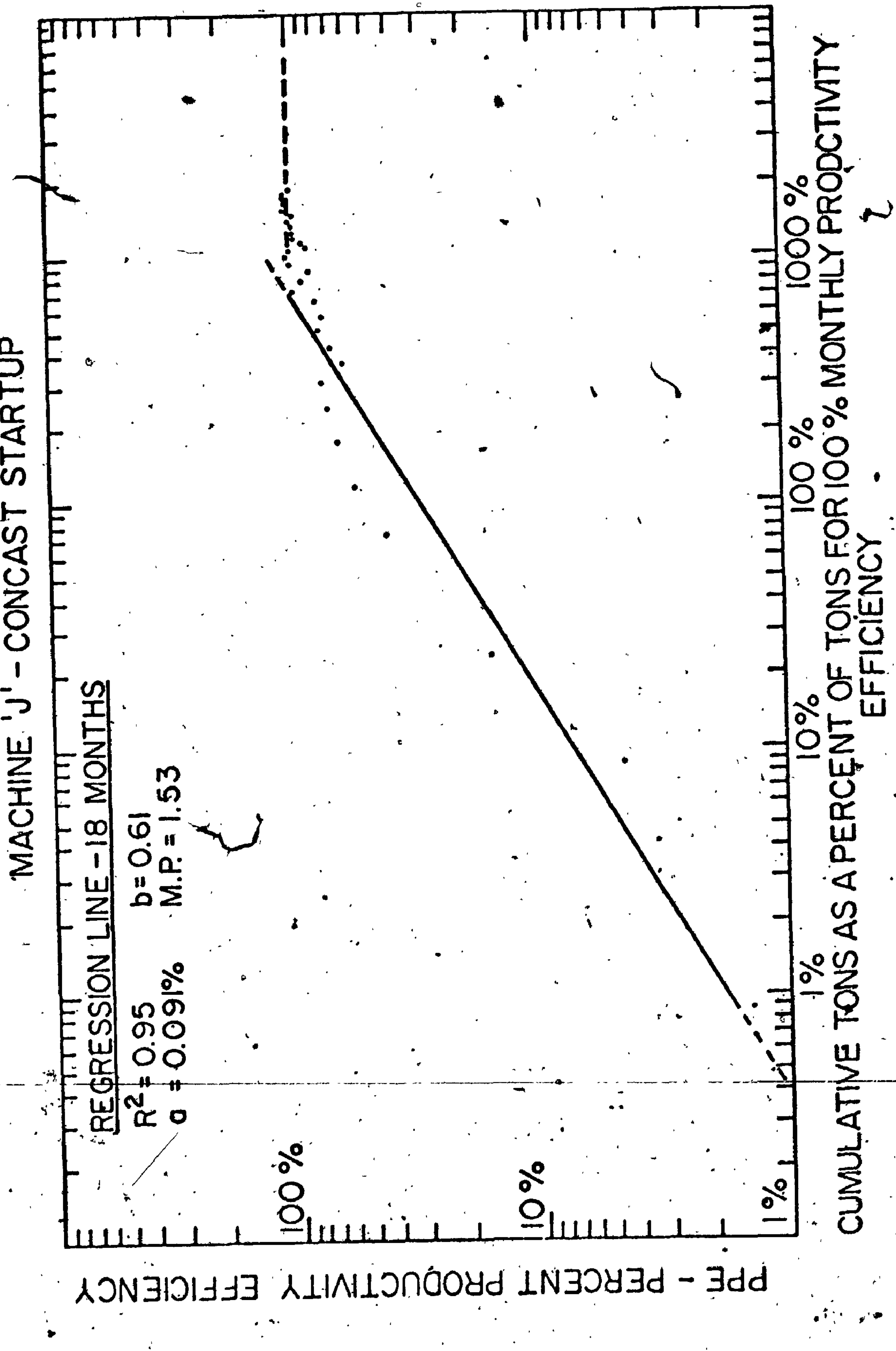
MACHINE 'G' – CONCAST STARTUP

MACHINE 'H' – CONCAST STARTUP

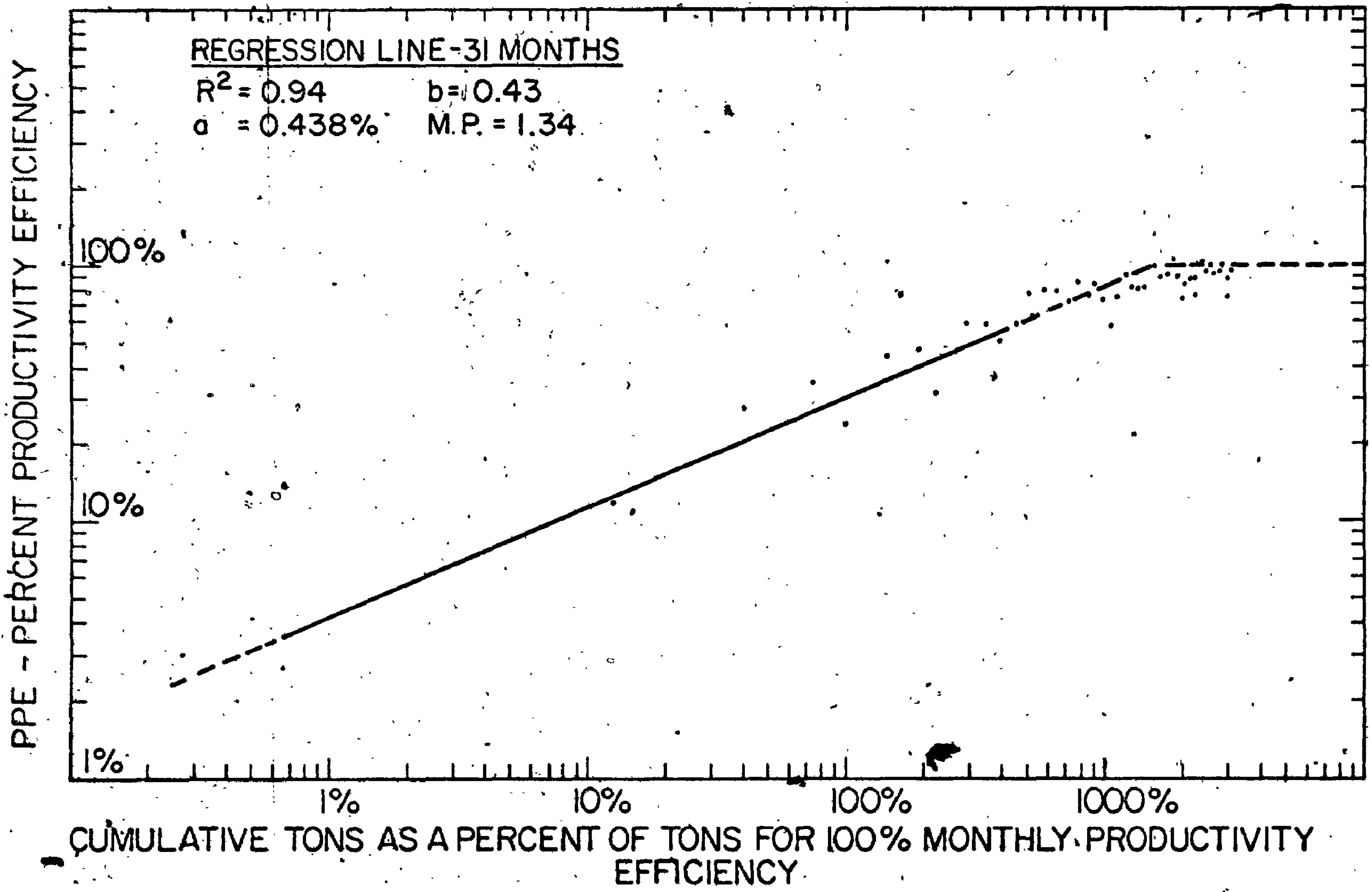


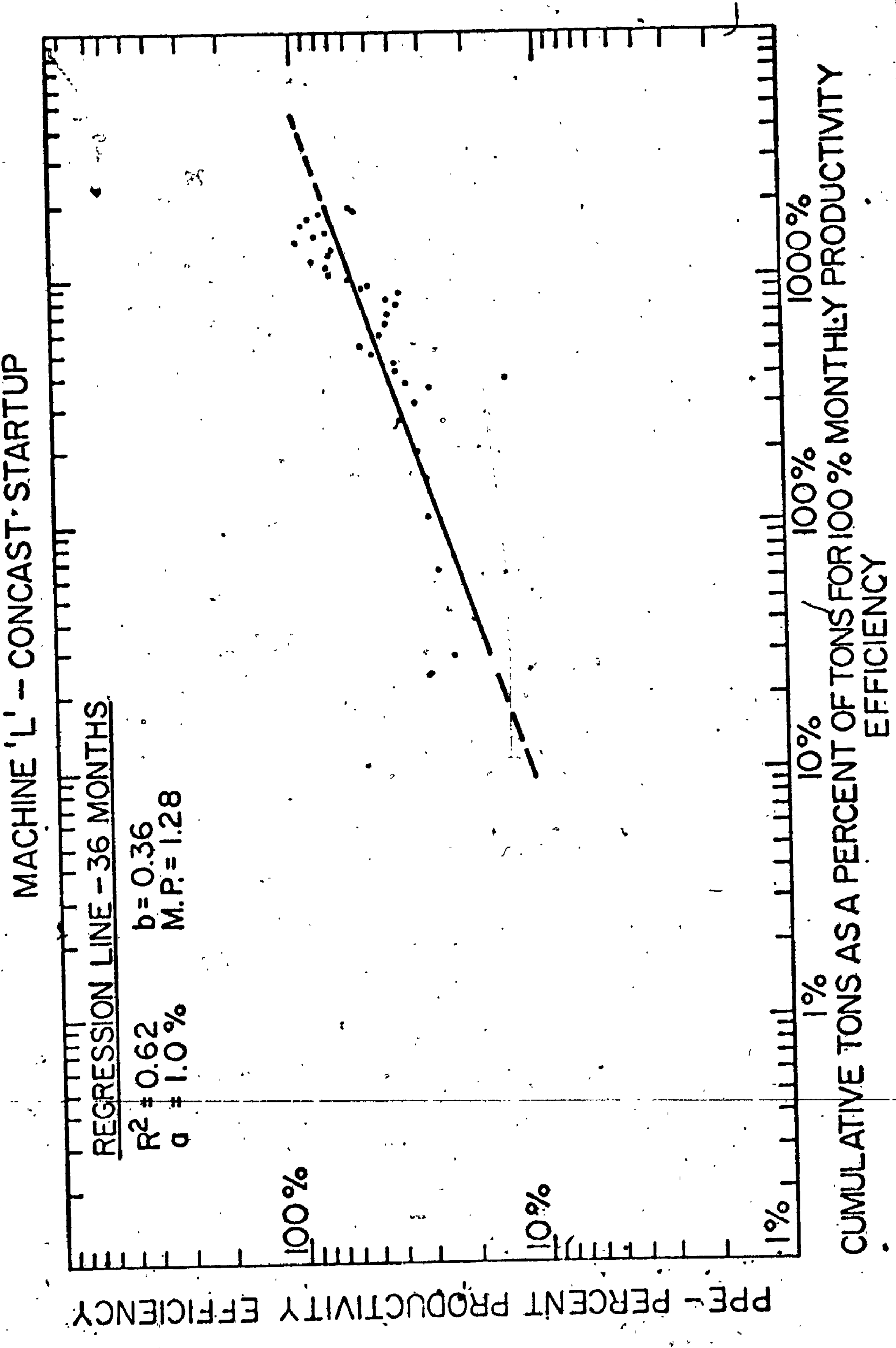
MACHINE 'I' - CONCAST STARTUP



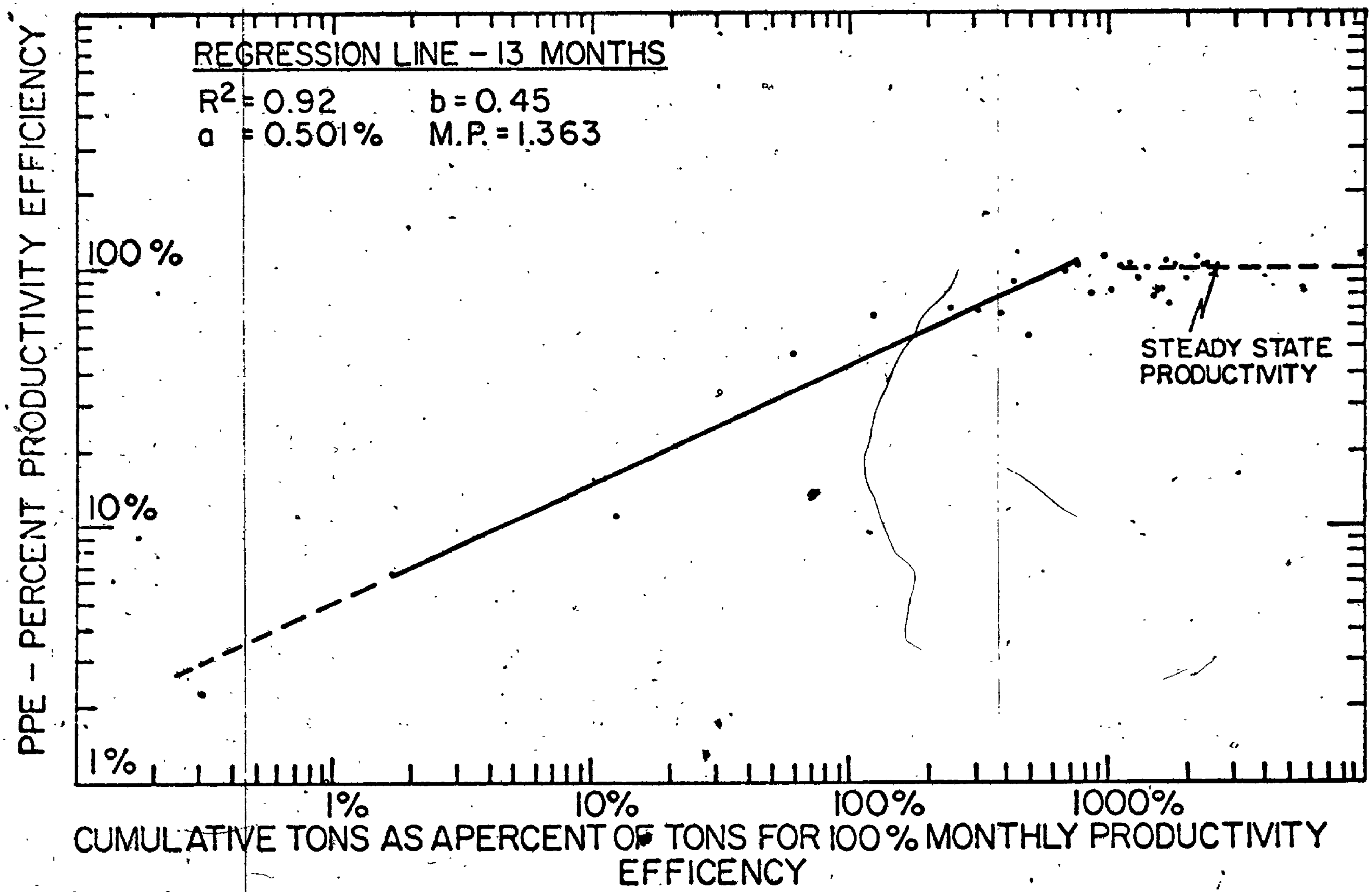

MACHINE 'J' - CONCAST STARTUP

MACHINE 'K' – CONCAST STARTUP

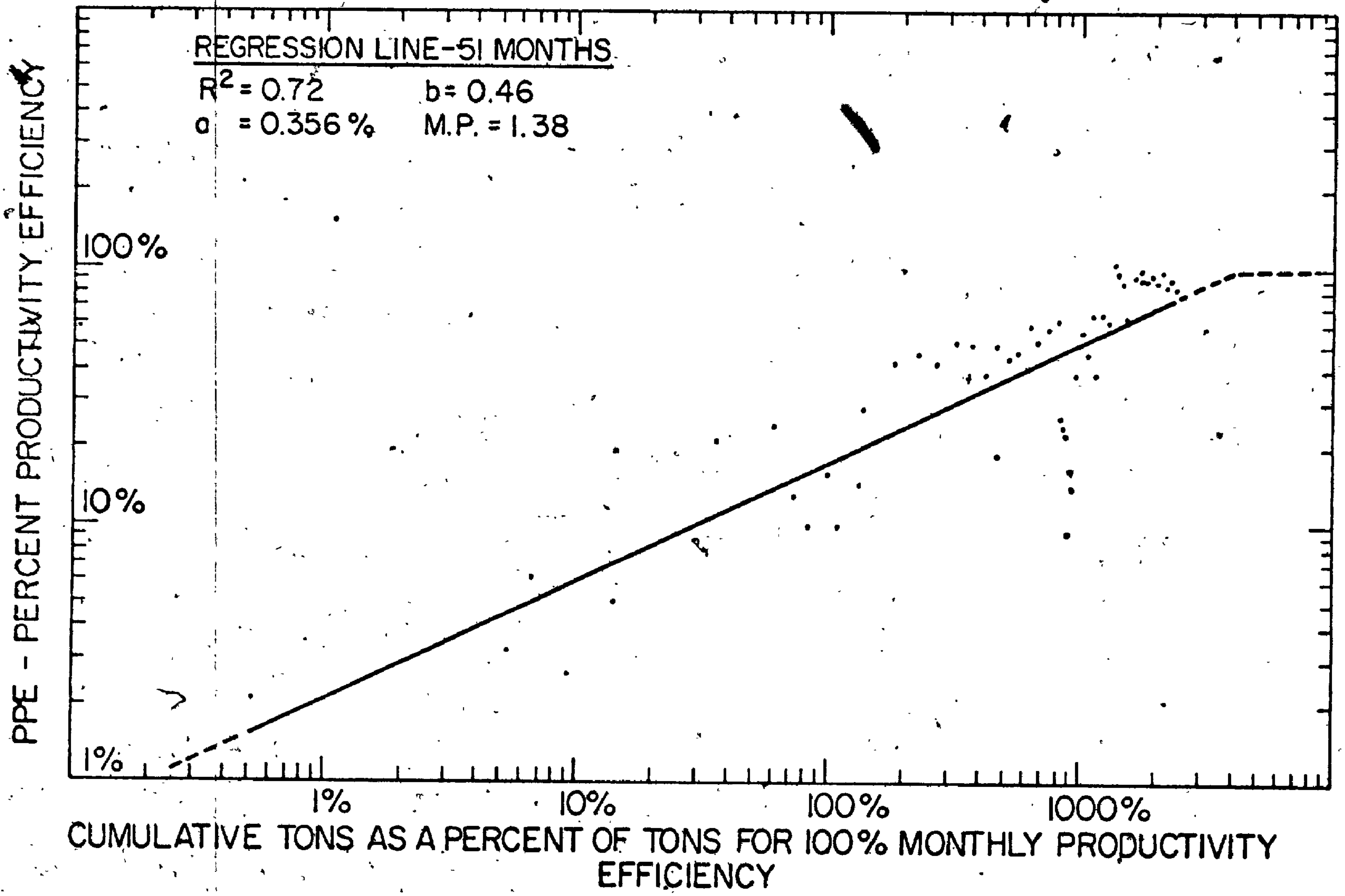



MACHINE 'L' - CONCAST STARTUP
REGRESSION LINE - 36 MONTHS
$R^2 = 0.62$
b = 0.36
a = 1.0 %
M.P. = 1.28
100%
10%
1%
1%
10%
100%
1000%
CUMULATIVE TONS AS A PERCENT OF TONS FOR 100% MONTHLY PRODUCTIVITY EFFICIENCY
PPE - PERCENT PRODUCTIVITY EFFICIENCY

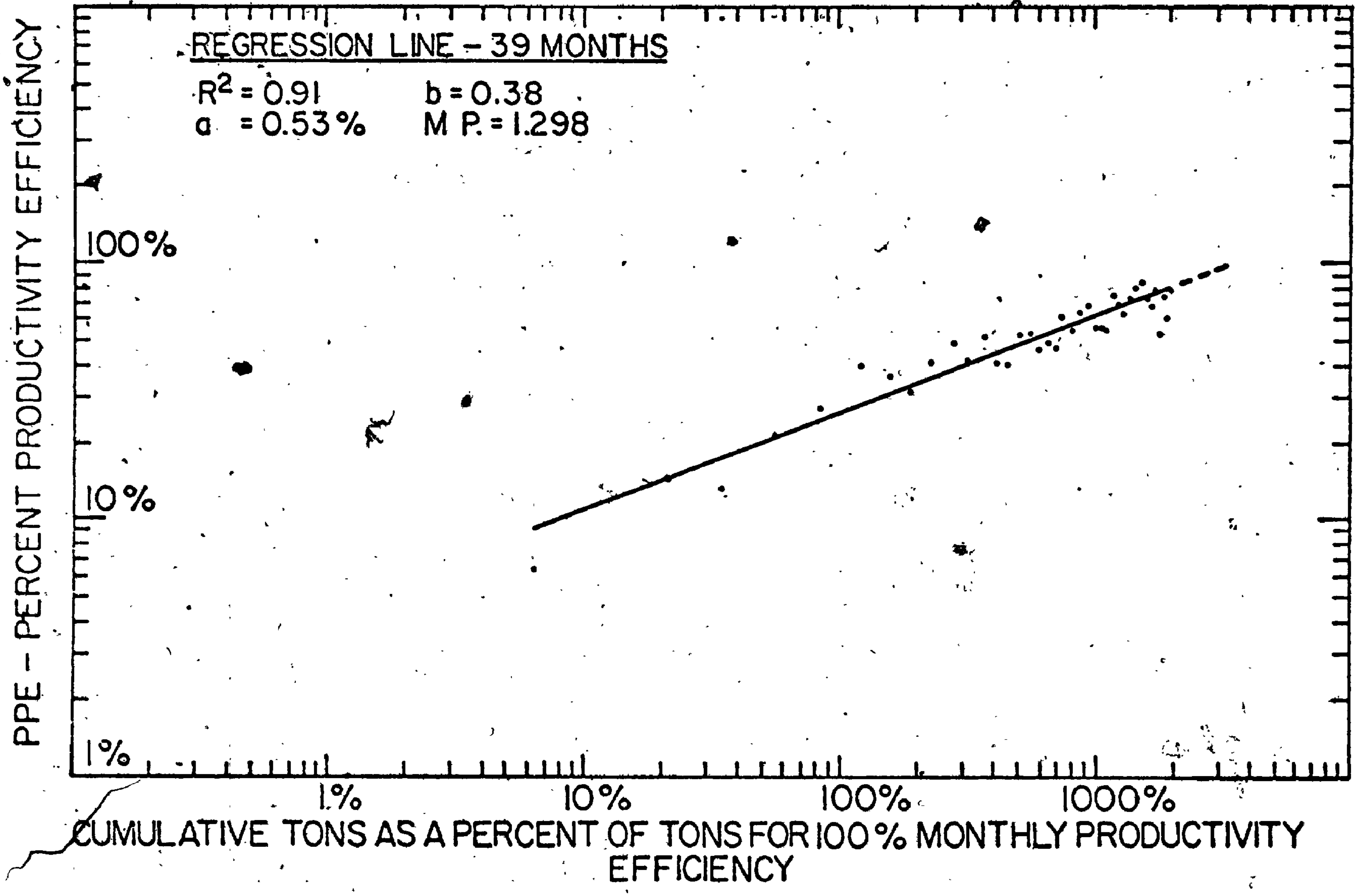
MACHINE 'M' - CONCAST STARTUP



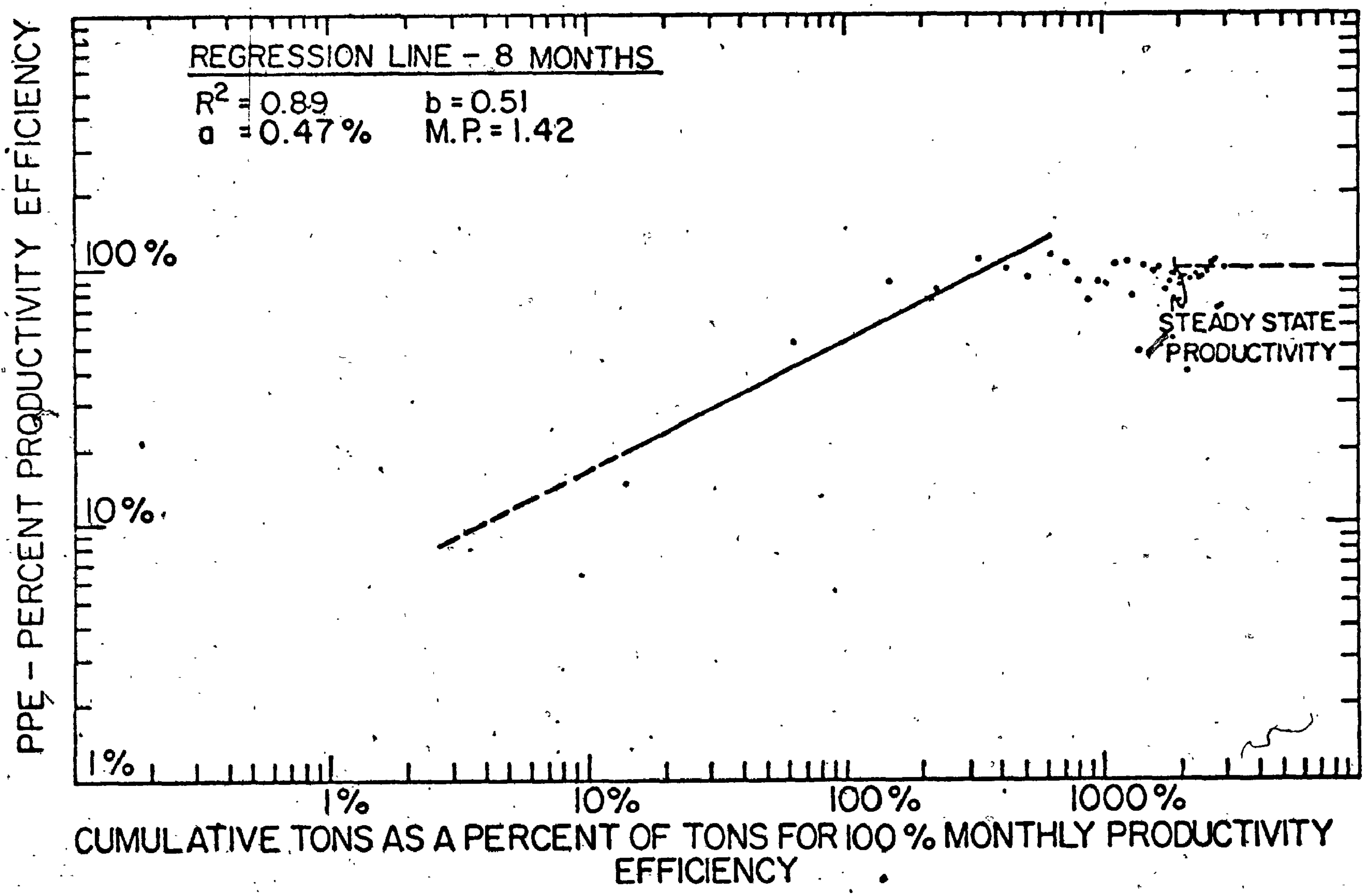
MACHINE 'N' - CONCAST STARTUP

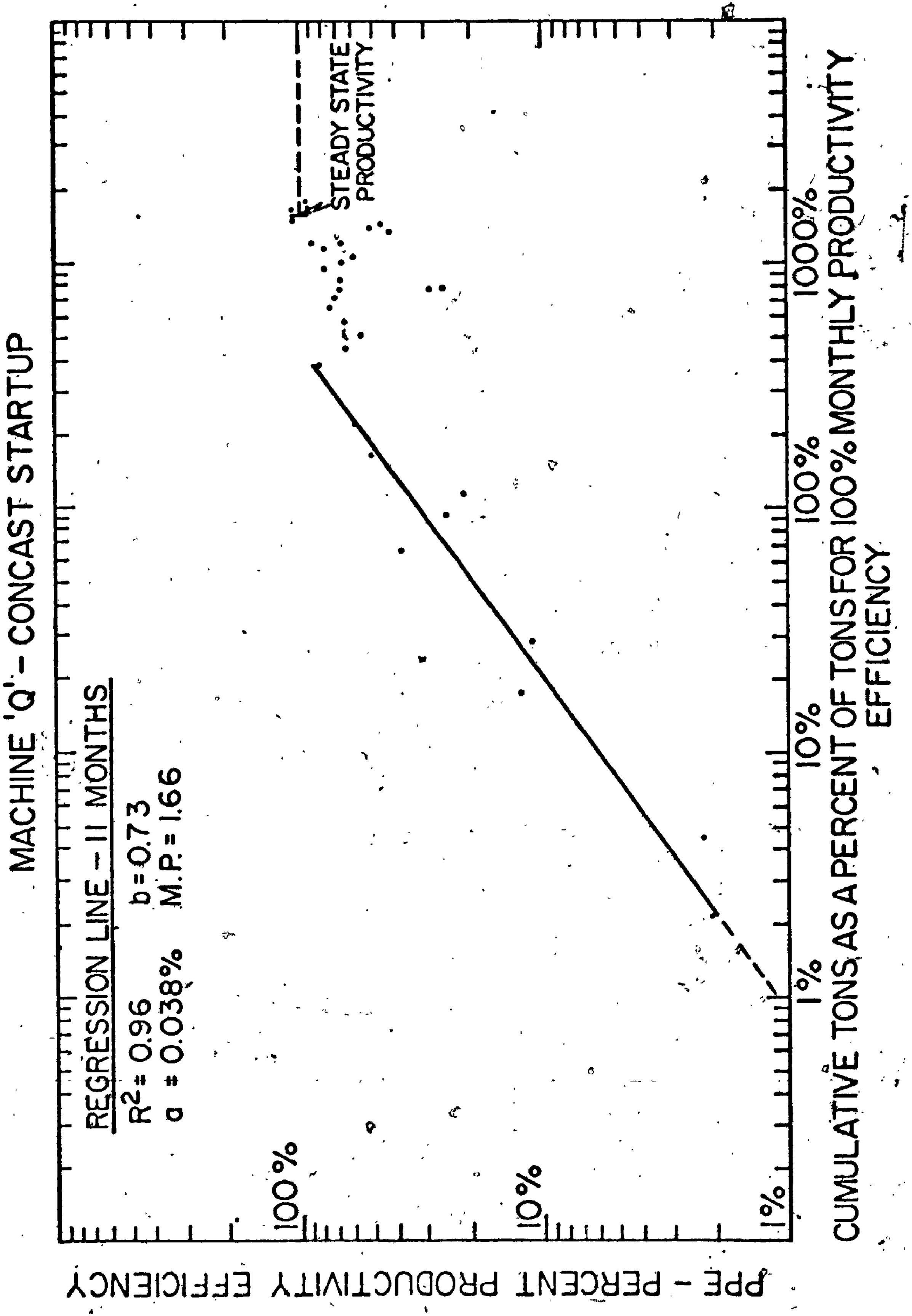


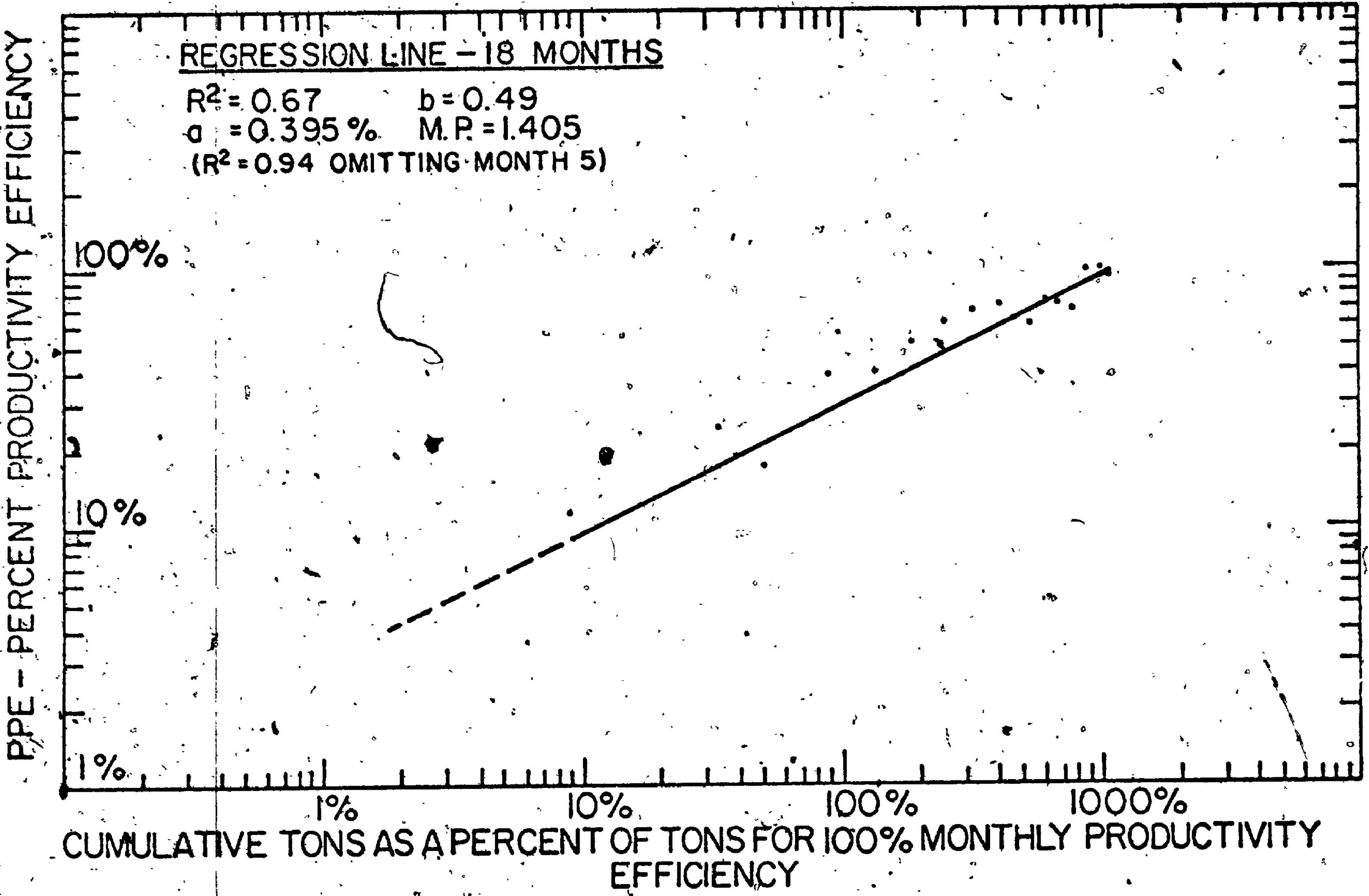
MACHINE 'O' - CONCAST STARTUP



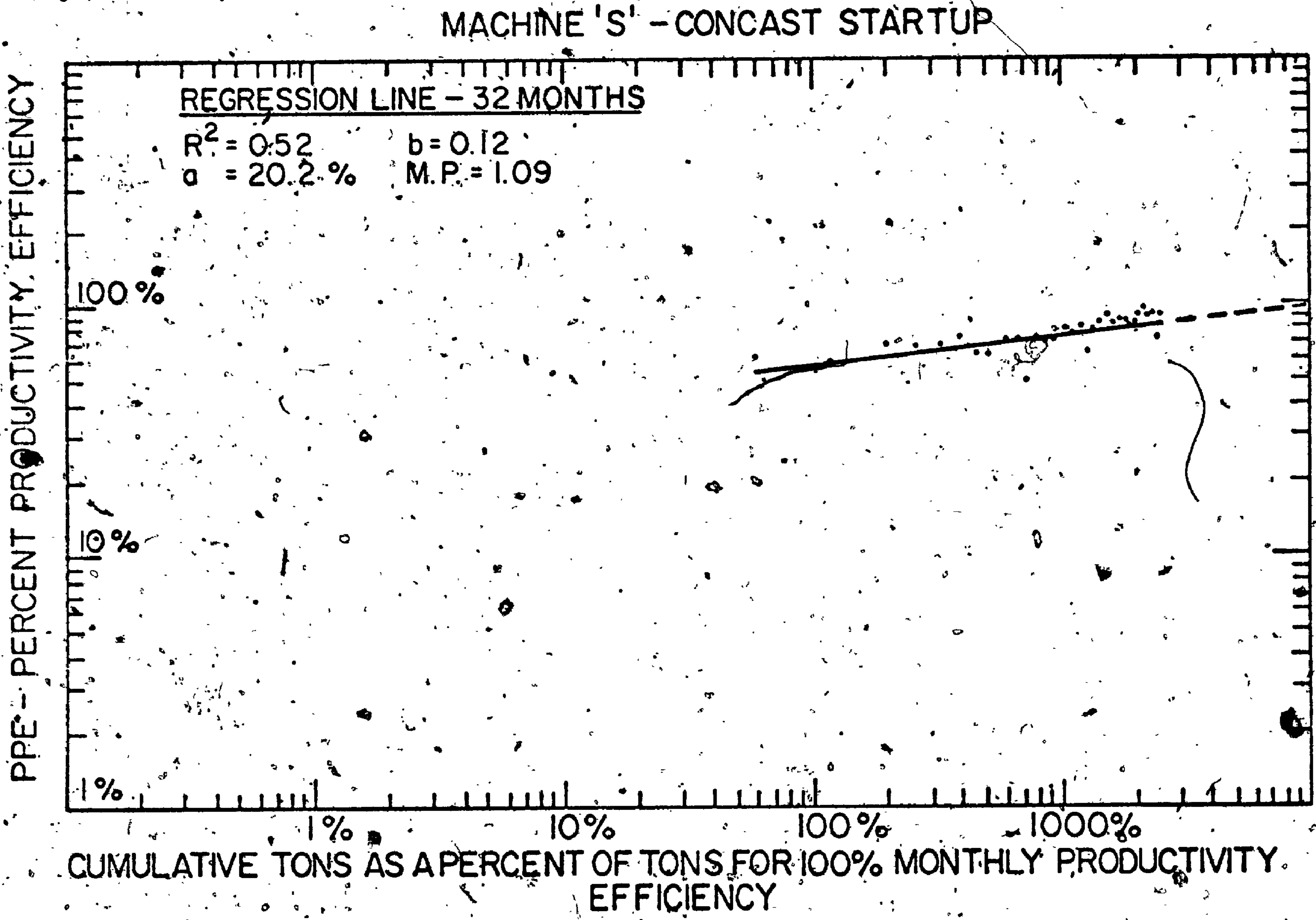
MACHINE 'P' - CONCAST STARTUP



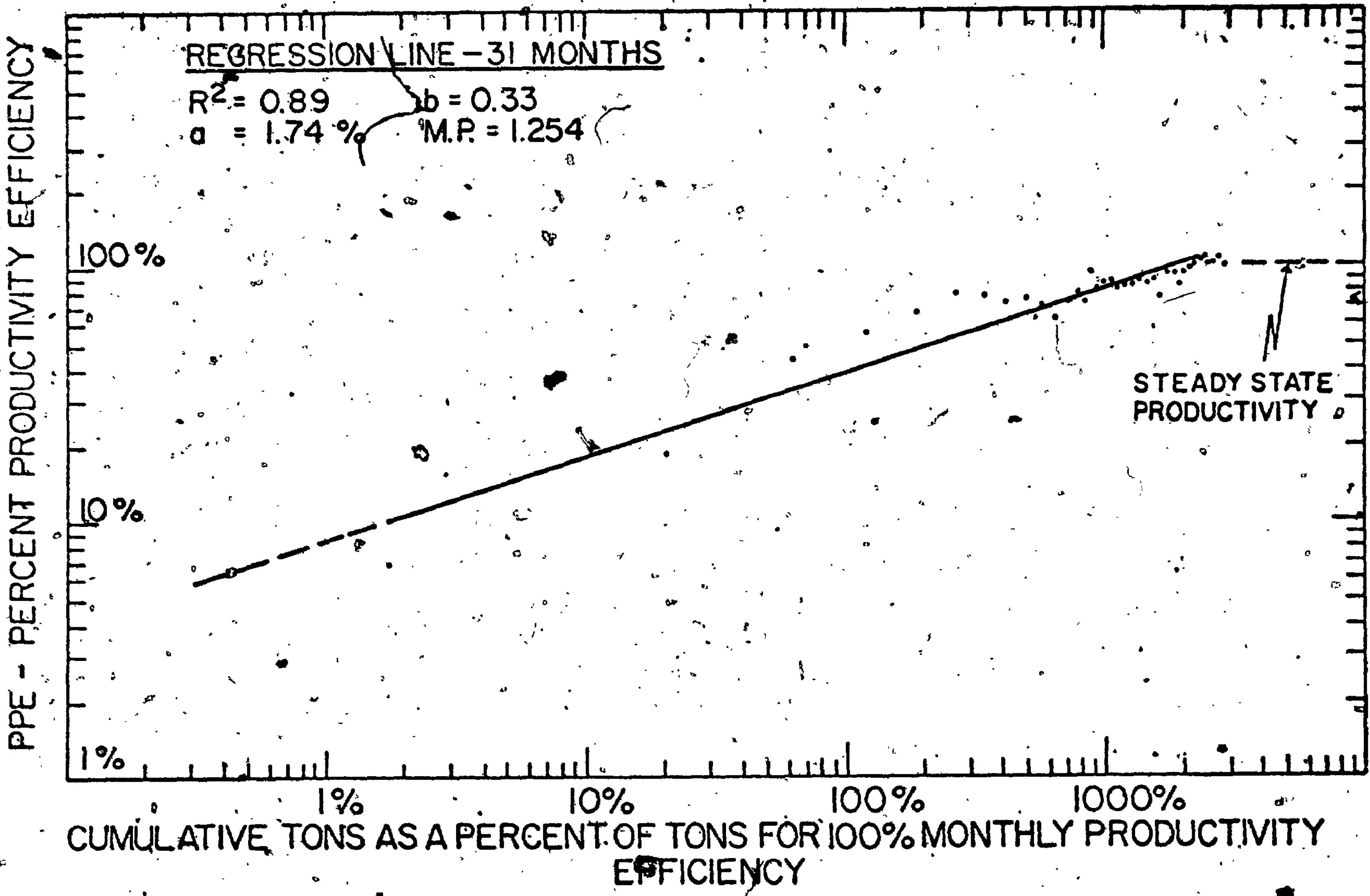

MACHINE 'Q' - CONCAST STARTUP
REGRESSION LINE - 11 MONTHS
R² = 0.96
b = 0.73
a = 0.038%
M.P. = 1.66
STEADY STATE PRODUCTIVITY
100%
10%
1%
1%
10%
100%
1000%
CUMULATIVE TONS AS A PERCENT OF TONS FOR 100% MONTHLY PRODUCTIVITY EFFICIENCY
PPE - PERCENT PRODUCTIVITY EFFICIENCY



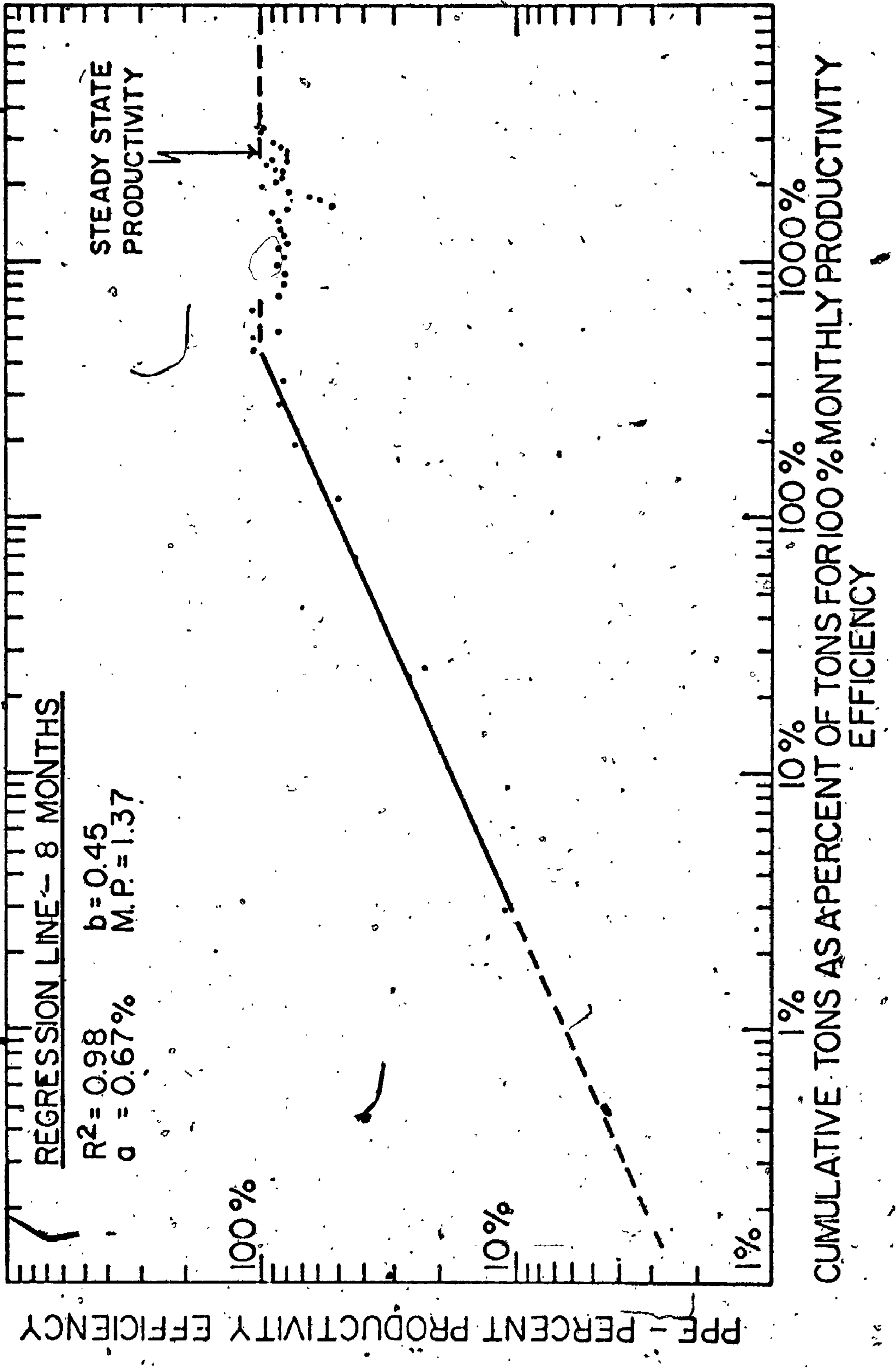
MACHINE 'R' - CONCAST STARTUP


MACHINE 'S' - CONCAST STARTUP
REGRESSION LINE - 32 MONTHS
R^2 = 0.52
a = 20.2 %
b = 0.12
M.P. = 1.09
100 %
10 %
1 %
1%
10%
100%
1000%
PPE - PERCENT PRODUCTIVITY EFFICIENCY
CUMULATIVE TONS AS A PERCENT OF TONS FOR 100% MONTHLY PRODUCTIVITY EFFICIENCY

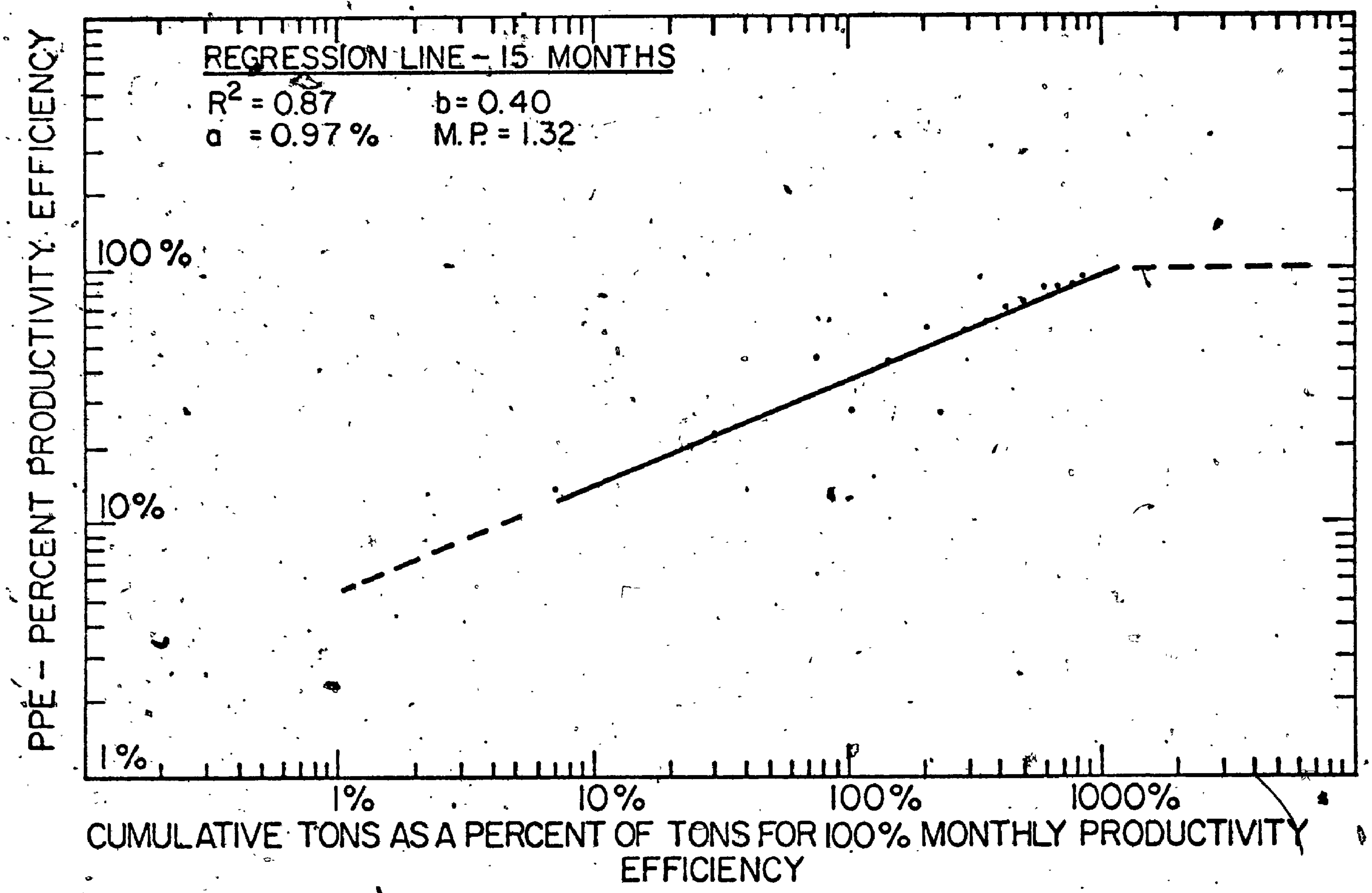
MACHINE 'T' – CONCAST STARTUP

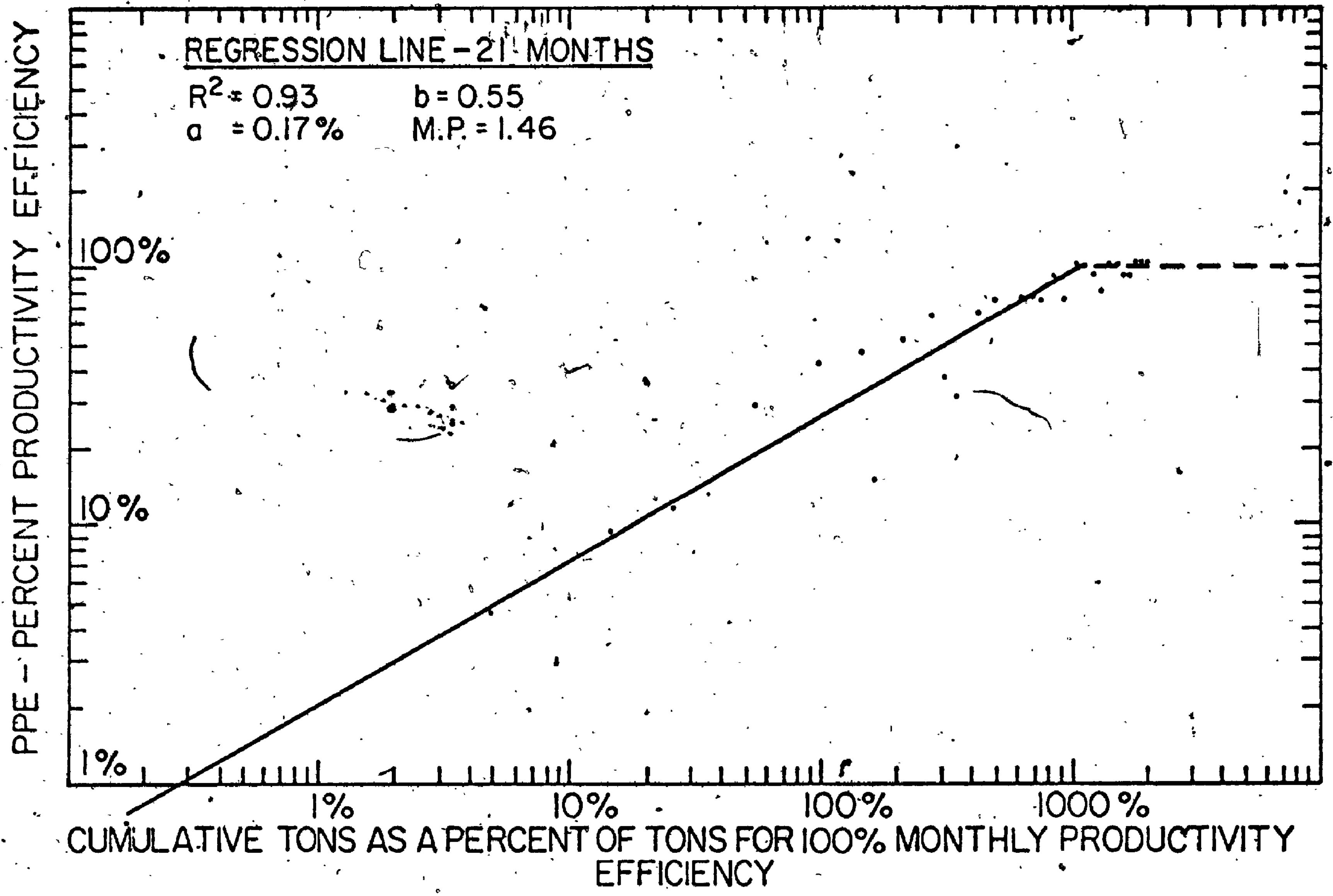


MACHINE 'U' — CONCAST STARTUP

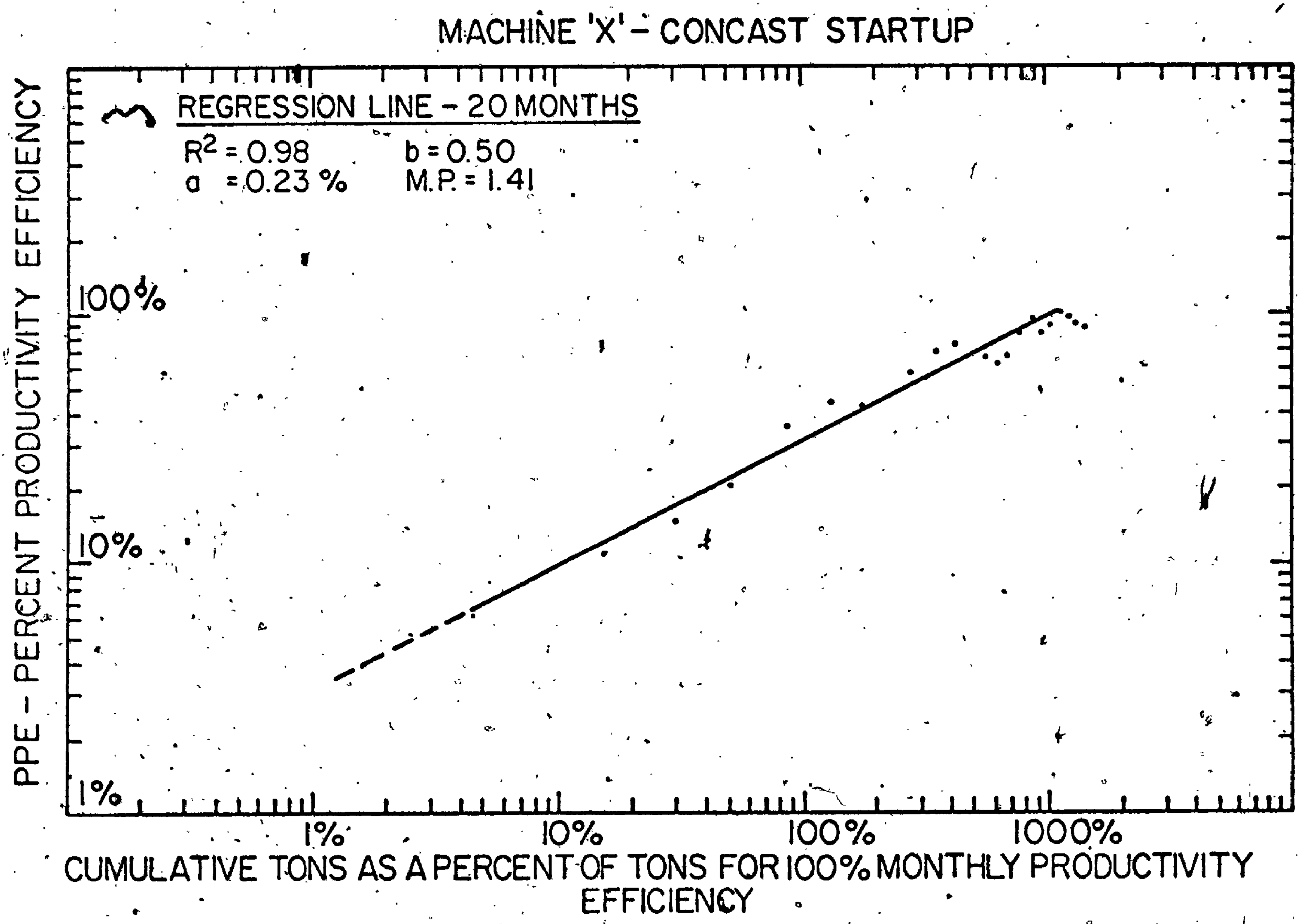


MACHINE 'V' — CONCAST STARTUP

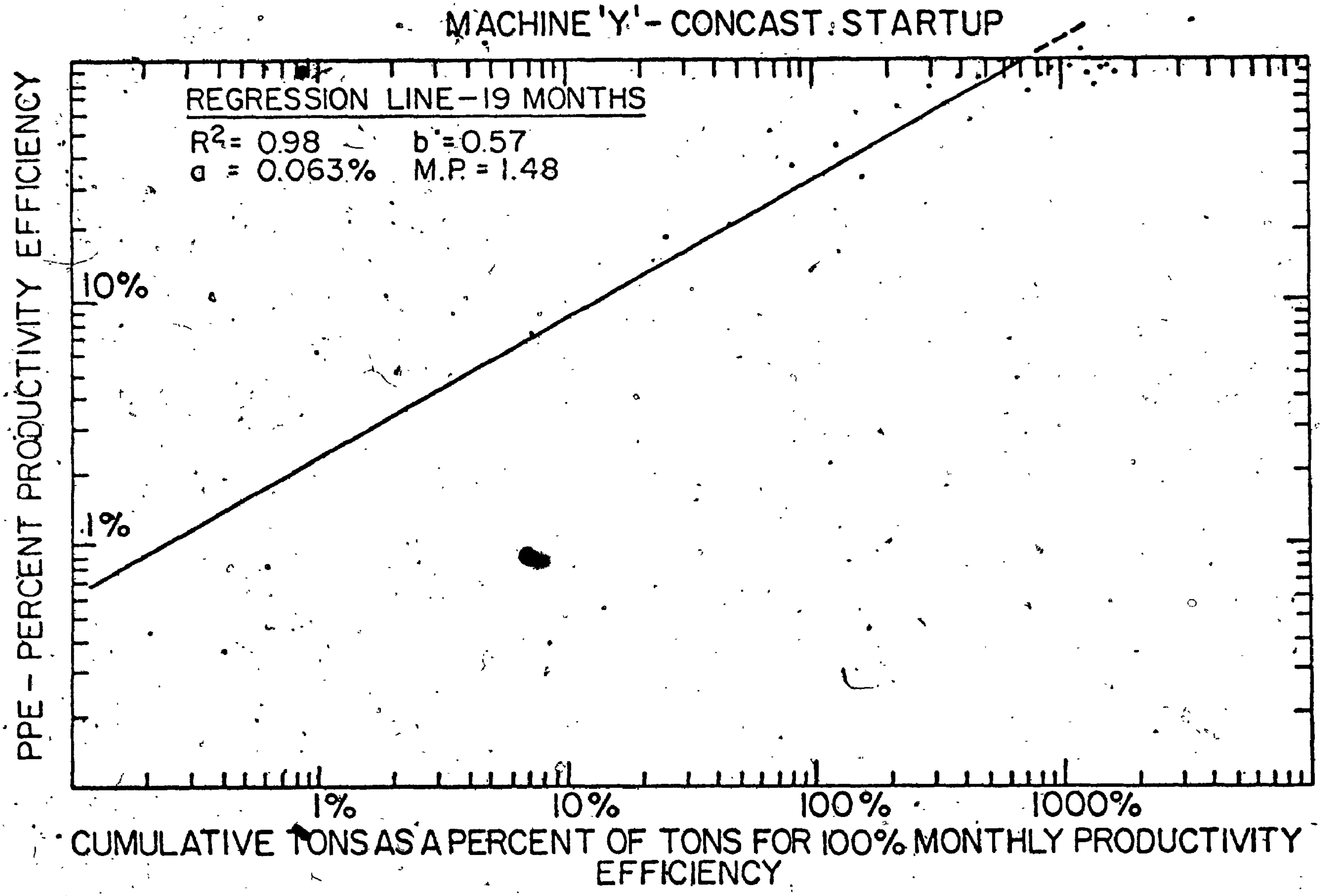


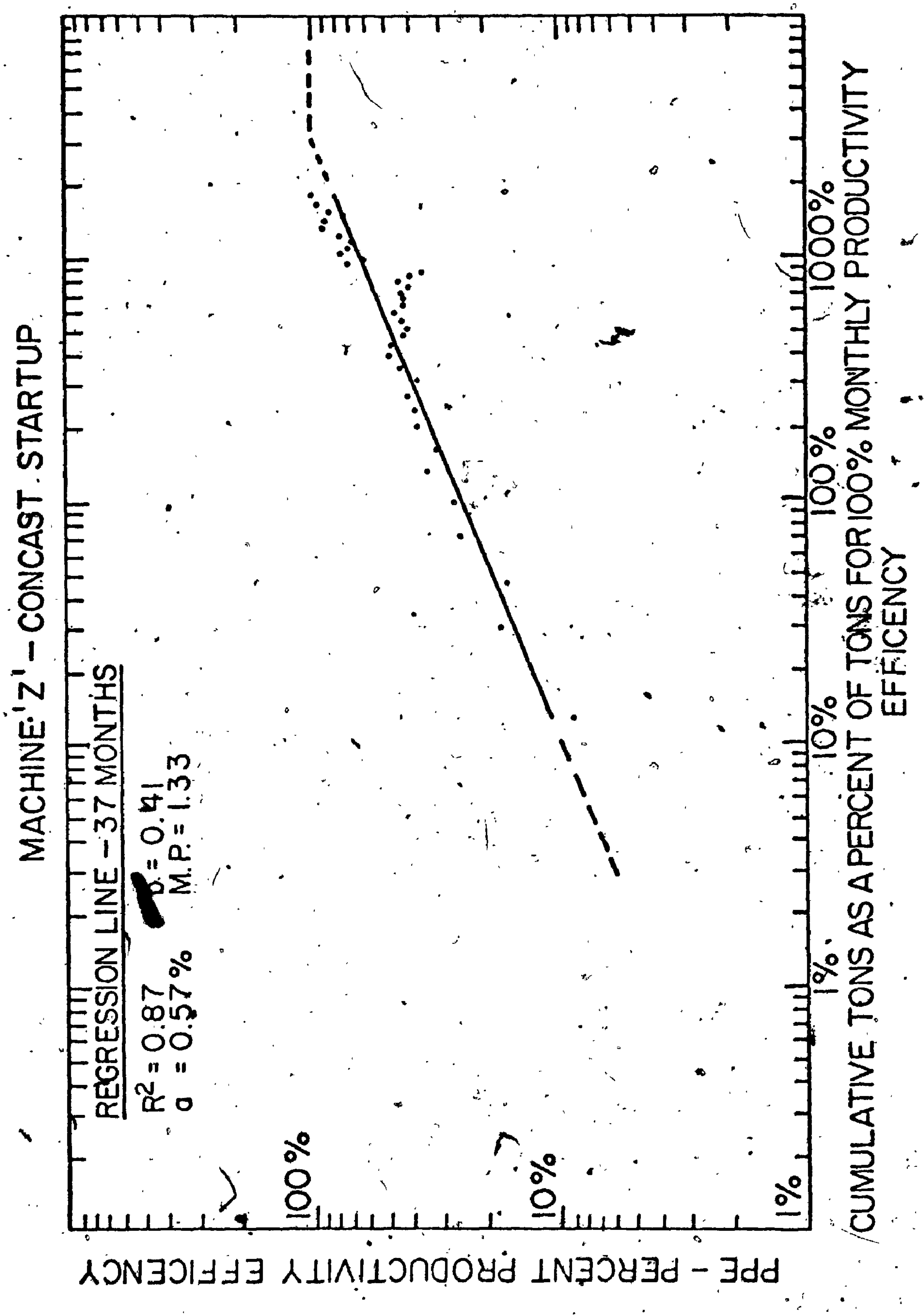


MACHINE 'W' – CONCAST STARTUP

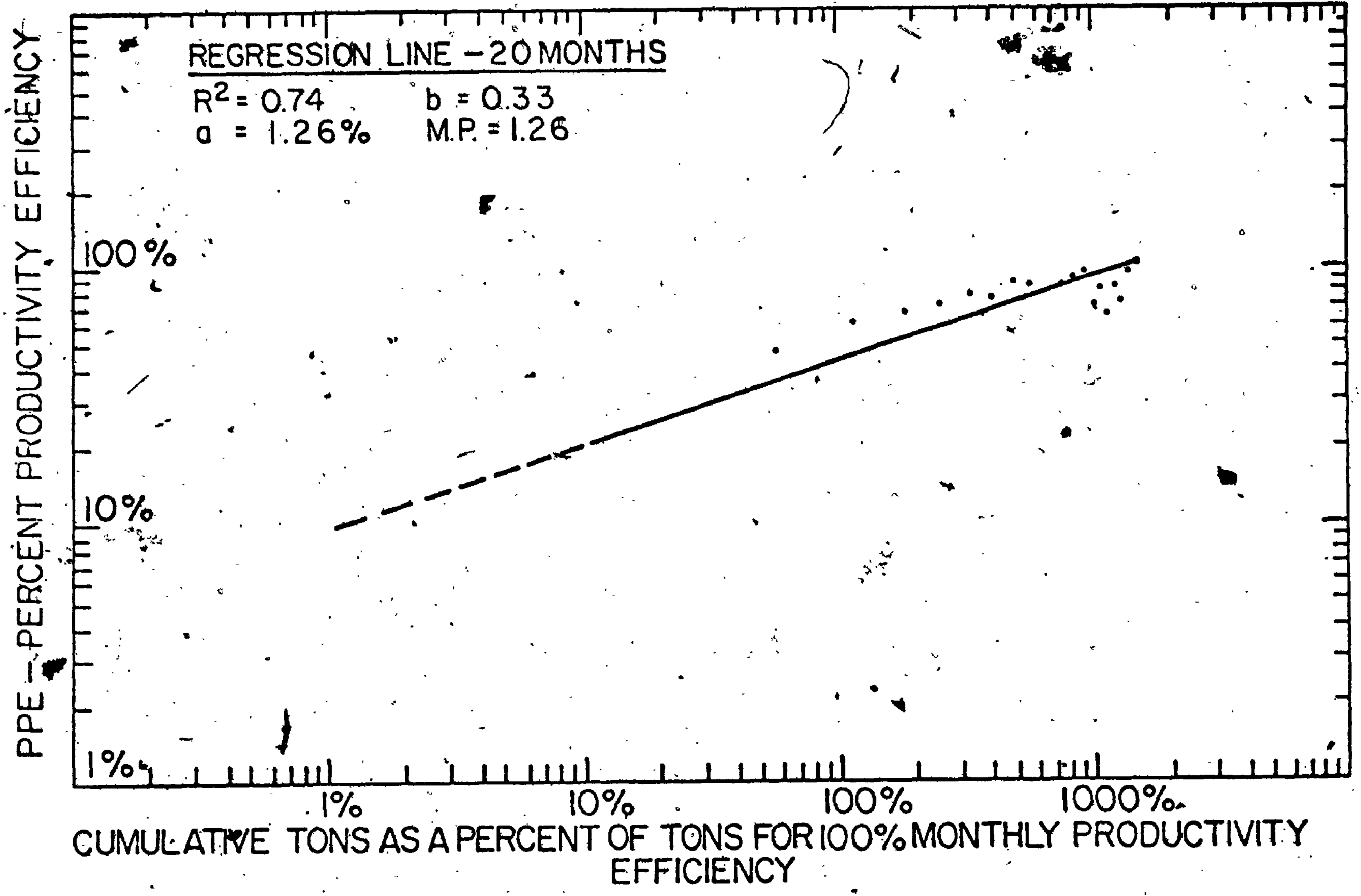


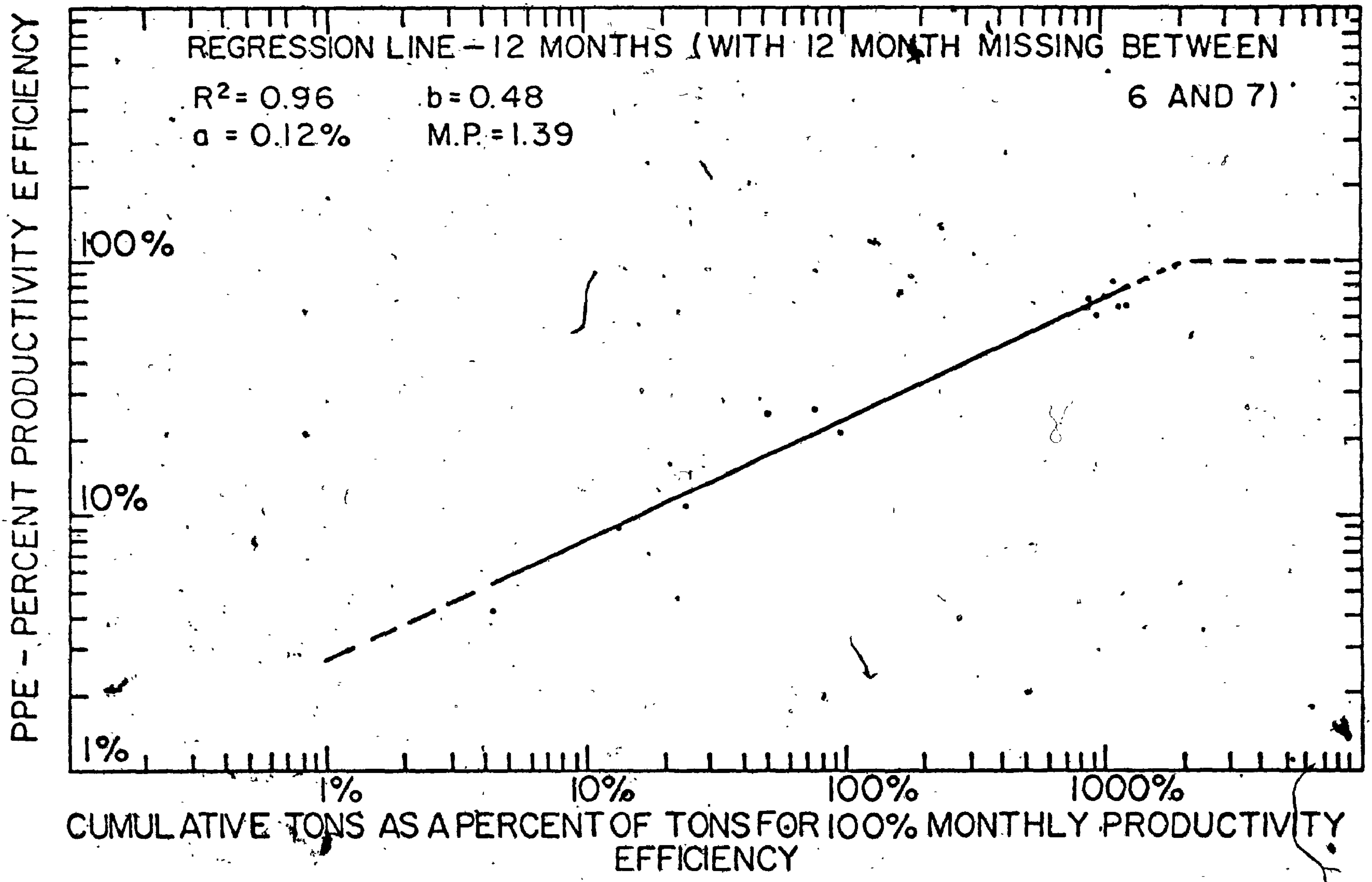
MACHINE 'X' - CONCAST STARTUP


MACHINE 'Y' - CONCAST STARTUP
REGRESSION LINE - 19 MONTHS
R² = 0.98   b = 0.57
a = 0.063%   M.P. = 1.48
PPE - PERCENT PRODUCTIVITY EFFICIENCY
10%
1%
1%
10%
100%
1000%
CUMULATIVE TONS AS A PERCENT OF TONS FOR 100% MONTHLY PRODUCTIVITY EFFICIENCY


MACHINE 'Z' – CONCAST STARTUP
REGRESSION LINE – 37 MONTHS
R² = 0.87
a = 0.57%
b = 0.41
M.P. = 1.33
100%
10%
1%
1%
10%
100%
1000%
CUMULATIVE TONS AS A PERCENT OF TONS FOR 100% MONTHLY PRODUCTIVITY EFFICENCY
PPE – PERCENT PRODUCTIVITY EFFICENCY

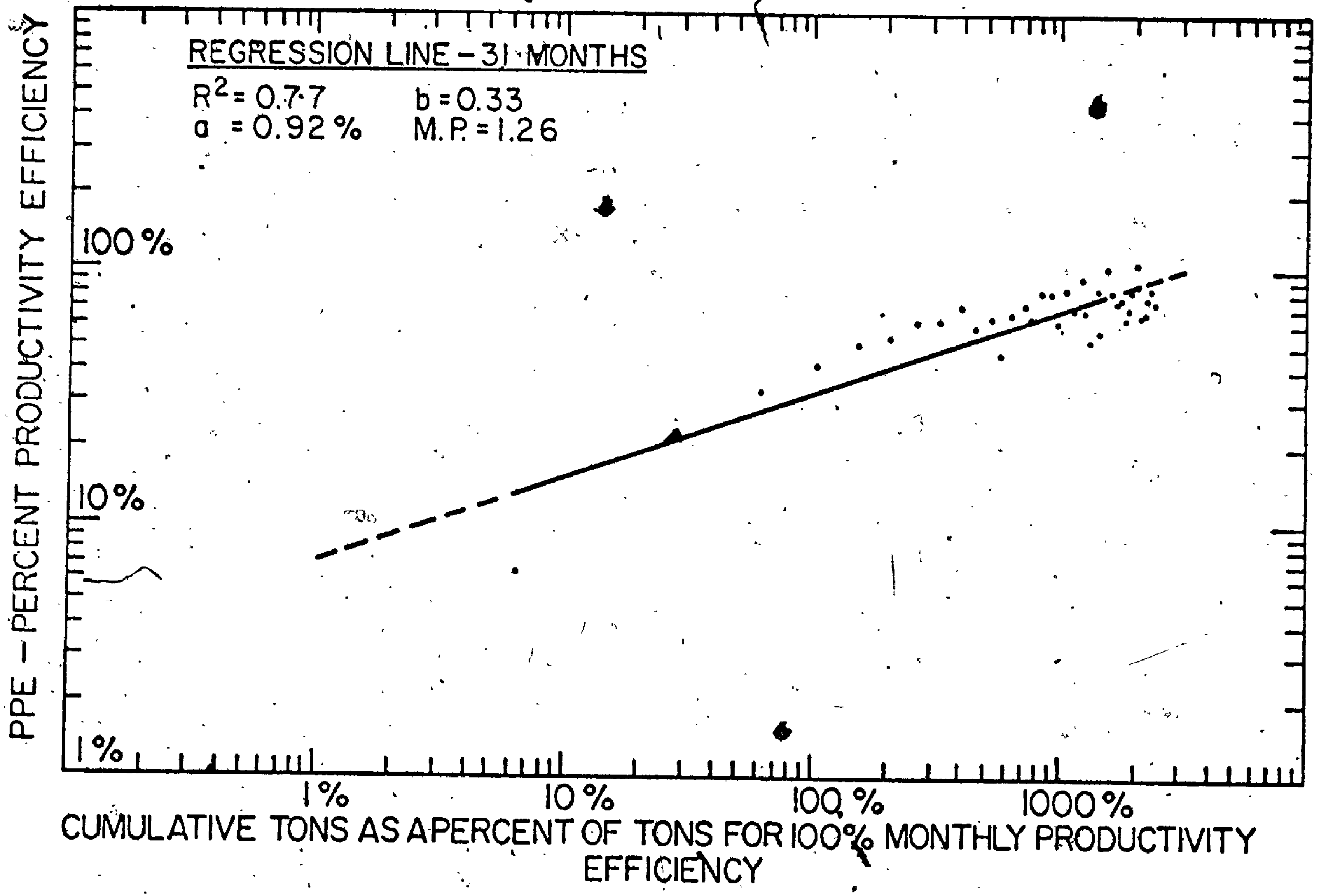
MACHINE 'AA'-CONCAST STARTUP



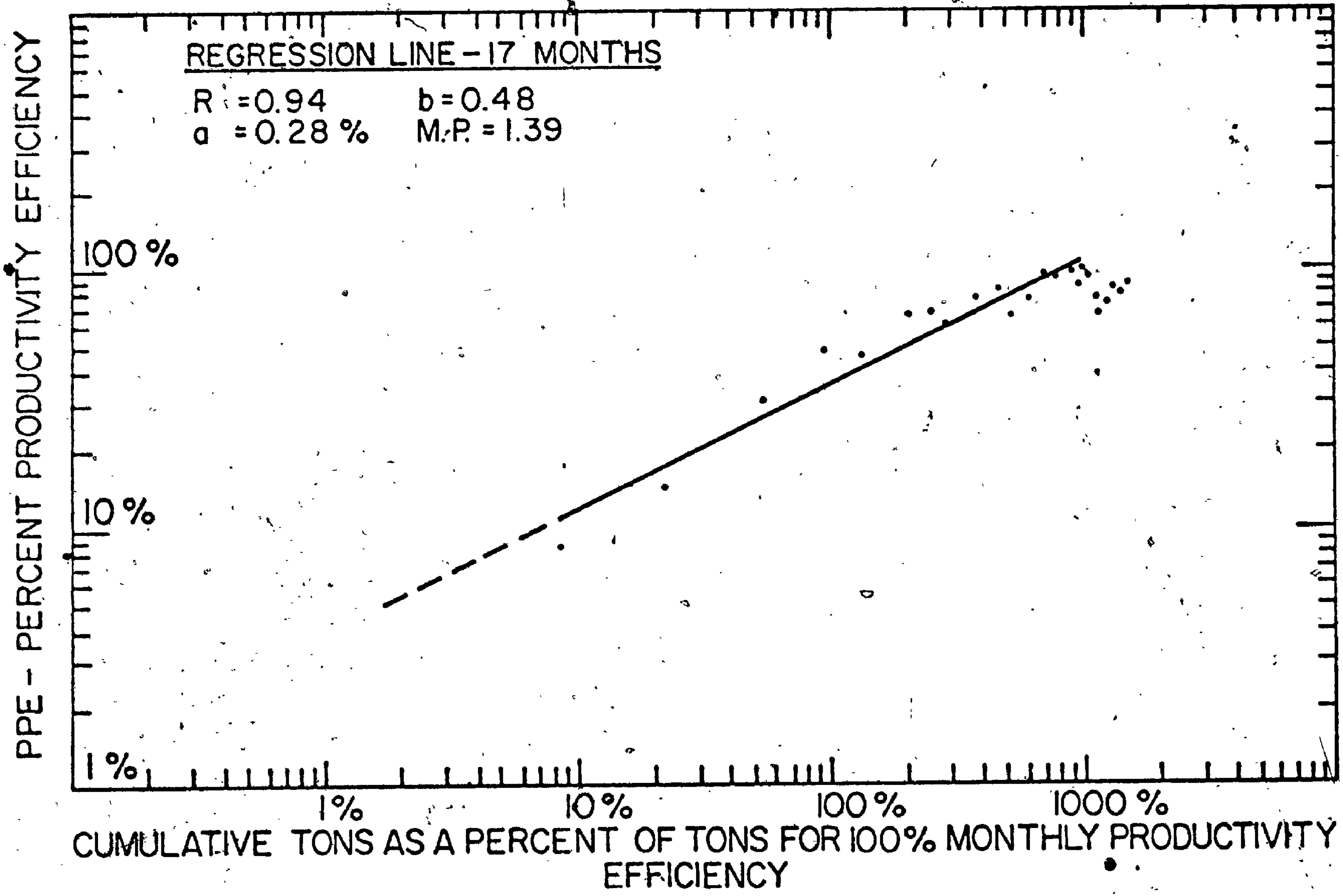


MACHINE 'BB'-CONCAST STARTUP

MACHINE 'CC' - CONCAST STARTUP



MACHINE 'DD' - CONCAST STARTUP



5

APPENDIX II

SEQUENTIAL REGRESSION ANALYSIS DATA FOR THIRTY CONCAST MACHINES

```
UCC3   DATA

  0.68   0.86   1.03   1.15   1.25   1.30   1.37   1.43   1.44   1.45   1.49   1.52   1.57   [illegible]   [illegible]   [illegible]
  1.51   1.43   [illegible]   1.64   1.67   1.32   1.51   1.65   1.49   1.72   1.72   1.74   1.74   [illegible]   [illegible]   [illegible]
  1.83   1.85   1.88   [illegible]   1.97   1.89

  EXP   [illegible]   INTERCEPT   [illegible]   [illegible]   SLOPE   [illegible]   YEAR   YEAR   SA   SB   STD ERR   [illegible]
  MANUFACTURING PROGRESS SEQUENTIAL REGRESSION                 MACHINE TAX

  [illegible]  -1.4617     [illegible]  1.3350       -0.0340      0.3792       0.7344       2.7036   0.8561       0.7418       0.2071       [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] -0.2717      [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] [illegible]  [illegible]  0.2341       [illegible]  [illegible]  [illegible]  0.9745       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  3.2017       1.0450       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  3.3857       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
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  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  3.5310       1.1161       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
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  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  3.7531       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
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  [illegible]  [illegible] [illegible]  [illegible]  0.4015       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  1.3426       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
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  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  1.3742       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] [illegible]  [illegible]  0.4075       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  4.0277       1.4321       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  0.4715       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  1.4374       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  4.1165       1.5174       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
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  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  1.4590       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
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  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  1.5376       [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]
  [illegible]  [illegible] -0.2006      [illegible]  [illegible]  0.4174       0.4536       4.4241       1.5563       [illegible]  0.3174       [illegible]  [illegible]  [illegible]
```

[illegible] 0.98 1.25 1.75 1.68 1.78 [illegible] [illegible] 2.02

[illegible] [illegible] INTERC [illegible] [illegible] SLOPE [illegible] YOAD YOAD SA SH STD ERR [illegible]

MANUFACTURING PROGRESS SEQUENTIAL REGRESSION MACHINE [illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.1727	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.7145	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.7112	1.2576	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	-1.5130	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.4768	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	-1.5121	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.5027	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

```
DATA
      0.98   0.91   1.24   1.29   1.40   1.76   1.73   1.81   1.92   1.88   1.96   1.84   1.88   1.76   1.[illegible]   1.76
      1.04

  RES   A-2SA   INTERP   A+2SA   B-2SB   SLOPE   B+2SB   XBAR   YBAR   SA   SB   STD ERR   SD X   SD Y
MANUFACTURING PROCESS SEQUENTIAL REGRESSION          MACHINE ICE

    0.7936  -4.2020  -1.6278   0.6471   0.1787   0.9609   1.3716   2.6377   0.4134   1.2075   0.3498   0.1024   0.4737   0.5096
    0.7773  -3.7940  -1.5647   0.7055   0.4379   0.7791   1.1205   0.9423   0.7810   1.0851   1.1207   0.1019   0.7579   0.6477
    0.7779  -3.2874  -1.6217   0.6642   0.5649   0.7614   0.3762   1.0774   0.7219   0.3330   0.1073   0.0313   0.2015   0.4027
    0.6847  -3.2231  -1.4541   0.3791   0.5247   0.7763   0.3240   1.5031   1.0621   0.8830   0.6760   0.0017   0.0106   0.4320
    0.3581  -3.0000  -1.3513   0.3141   0.5273   0.7503   0.0772   2.1050   1.1574   0.9528   0.0467   0.0240   0.0605   0.4179
    0.0947  -2.0034  -1.3655   0.3324   0.5256   0.7331   1.3671   2.5211   1.2305   0.9240   0.3564   0.1166   0.2140   0.4376
    0.0041  -2.0173  -1.2962   [illegible]   0.4179   0.7273   1.0145   1.6372   1.3150   0.7971   0.0458   0.0707   0.0641   0.4316
    0.0021  -2.8423  -1.2874   0.3074   0.4105   0.7377   0.7050   2.7241   1.4710   0.7874   0.0471   0.0005   0.2774   0.4230
    0.3956  -2.7844  -1.2330   0.3509   0.5042   0.6966   0.7760   3.3167   1.4157   0.7813   0.0467   0.1107   0.9719   0.4099
    0.3640  -2.4864  -1.1393   0.4001   0.8728   0.6655   0.7591   3.9916   1.4595   0.7717   0.0463   0.1122   0.2760   0.4704
    0.3522  -2.6032  -1.0637   0.4359   0.5513   0.6676   0.7360   3.7607   1.4915   0.7527   0.0457   0.1211   0.9750   0.5779
    3.0419  -2.5243  -1.0052   0.5159   0.5234   0.6228   0.7312   4.0229   1.4907   0.7603   0.0407   0.1410   0.2797   0.5494
    0.3900  -2.4302  -0.7641   0.5600   0.5044   0.6129   0.4021   4.0749   1.5174   0.7470   0.0407   0.1517   0.9727   0.5464
    3.0133  -2.3584  -0.5555   0.5976   0.4959   0.5932   0.4966   4.1399   1.5315   0.7341   0.0417   0.1412   0.6437   0.4229
    0.0154  -2.2967  -0.5700   0.5573   0.4806   0.5109   0.6719   4.1777   1.5553   0.7180   0.0456   0.1566   0.0501   0.5415
```

```
DATE

 -0.0C5 A  0.70   0.14   1.37   1.48   1.52   1.56   1.55   1.39   1.41   1.17   1.64   1.57

 EOB    9-25A   INTERC  A-25A  B-25B   SLOPE  B-25O   XBAR   YBAR    SA     SB : STD ERR   SD X SD Y

MANUFACTURING PROGRESS SEQUENTIAL REGRESSION             MACHINE  [illegible]

 [illegible] -2.2544 -1.4571  0.1127  0.[illegible]507  0.8116  0.9[illegible]  2.5940  0.6143  0.7849  0.0404  0.0319  [illegible]  [illegible]
 0.[illegible] -2.[illegible]  -1.4163  0.1103  1.7092  0.7426  0.1770  2.6013  0.8044  0.7597  0.0422  0.0217  [illegible]  0.4403
 [illegible] -2.[illegible]  -1.[illegible]7  0.1[illegible]1  0.6635  0.7641  0.[illegible]  2.9902  0.9307  0.7604  0.0501  0.0511  [illegible]  0.4304
 [illegible] -2.[illegible]  -1.2[illegible]  [illegible]  0.6243  0.7142  0.[illegible]  3.1[illegible]  4.0[illegible]4  0.7659  0.0549  0.0[illegible]3  0.8400  0.5128
 0.6[illegible]0 -2.7579 -1.2107  0.[illegible]  0.5575  0.7173  0.8174  3.[illegible]  1.1117  0.7736  0.0545  0.0972  0.9320  0.5533
 0.6733 -2.[illegible]  -1.1145  0.[illegible]  0.5627  0.[illegible]81  0.7[illegible]  3.[illegible]  1.1656  0.7662  0.0577  0.2045  0.[illegible]  0.5703
 0.6975 -2.[illegible]  -1.[illegible]7  0.[illegible]  0.[illegible]  0.[illegible]  0.7065  3.[illegible]  1.1908  0.7574  0.0743  0.1442  [illegible]  0.5[illegible]
 0.5100 -2.[illegible]  -0.[illegible]1  0.[illegible]  0.45[illegible]  0.[illegible]011  0.7516  3.[illegible]  1.2126  0.7917  0.0757  0.1[illegible]  0.8144  0.5127
 0.5[illegible] -2.[illegible]  -0.7431  0.[illegible]47  0.2714  0.[illegible]  0.7[illegible]  3.6276  1.2093  0.8139  0.0903  0.2109  [illegible]  0.4[illegible]
 0.[illegible] -2.[illegible]  -0.[illegible]  0.[illegible]  0.[illegible]  0.[illegible]46  0.7125  3.6190  1.2445  0.7719  0.0771  0.[illegible]2  0.7[illegible]  0.4[illegible]
 0.[illegible] -2.[illegible]  -0.[illegible]  0.[illegible]  0.4065  0.[illegible]477  0.[illegible]  3.7[illegible]  1.2703  0.7225  0.0764  0.1720  0.7974  0.4[illegible]
```

```
1406  DATA

      0.94   1.38   1.68   1.81   1.90   1.90   1.92   1.97   1.97   1.94   1.92   2.05

      R*R   A-2SA   INTERC   A+2SA   B-2SB   SLOPE   B+2SB   XBAR   YBAR   SA   SB   STD ERR   SD X SD Y
MANUFACTURING PROGRESS SEQUENTIAL REGRESSION.          MACHINE 'E'

SS IS NEGATIVE  -0.53644100-05
CHS IS NEGATIVE SO SE IS WRONG   -0.8165836E-05
      1.0131************ -1.4478************************  0.76595322.6090  3.6251  1.3288**********2910.9220 999.9991  0.4958  0.3721
      0.9457 -2.4872 -1.3195 -0.1519  0.6257  0.7282  0.8108  3.8031  1.4500  0.5838  0.0513  0.0273  0.5330  0.3983
      0.9426 -2.4059 -1.2009  0.0042  0.5874  0.6944  0.8014  3.9461  1.5393  0.6075  0.0535  0.0388  0.5616  0.3914
      0.9793 -2.3460 -1.1333  0.2794  0.5115  0.6478  0.7841  4.0636  1.5988  0.6561  0.0691  0.0624  0.5799  0.3792
      0.9572 -2.1459 -0.9929  0.3329  0.4798  0.6119  0.7439  4.1629  1.6451  0.6420  0.0660  0.0729  0.5902  0.3572
      0.9517 -1.9829 -0.8173  0.4023  0.4705  0.5871  0.7040  4.2492  1.6851  0.6063  0.0584  0.0754  0.5964  0.3523
      0.9542 -1.8514 -0.7132  0.4421  0.4556  0.5632  0.6709  4.3249  1.7167  0.5811  0.0539  0.0796  0.6041  0.3483
      0.9371 -1.7533 -0.6103  0.5343  0.4276  0.5343  0.6422  4.3918  1.7397  0.5713  0.0537  0.0813  0.6075  0.3357
      0.9160 -1.6265 -0.5045  0.6175  0.4305  0.5375  0.6146  4.4539  1.7548  0.5510  0.0535  0.0396  0.6098  0.3220
      0.9211 -1.5420 -0.4841  0.5739  0.4095  0.5324  0.5954  4.5954  1.7795  0.5790  0.0465  0.0941  0.6104  0.3145
```

```
DATA
  -0.57    0.34    1.17    1.63    1.76    1.72    1.51    1.68    1.56    1.79    1.82    1.74    1.78    1.81    1.78    1.83
   1.78    1.77    1.83    1.79    1.75    1.80    1.77    1.99    1.77    1.93    1.94    1.73

    OBS    A-258   INTERC    SA258    B-258    SLOPE    R-258     XBAR     YBAR       SA       SB  STD ERR     SD X     SD Y
MANUFACTURING PROCESS: SEQUENTIAL REGRESSION            MACHINE  [illegible]

 0.1969  -4.4572  -1.9012   0.8549   0.5080   0.9295   1.1510   2.5944   0.2743   1.3289   0.1617   0.0299   1.1136   0.3255
 0.0277  -4.3773  -1.9112   0.7909   0.6857   0.9345   0.9914   3.0057   0.6146   1.2306   0.0766   0.0591   1.2140   1.0163
 0.2040  -4.2003  -1.7603  [illegible] 0.6314  0.9152   0.8300   3.9056   0.4632   1.2155   0.0619   0.0553   1.2668   1.3171
 0.3012  -4.2336  -1.7019   0.9317   0.6251   0.7151   0.7451   3.4259   0.9395   1.2513   0.0511   0.1276   1.2100   0.9774
 0.1759  -4.1767  -1.6727   0.9237   0.5541   0.7514   0.7498   3.5962   1.0715   1.2772   0.0587   0.1649   1.2147   0.7726
 0.0721  -4.0701  -1.5294   0.8337   0.5402   0.7201   0.9179   3.7316   1.1502   1.2290   0.0744   0.1565   1.1871   0.4979
 0.2494  -3.9009  -1.5117   0.8275   0.5166   0.7359   0.8370   3.9359   1.1062   1.1994   0.0956   0.1772   1.1643   0.3017
 0.3421  -3.7632  -1.5713   0.7676   0.5371   0.7312   0.9567   3.0278   1.2557   1.1309   0.0874   0.1447   1.1991   0.9973
 0.4159  -3.6391  -1.6005   0.7609   0.5526   0.6975   0.9674   4.0001   1.3067   1.0740   0.0726   0.1585   1.1117   0.7643
 0.2604  -3.5291  -1.4815   0.6057   0.5524   0.5977   0.9220   4.0900   1.3429   1.0333   0.0676   0.1562   1.0913   0.7597
 0.0045  -3.4772  -1.4774   0.5535   0.5526   0.4795   0.9016   4.1649   1.3742   0.9769   0.0625   0.1566   1.0615   0.7758
 0.2548  -3.3360  -1.4143   0.5375   0.5546   0.4797   0.7970   4.2963   1.4059   0.9509   0.0582   0.1540   1.0641   0.7142
 0.0531  [illegible] -1.3959 [illegible] 0.5600  0.6430   0.7719   4.2622   1.4220   0.9136   0.0555   0.1515   1.0204   0.6279
 0.0577  [illegible] -1.3630  0.6577   0.5676   0.6527   0.7579   4.3141   1.4561   0.9070   0.0526   0.1566   1.0161   0.6802
 0.0438  [illegible] -1.3231  0.6567   0.5372   0.6111   0.7459   4.3323   1.4792   0.9909   0.0513   0.1495   1.0017   0.6624
 0.2764  [illegible] -1.3026  0.4469   0.5306   0.6214   0.7373   4.4268   1.4999   0.9687   0.0496   0.1456   0.9919   0.6665
 0.0351  -2.9589  -1.2681   0.4271   0.5270   0.6237   0.7205   4.4479   1.5064   0.9675   0.0484   0.1457   0.9134   0.6324
 0.3319  [illegible] -1.2424  0.4174   0.5224   0.6149   0.7004   4.4659   1.5294   0.8396   0.0449   0.1447   0.0403   0.6167
 0.0520  -2.8309  [illegible] 0.4117   0.5464   0.6071   0.5947   4.5214   1.5314   0.8173   0.0458   0.1761   0.0517   0.6181
 0.0218  -2.7691  [illegible] 0.3997   0.5120   0.6003   0.6907   4.5550   1.5436   0.7246   0.0442   0.1703   0.0488   0.6033
 0.0219  -2.7333  -1.1595   0.3723   0.5135   0.6077   0.6900   4.5971   1.5591   0.7764   0.0413   0.1671   0.0376   0.6066
 0.0734  -2.6021  -1.1761   0.3631   0.5175   0.5365   0.6755   4.6131   1.5749   0.7695   0.0395   0.1633   0.0316   0.5791
 0.2749  -2.5625  -1.1717   0.3191   0.5199   0.5347   0.6696   4.6492   1.5927   0.7454   0.0376   0.1591   0.0261   0.5715
 0.0359  -2.4767  -1.1433   0.2989   0.5216   0.5295   0.6639   4.6973   1.6076   0.7314   0.0354   0.1572   0.0175   0.5551
 0.2250  -2.5066  -1.1607   0.2976   0.5201   0.5294   0.6567   4.7055   1.6107   0.7183   0.0361   0.1558   0.0116   0.5577
 0.2339  -2.5451  -1.1327   0.2797   0.5191   0.5937   0.6608   4.7727   1.6390   0.7062   0.0329   0.1549   0.0069   0.5595
```

```
DATA

 0.87   1.10   1.22   1.43   1.46   1.54   1.60   1.01   1.70   1.76   1.82   1.66   1.61   1.42   1.44   1.72

 1.70   1.83   1.02   [illegible]   1.53   1.45   1.57   1.47   1.48   1.59   1.95   2.03

 LAG   [illegible]   INTERC   AB-SA   R-259   SLOPE   R-25[illegible]   ADAN   MEAN   SA   SH   STD ERR   SD X SD Y

[illegible] PROGRESS SEGMENTS [illegible] REGRESSION        MACHINE [illegible]

 [illegible]  -3.5076  [illegible]  1.1284  0.1347  0.6573  1.1002  [illegible]  0.9951  1.1578  0.2615  0.0525  0.4370  0.2598
 [illegible]  [illegible]  [illegible]  0.2657  0.4246  0.6647  [illegible]  3.4796  1.1030  0.7396  0.1276  0.0179  [illegible]  0.3201
 [illegible]  [illegible]  [illegible]  [illegible]  0.5153  0.6565  [illegible]  [illegible]  1.1904  0.5559  0.0721  0.0313  [illegible]  [illegible]
 [illegible]  [illegible]  [illegible]  [illegible]  0.4779  0.6262  [illegible]  [illegible]  1.2554  0.6197  0.0742  0.0414  [illegible]  [illegible]
 [illegible]  [illegible]  [illegible]  0.1564  [illegible]  0.6167  [illegible]  [illegible]  1.3158  0.5681  [illegible]  0.0349  [illegible]  0.3512
 [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  1.3770  0.5426  [illegible]  0.0270  [illegible]  [illegible]
 [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  0.6135  [illegible]  [illegible]  1.4214  0.5797  [illegible]  [illegible]  [illegible]  [illegible]
 [illegible]  [illegible]  [illegible]  [illegible]  0.5144  [illegible]  [illegible]  [illegible]  1.4557  0.5333  0.0413  0.0449  0.4170  [illegible]
 [illegible]  -2.0462  [illegible]  [illegible]  0.5114  0.5667  [illegible]  4.1403  1.4382  0.5197  0.1175  0.0478  [illegible]  0.3641
 [illegible]  -1.9175  [illegible]  [illegible]  0.5087  0.5775  [illegible]  [illegible]  1.5204  0.5378  0.0144  0.0466  [illegible]  [illegible]
 [illegible]  [illegible]  [illegible]  0.1363  0.4034  0.5744  0.6057  [illegible]  1.5274  0.6275  0.0656  0.0572  [illegible]  [illegible]
 [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  0.5011  [illegible]  [illegible]  [illegible]  [illegible]  0.0726  [illegible]  [illegible]  [illegible]
 [illegible]  -1.5214  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  0.6363  0.0708  [illegible]  [illegible]  [illegible]
 [illegible]  [illegible]  [illegible]  0.7170  [illegible]  [illegible]  0.6000  4.3951  [illegible]  0.6105  0.0667  0.1233  [illegible]  0.3175
 [illegible]  -1.7174  [illegible]  [illegible]  0.2233  [illegible]  0.6012  [illegible]  [illegible]  0.5444  [illegible]  0.1208  [illegible]  [illegible]
 [illegible]  [illegible]  [illegible]  0.7316  0.3361  [illegible]  [illegible]  [illegible]  [illegible]  0.5561  0.1562  0.1174  [illegible]  [illegible]
 [illegible]  [illegible]  [illegible]  [illegible]  0.3517  [illegible]  [illegible]  [illegible]  [illegible]  0.5476  0.0515  0.1142  [illegible]  [illegible]
 [illegible]  [illegible]  [illegible]  [illegible]  0.3625  0.4655  [illegible]  [illegible]  1.6197  0.5293  0.0475  0.1112  [illegible]  [illegible]
 [illegible]  [illegible]  [illegible]  0.5714  0.3671  [illegible]  [illegible]  [illegible]  [illegible]  0.5136  [illegible]  [illegible]  [illegible]  0.3127
 [illegible]  [illegible]  [illegible]  [illegible]  0.3744  [illegible]  0.5501  [illegible]  1.6461  0.4548  0.0410  [illegible]  [illegible]  [illegible]
 [illegible]  [illegible]  -0.4671  0.5144  0.3763  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  0.0372  0.1036  [illegible]  [illegible]
 [illegible]  [illegible]  [illegible]  0.5132  [illegible]  [illegible]  [illegible]  [illegible]  1.6725  0.4755  [illegible]  0.1013  [illegible]  0.3077
 [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  0.4540  [illegible]  [illegible]  1.6833  0.4047  [illegible]  [illegible]  [illegible]  [illegible]
 [illegible]  [illegible]  -0.4413  0.8776  0.3845  0.4555  [illegible]  [illegible]  [illegible]  0.4559  0.0315  [illegible]  [illegible]  [illegible]
 [illegible]  [illegible]  [illegible]  0.4577  0.3931  0.4561  [illegible]  [illegible]  1.7063  0.4475  0.0257  [illegible]  0.6414  [illegible]
 [illegible]  -1.3319  [illegible]  0.4271  0.3598  [illegible]  0.5117  [illegible]  1.7169  0.4398  0.0250  [illegible]  0.6414  [illegible]
```

```
0306     DATA 4

      1.47   1.57   1.64   1.65   1.63   1.32   1.94   1.71   1.75   1.89   1.81   1.90   1.86   1.90   1.93   1.90
      1.89   1.88   1.91   1.92   2.00   1.54

      RSR.   A-2SA   INTERC   A+2SA   B-2SB   SLOPE   B+2SB   XBAR   YBAR   SA   SB   STD ERR   SD X SD Y
 MANUFACTURING PROGRESS SEQUENTIAL REGRESSION                    MACHINE H

   0.9597   0.1453   0.4603   0.7753   0.2421   0.2781   0.3145   3.9453   1.5582   0.1575   0.0181   0.0081   0.3073   0.0361
   0.9937  -0.0637   0.5706   1.2047   0.1337   0.2492   0.3647   4.0519   1.5805   0.3172   0.0577   0.0141   0.3306   0.0932
   0.9635  -0.0947   0.7204   1.5356   0.0497   0.2104   0.3710   4.1355   1.5904   0.4076   0.0803   0.0262   0.3418   0.0754
   0.3033  -1.8254   1.4542   4.7333  -0.6578   0.0417   0.7413   4.1949   1.5455   1.6398   0.3498   0.1441   0.3437   0.1271
   0.1734  -2.9994   0.6568   4.3130  -0.5459   0.2217   0.9893   4.2653   1.6024   1.8281   0.3838   0.1904   0.3759   0.1721
   0.2687  -2.2333   0.6566   3.5464  -0.3628   0.2217   0.8063   4.3247   1.6156   1.4449   0.2923   0.1733   0.3726   0.1176
   0.2597  -1.7714   0.6119   2.9952  -0.2316   0.2327   0.6970   4.3784   1.6308   1.1917   0.2322   0.1512   0.3835   0.1752
   0.3538  -1.6756   0.4299   2.5354  -0.1156   0.2769   0.6694   4.4232   1.6562   1.0527   0.1962   0.1504   0.3948   0.1537
   0.3455  -1.4110   0.4138   2.2836  -0.0465   0.2808   0.6081   4.4733   1.6701   0.9124   0.1636   0.1477   0.4037   0.1503
   0.4574  -1.3211   0.3222   1.9655   0.0204   0.3027   0.5850   4.5157   1.6893   0.8217   0.1411   0.1424   0.4118   0.1941
   0.4940  -1.1781   0.3006   1.7793   0.0635   0.3079   0.5522   4.5541   1.7027   0.7394   0.1222   0.1354   0.4175   0.1729
   0.5336  -1.0905   0.2615   1.6135   0.1027   0.3171   0.5315   4.5905   1.7124   0.6760   0.1072   [illegible]   [illegible]   [illegible]
   0.5706  -1.0282   0.2221   1.4725   0.1362   0.3263   0.5164   4.6247   1.7313   0.6252   0.0951   0.1251   0.4279   0.1865
   0.5928  -0.9323   0.2242   1.3805   0.1566   0.3258   0.4951   4.6575   1.7417   0.5781   0.0846   0.1215   0.4349   0.1543
   0.6078  -0.8358   0.2403   1.3164   0.1701   0.3221   [illegible]   4.6894   1.7504   0.5380   0.0760   0.1176   0.4339   0.1817
   0.6151  -0.7394   0.2689   1.2772   0.1776   0.3155   0.4535   4.7176   1.7573   0.5041   0.0690   0.1143   0.4444   0.1752
   0.6255  -0.6712   0.2785   1.2282   0.1878   0.3133   0.4388   4.7453   1.7652   0.4749   0.0627   0.1107   0.4436   0.1771
   0.6443  -0.6160   0.2833   1.1826   0.1975   0.3122   0.4269   4.7719   1.7731   0.4496   0.0574   0.1074   0.4526   0.1785
   0.6665  -0.6121   0.2531   1.1183   0.2130   0.3191   0.4251   4.7973   1.7838   0.4326   0.0530   0.1056   0.4561   0.1773
   0.6775  -0.5642   0.2618   1.0878   0.2192   0.3171   0.4150   4.8217   1.7907   0.4130   0.0489   0.1050   0.4575   0.1763
```

```
CATA

   1.47   1.59   1.70   1.76   1.80   1.79   1.81   1.80   1.78   1.76   1.80   1.85   1.81   1.80   1.82   1.93

     R*R    A-2SA   INTERC   A+2SA   B-2SB   SLOPE   B+2SB     XBAR     YBAR      SA       SA    STD ERR  | SD X SC Y

MANUFACTURING PROGRESS SEQUENTIAL REGRESSION

   0.9835  -0.1993  0.6126  1.4245  0.1012  0.2550  0.4088  3.8197  1.5867  0.4060  0.0769  0.0295  0.4363  0.1172
   0.9668  -0.3396  0.5032  1.3460  0.1354  0.2859  0.4362  3.9402  1.6293  0.4214  0.0752  0.0279  0.4301  0.1250
   0.9755  -0.1800  0.4730  1.1263  0.1578  0.2940  0.3932  4.0471  1.6628  0.3265  0.0491  0.0234  0.4474  0.1317
   0.9691  -0.0604  0.5371  1.1347  0.1946  0.2770  0.3593  4.1394  1.6936  0.2988  0.0412  0.0256  0.4454  0.1233
   0.9657   0.0423  0.5758  1.1174  0.1581  0.2658  0.3345  4.2105  1.7011  0.2688  0.0439  0.0254  0.4454  0.1245
   0.9567   0.1185  0.6294  1.1332  0.1913  0.2533  0.3153  4.2859  1.7139  0.2549  0.0310  0.0273  0.4715  0.1121
   0.9272   0.1750  0.6970  1.2191  0.1692  0.2353  0.3023  4.3454  1.7215  0.2510  0.0393  0.0335  0.4756  0.1117
   0.8710   0.2311  0.7770  1.3245  0.1413  0.2154  0.2895  4.3979  1.7250  0.2733  0.0271  0.0421  0.4762  0.1175
   0.8688   0.3032  0.8073  1.3113  0.1430  0.2093  0.2731  4.4463  1.7322  0.2520  0.0325  0.0311  0.4413  0.1176
   0.8219   0.3320  0.8003  1.2685  0.1537  0.2098  0.2659  4.4908  1.7423  0.2341  0.0293  0.0307  0.4742  0.1072
   0.8764   0.3855  0.8277  1.2659  0.1520  0.2030  0.2541  4.5313  1.7477  0.2211  0.0277  0.0337  0.4461  0.1056
   0.8500   0.4371  0.8629  1.2888  0.1460  0.1946  0.2429  4.5036  1.7514  0.2129  0.0242  0.0395  0.4874  0.1022
   0.8583   0.4709  0.8936  1.2882  0.1450  0.1955  0.2340  4.6085  1.7557  0.2023  0.0223  0.0393  0.4877  0.0999
   0.8092   0.3378  0.8110  1.2342  0.1532  0.2070  0.2607  4.6333  1.7699  0.2366  0.0269  0.0307  0.4275  0.1121
```

MACHINE I

DATA

```
   2.15   0.92   0.6[illegible]   1.19   1.61   1.73   1.81   1.65   1.87   1.78   1.84   1.89   1.87   1.50   1.59   1.95
   1.57   2.00

   RMF    A-2SA    INTERC   A+2SA    B-2SB    SLOPE    B+2SB    XBAR     YBAR     SA       SB       STD ERR   SM X     SE Y
MANUFACTURING PROGRESS SEQUENTIAL REGRESSION                     MACHINE 'J'

   0.0932  -1.8217  -0.9881  -0.0326  0.3880   0.1528   0.6576   2.0020   0.6422   0.4413   0.0474   0.0158   0.4381   0.2746
   0.5449  -3.9811  -1.[illegible]  0.0944   0.2105   0.6938   1.1770   2.6236   0.6292   1.1147   0.2416   0.1199   0.6071   0.4724
   0.5419  -2.7122  -1.5776  0.0266   0.4456   0.7901   1.1553   3.0418   0.8261   1.1027   0.1727   0.1303   0.7177   [illegible]
   0.3787  -3.5[illegible]  -1.5521  0.4018   1.5791   0.7420   1.0129   3.2313   0.9767   0.9921   0.1108   0.1129   0.7618   0.6051
   0.5794  -1.4117  -1.[illegible]  0.3728   0.6174   0.7787   0.8592   3.3432   1.0074   0.9734   0.0904   0.1022   0.5462   [illegible]
   0.5603  -3.2036  -1.[illegible]  0.3088   0.6275   0.7551   0.8806   3.5315   1.1910   0.8593   0.0956   0.1119   0.5708   [illegible]
   0.5731  -4.1532  -1.4321  0.3190   0.6230   0.7301   0.7986   3.6509   1.2770   0.8750   0.0577   0.1027   [illegible]  0.5645
   0.5491  -3.0034  -1.3414  0.4125   0.6065   0.7084   [illegible]  3.7556   1.3186   0.8765   0.0710   0.1276   0.5457   0.6474
   0.5641  -2.9976  -1.2746  0.4305   0.5732   0.6475   0.8029   3.8440   1.3659   0.8565   0.0573   0.1282   0.5347   0.6141
   0.5420  -2.8916  -1.2334  0.4248   0.5543   0.6733   0.7782   3.9253   1.4093   0.8291   0.0525   0.1230   [illegible]  [illegible]
   0.5646  -2.9094  -1.1916  0.4243   0.5577   0.6972   0.7866   3.9754   1.4446   0.8047   0.0457   0.1235   0.5276   0.6046
   0.5535  -2.7157  -1.1417  0.4333   0.5516   0.7442   0.7323   4.0486   1.4767   0.7875   0.0477   0.1263   [illegible]  [illegible]
   0.5542  -2.6145  -1.1217  0.4071   0.5541   0.7186   0.7230   4.1252   1.5106   0.7654   0.0422   0.1105   0.5367   0.5512
   0.4534  -2.5541  -1.0855  0.3971   0.5512   0.6800   0.7087   4.1307   1.5391   0.7464   0.0364   0.1297   0.5217   0.5517
   0.5501  -2.5211  -1.0603  0.4035   0.5445   0.6183   0.6947   4.2322   1.5709   0.7304   0.0377   0.1117   [illegible]  0.5775
   0.5505  -2.4695  -1.0425  0.3844   0.5439   0.6140   0.6590   4.2794   1.5862   0.7134   0.0380   0.1292   0.8548   0.5835
```

```
DATA

 0.42   1.08   1.44   1.56   1.38   1.64   1.67   1.51   1.[illegible]8   1.77   1.71   1.77   1.69   1.91   1.90   1.[illegible]

 1.86   1.94   1.88   1.93   1.86   1.76   1.87   1.58   1.91   1.90   1.92   2.00   1.95   1.96   2.02

  R*R    A-2SA    INTERC    A+2SA    B-2SB    SLOPE    B+2SB    XBAR      YBAR     SA       SB        STD ERR    SD X SD Y

MANUFACTURING PROGRESS SEQUENTIAL REGRESSION                   MACHINE 'K'

 0.5530  -2.7690  -0.7809   1.2072   0.2579   0.5606   0.8632   3.1437    0.9813   0.9341   0.1513   0.0413   0.9714   0.5143
 0.9949  -2.3143  -0.7667   0.7808   0.3990   0.5551   0.7112   3.4024    1.1220   0.7738   0.0791   0.0444   0.9151   0.5034
 0.9519  -2.6896  -0.6221   1.4453   0.1773   0.5009   0.8245   3.5818    1.1741   1.0347   0.1619   0.1152   0.8467   0.4552
 0.9600  -2.4118  -0.6363   1.1393   0.2716   0.5066   0.7415   3.7278    1.2521   0.9478   0.1175   0.1056   0.4766   0.4478
 0.9551  -2.2365  -0.6457   0.9451   0.3241   0.5047   0.6853   3.9437    1.3122   0.7479   0.1934   [illegible]  0.9578   0.4434
 0.9434  -2.1344  -0.5454   1.0435   0.2840   0.4768   0.6696   3.9490    1.3375   0.7345   0.0964   0.1343   [illegible]  0.4133
 0.9456  -2.0402  -0.5635   0.9131   0.3220   0.4834   0.6448   4.0354    1.3862   0.7359   0.0637   0.1526   [illegible]  0.4137
 0.9512  -1.9433  -0.5651   0.8131   0.3470   0.4813   0.6156   4.1195    1.4248   0.5436   0.0441   [illegible]  [illegible]  [illegible]
 0.9468  -1.8430  -0.5331   0.7768   0.3503   0.4734   0.5965   4.1902    1.4505   0.4550   0.0615   0.0547   0.9178   [illegible]
 0.9509  -1.7610  -0.5199   0.7213   0.3531   0.4655   0.5779   4.2543    1.4775   0.6206   0.0562   [illegible]  [illegible]  [illegible]
 0.9534  -1.7413  -0.5387   0.6639   0.3772   0.4749   0.5727   4.3120    1.5093   0.6013   0.0497   [illegible]  0.9031   [illegible]
 0.9547  -1.6799  -0.5277   0.6246   0.3835   0.4718   0.5600   4.3628    1.5306   0.5761   0.0441   0.0449   0.7364   [illegible]
 0.9569  -1.6565  -0.5384   0.5797   0.3945   0.4748   0.5551   4.4100    1.5555   0.5591   0.0431   0.0722   0.7772   0.3771
 0.9592  -1.6235  -0.5406   0.5423   0.4024   0.4754   0.5484   4.4539    1.5769   0.5415   0.0365   0.0793   [illegible]  0.3739
 0.9594  -1.5777  -0.5271   0.5234   0.4040   0.4717   0.5394   4.4553    1.5934   0.5253   0.0339   0.0777   0.7749   0.3731
 0.9612  -1.5555  -0.5310   0.4935   0.4105   0.4728   0.5351   [illegible]  1.6126   0.5123   0.0311   0.0753   0.7706   0.3712
 0.9610  -1.5151  -0.5163   0.4825   0.4104   0.4690   0.5275   [illegible]  1.6269   0.4797   0.0293   0.0744   [illegible]  [illegible]
 0.9622  -1.4876  -0.5123   0.4630   0.4134   0.4678   0.5222   4.6054    1.6420   0.4878   0.0277   [illegible]  [illegible]  [illegible]
 0.9591  -1.4495  -0.4897   0.4701   0.4087   0.4618   0.5150   4.6333    [illegible]  0.4739   0.0265   [illegible]  [illegible]  [illegible]
 0.9443  -1.4159  -0.4469   0.5221   0.3926   0.4507   0.5088   4.6692    1.6574   0.4845   0.0291   [illegible]  0.7525   0.3443
 0.9424  -1.3785  -0.4285   0.5216   0.3900   0.4459   0.5018   [illegible]  1.6668   0.4750   0.0233   [illegible]  0.7422   0.3437
 [illegible] -1.3568  -0.4257   0.5054   0.3927   0.4452   0.4978   4.7272    1.6789   0.4655   0.0243   [illegible]  0.7455   0.3414
 [illegible] -1.3251  -0.4112   0.5026   0.3912   0.4416   0.4919   4.7545    [illegible]  0.4569   0.0252   0.0521   0.7419   0.3373
 0.9418  -1.2933  -0.3950   0.5034   0.3789   0.4375   0.4960   4.7806    1.6964   0.4472   0.0245   0.0321   0.7311   0.3313
 0.9439  -1.2538  -0.3605   0.5328   0.3871   0.4338   0.4805   [illegible]  1.7045   0.4417   0.0236   0.0313   0.7365   0.3236
 0.9425  -1.2499  -0.3800   0.4899   0.3895   0.4337   0.4780   4.8303    1.7150   0.4350   0.0221   0.0302   0.7342   [illegible]
 0.9425  -1.2260  -0.3698   0.4865   0.3888   0.4312   0.4736   [illegible]  1.7233   0.4281   0.0212   0.0276   0.7329   0.3252
 0.9426  -1.2027  -0.3592   0.4843   0.3879   0.4286   0.4694   4.8776    1.7311   0.4219   0.0204   [illegible]  0.7335   0.3226
 0.9439  -1.1913  -0.3586   0.4741   0.3896   0.4285   0.4673   4.8587    1.7404   0.4153   0.0194   [illegible]  0.7232   0.3212
```

DATA

1.39 1.43 1.47 1.47 1.51 1.58 1.51 1.46 1.56 1.14 1.50 1.60 1.73 1.74 1.64 1.64

1.42 1.56 1.43 1.53 1.73 1.70 1.70 1.86 1.87 1.93 1.85 1.35 2.00 1.01 1.88 1.97

1.54 1.60 1.76 1.78

MANUFACTURING PROGRESS SEQUENTIAL REGRESSION MACHINE [illegible]

PRED.	[illegible]	INTERC	[illegible]	R-SQR	SLOPE	[illegible]	XBAR	YBAR	[illegible]	SD	STD ERR.	SD X	SD Y
0.0330	0.5747	-0.7803	1.0333	0.1425	0.1741	[illegible]	3.5550	1.4252	0.1071	0.0154	0.0330	0.2243	1.0325
0.0546	0.2037	0.5577	1.4327	0.0125	0.1461	0.3736	3.7613	1.4347	0.2975	0.1661	0.1110	0.3115	[illegible]
0.2651	[illegible]	0.1506	1.3130	0.0674	0.1565	0.2425	3.4635	1.4519	0.2313	[illegible]	0.2113	[illegible]	[illegible]
0.2126	0.0641	0.7360	1.4115	0.0511	0.1806	0.2270	3.2323	1.4727	0.3600	[illegible]	[illegible]	0.3510	[illegible]
0.2714	0.1503	0.9103	1.4511	0.2173	0.1675	0.2170	3.9973	1.4737	0.3255	0.2651	0.1271	0.3448	0.2456
0.4332	0.1727	1.0517	1.2459	-0.0425	0.1299	0.2323	4.0629	1.4763	0.4034	0.2757	0.1631	0.3725	[illegible]
0.5413	0.2051	0.7177	1.6303	-0.3346	0.1309	0.8022	4.1336	1.4353	0.3543	0.0717	0.0701	0.3764	0.0611
0.0032	-0.7363	1.3203	2.3555	-0.6112	0.1305	0.6732	4.1231	1.4511	1.0331	[illegible]	0.1325	0.3746	0.1235
0.2154	[illegible]	1.2610	[illegible]	-0.3243	0.1631	0.3606	4.1427	1.4644	0.2523	[illegible]	0.1297	[illegible]	[illegible]
[illegible]	-0.4471	1.1061	2.0545	-0.2689	0.1533	1.4454	4.1233	1.4757	0.0745	0.1736	0.1222	[illegible]	0.1257
0.1221	-0.3647	0.6595	[illegible]	-0.2132	0.1279	0.7487	4.2313	1.4376	0.0546	0.1736	0.1318	[illegible]	[illegible]
0.1274	-0.4716	0.0016	[illegible]	-0.1607	0.1666	1.6310	4.2510	1.5150	0.3306	0.1737	0.1314	0.4718	0.1450
0.2734	-0.2095	0.2401	1.2307	-0.1121	0.1373	0.6768	4.2778	1.5109	0.7769	0.1473	0.1327	[illegible]	0.1448
0.2493	-0.7157	0.2201	2.1335	-0.2744	0.1291	0.6545	4.2966	1.5272	0.7127	0.1327	0.1231	0.2767	0.1437
0.2426	[illegible]	[illegible]	2.0519	-0.0465	[illegible]	0.4207	4.2390	1.5130	0.4540	0.1121	0.1213	[illegible]	[illegible]
0.2230	-0.4831	0.7344	1.5371	-0.1060	0.1363	0.4073	4.3347	1.5386	[illegible]	0.1222	0.1226	[illegible]	0.1363
0.2011	-0.4177	0.7142	1.5454	-0.0057	0.1038	0.2956	4.3792	1.5604	[illegible]	0.0936	0.1167	0.2162	0.1358
0.2313	-0.3213	0.7376	1.7255	-0.0115	0.1133	0.3636	4.4006	1.5631	0.5233	0.1033	0.1139	0.2311	0.1316
0.2761	-0.3303	0.6709	1.7005	0.0176	0.1077	0.3669	4.4315	1.5519	0.5034	0.0360	0.1122	[illegible]	0.1346
0.2514	-0.2761	0.6659	1.6175	0.0676	0.1155	0.3535	4.4416	1.5587	0.4950	0.0720	0.1112	0.3033	0.1360
0.3013	-0.2314	[illegible]	[illegible]	0.0713	[illegible]	0.3752	4.4600	1.5606	0.4735	0.1701	0.1123	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1.4519	[illegible]	0.2261	0.3349	4.4736	1.5107	0.4775	0.0741	0.1151	[illegible]	[illegible]
0.4529	-0.4743	[illegible]	1.2703	0.1101	[illegible]	0.4113	4.4675	1.5923	0.4843	[illegible]	0.1131	[illegible]	0.1573
0.4543	-0.4321	0.3073	1.2317	0.1311	0.2307	[illegible]	4.5152	1.6014	0.4072	[illegible]	0.1249	[illegible]	0.1120
0.5019	-0.3245	0.3476	1.2106	0.1524	0.1114	0.4404	4.5334	1.6145	0.4049	[illegible]	0.1234	[illegible]	0.1215
0.5745	-0.3337	0.2303	1.1553	0.1203	0.1110	0.4527	4.5731	1.6220	0.4725	[illegible]	0.1232	[illegible]	0.1735
0.5464	-0.3522	[illegible]	1.0734	0.2024	0.2334	0.4473	4.5650	1.6357	0.4932	[illegible]	0.1207	[illegible]	[illegible]
0.5477	[illegible]	[illegible]	1.0141	0.2103	[illegible]	[illegible]	4.6033	1.6540	0.4751	0.3035	0.1241	0.4136	0.1371
0.5934	[illegible]	0.5427	0.6457	0.2116	[illegible]	[illegible]	4.5811	1.6596	0.4419	0.1532	0.1244	0.4137	0.1216
0.6036	-0.0274	-0.0116	0.9261	0.2495	[illegible]	0.4769	4.6139	1.6624	0.4579	0.0544	0.1247	[illegible]	0.1344
0.6032	-0.0645	[illegible]	0.7531	0.2412	0.1709	0.4709	4.6295	1.6737	0.4437	0.0545	0.1277	0.4103	0.1055
0.4335	-0.0311	0.1043	0.5195	0.2701	0.1733	0.4767	4.6447	1.6772	0.4322	0.0517	0.1210	0.4727	0.1131
0.4345	-0.0736	-0.1191	0.8363	0.2453	0.1643	0.4437	4.6534	1.6705	0.4272	0.3637	0.1234	0.4251	0.1257
0.5237	-0.0211	0.0115	0.8443	0.2422	0.1575	0.4576	4.6736	1.6822	0.4143	0.3474	0.1235	0.4335	0.1035

```
DATA

  0.82    1.06    1.49    1.93    1.72    1.09    1.86    1.83    1.96    1.76    1.98    2.00    2.01

     RSQ   A-2SA   INTERC   A+2SA   B-2SB   SLOPE   B+2SB    XBAR    YBAR     SA      SB   STD ERR    SD X    SD Y
MANUFACTURING PROGRESS SEQUENTIAL REGRESSION                 MACHINE [illegible]

  0.8848 -4.0721 -0.5164  2.9337 -0.2629  0.5360  1.3349  1.2534  1.1796  1.7519  0.3995  0.2134  0.7045  0.4478
  0.9331 -2.9352 -0.6192  1.6967 -0.1729  0.5537  0.9496  3.5317  1.3418  1.1480  0.1724  0.1547  0.9360  0.4603
  0.9351 -2.4564 -0.3214  1.4127  0.2451  0.5315  0.8070  3.7229  1.4190  0.9706  0.1382  0.1462  0.9613  0.5042
  0.9364 -2.1503 -0.4085  1.1977  0.3147  0.5125  0.7103  3.9751  1.4999  0.8277  0.0030  0.1370  0.4142  0.4444
  0.9363 -1.0271 -0.4414  1.0423  0.3177  0.5165  0.6560  3.2072  1.5326  0.7628  0.0797  0.1106  0.8419  0.4261
  0.9358 -1.7554 -0.3337  0.9990  0.3527  0.5773  0.6135  4.0203  1.5777  0.6959  0.0679  0.1159  0.8333  0.4059
  0.9325 -1.6451 -0.3001  0.9947  0.3573  0.5710  0.7024  4.1360  1.4111  0.6375  0.0563  0.1274  0.8182  0.4071
  0.9285 -1.5440 -0.3019  0.0636  0.3757 [illegible] 0.5710 4.2593 1.6335  0.5376  0.0531  0.1202  0.7033  0.3011
  0.0130 -1.4075 -0.3045  0.8974  0.3537 [illegible] 0.5577 4.3254 1.6626  0.5376  0.0519  0.1177  0.7033  0.3723
  0.8133 -1.4420 -0.3374  0.8776  0.3663  0.4554  0.5446  4.3957  1.6304  0.5471  0.0464  0.1112  0.7071  0.3721
  0.8398 -1.3909 -0.3743  0.7910  0.3757  0.4549  0.5313  4.4475  1.7154  0.5626  0.0374  0.1041  0.7770  0.3674
```

```
DATA

  0.33   0.76   0.42   0.70   1.34   1.39   1.18   1.00   1.22   1.00   1.46   1.63   1.66   1.64   1.72   1.71
  1.49   1.73   1.28   1.50   1.19   1.78   1.73   1.77   1.60   1.43   1.40   1.37   1.08   1.27   1.14   1.49
  1.75   1.67   1.83   1.54   1.63   1.82   1.99   1.95   1.82   1.97   2.00   1.96   1.56   1.56   1.55   1.59
  1.53   1.55   1.93

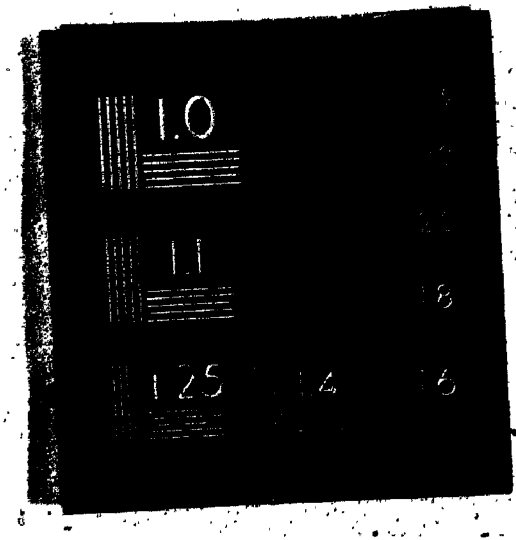
  POS.    A-2SA    INTERC    A+2SA    B-2SB    SLOPE    B+2SB    XBAR     YBAR     SA       SB     STD ERR    SC X     SC Y
MANUFACTURING PROGRESS SEQUENTIAL REGRESSION                     MACHINE [illegible]

 0.3154  -5.7443  [illegible] [illegible] -2.2577  0.2037   2.6011  2.1756   0.5120   2.5190   1.2287   0.2868   0.6324   0.2454
 0.4253  -3.4553  -0.0317   3.5445  -1.3675  [illegible] 1.5305  2.3300   0.5580   1.7566   0.5545   0.2045   0.6434   0.2214
 0.5563  [illegible] -0.4030 3.7550  -2.5326  0.4446   1.1210   2.5150   0.7145   2.1294   0.6486   0.2950   0.6641   0.2572
 0.7021  -4.1206  [illegible] 2.5620 -0.4710  0.5226   1.1151   2.6716   0.6272   1.7758   0.4963   0.2745   0.7215   0.4510
 0.7057  -3.4826  [illegible] 2.4419 -0.2727  [illegible] 1.2455 2.7352  0.6666   1.4846   0.3751   0.2525   0.7353   0.4251
 [illegible] -3.2354 [illegible] [illegible] -0.2025 [illegible] [illegible] [illegible] 0.8850 1.3156 0.3210 0.2478 [illegible] [illegible]
 [illegible] -2.7777 -0.3523  1.9561  -0.1072  [illegible] [illegible] [illegible] 0.9221 1.1652 0.2624  [illegible] [illegible] [illegible]
 0.6575  -2.4711  -0.7051   1.8609  -0.0654  [illegible] 0.7741  3.0339   [illegible] 1.0430  0.2340   0.2282   0.7314   0.3857
 [illegible] -2.4531 [illegible] 1.7311 -0.0175 0.4330  [illegible] [illegible] 0.9779 1.0379  0.2101   0.2256   [illegible] [illegible]
 0.7113  -2.6431  [illegible] 1.5565  0.0759   0.4712   [illegible] [illegible] 1.0225 1.0267  0.1657   0.2312   0.7244   0.4113
 [illegible] -2.5576 -0.4427 1.4722  0.1460   [illegible] [illegible] [illegible] [illegible] 1.0075 0.1775 [illegible] 0.7464 [illegible]
 [illegible] [illegible] [illegible] 1.2441 0.1574 [illegible] [illegible] 3.3100 1.1206 0.9627 0.1530 [illegible] [illegible] [illegible]
 0.7413  -2.4430  [illegible] 1.2371 [illegible] [illegible] [illegible] 3.3720 1.1402 [illegible] 0.1423 0.2176 [illegible] [illegible]
 0.8315  -2.4152  [illegible] 1.1422  0.2914  0.5373   0.7233   3.4210  1.1947   [illegible] [illegible] 0.2105 [illegible] 0.4551
 [illegible] -2.3413 [illegible] 1.0772 0.3007 [illegible] 0.7635 3.4775  [illegible] 0.8566 0.1157  0.2042   0.7444   [illegible]
 0.8207  -2.2852  [illegible] 1.0052  0.3261   0.5343   0.7465   [illegible] 1.2452 0.6238   0.1251   0.1578   0.7637   0.4512
 0.7751  -2.1075  -0.5527   1.0322   0.2502   0.5043   0.7153   3.5060   1.2470   0.8224   0.1170   0.2135   [illegible] 0.4406
 [illegible] -2.1134 [illegible] 1.0161 [illegible] [illegible] 0.7007 3.6100 1.2275 [illegible] [illegible] 0.2075 [illegible] [illegible]
 0.7548  [illegible] -0.5513 0.9261   0.3215   [illegible] [illegible] [illegible] 1.2471 0.7667 [illegible] 0.2020 0.7735 [illegible]
 0.8031  [illegible] [illegible] 0.9365 0.3344 [illegible] 0.7703 [illegible] 1.3065  0.7511   0.0447   [illegible] 0.7754 0.4991
 [illegible] -2.0276 [illegible] [illegible] 0.3510 0.5076 [illegible] [illegible] 1.3276 0.7310 0.0768 0.1529 [illegible] [illegible]
 [illegible] [illegible] [illegible] 0.8584 0.3627 0.5102 [illegible] [illegible] 1.3411 0.7143 0.0736 [illegible] [illegible] [illegible]
 [illegible] [illegible] [illegible] 0.8232 [illegible] 0.5118 [illegible] [illegible] 1.3642 [illegible] [illegible] 0.1844 0.7711 0.4377
 [illegible] [illegible] -0.5217 [illegible] 0.3555 [illegible] [illegible] [illegible] 1.3667 [illegible] [illegible] [illegible] [illegible] [illegible]
 0.7212  [illegible] [illegible] [illegible] [illegible] 0.4774 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] 0.7701 [illegible]
 [illegible] [illegible] [illegible] [illegible] 0.3210 [illegible] [illegible] [illegible] 1.3672 [illegible] [illegible] [illegible] [illegible] 0.4129
 [illegible] [illegible] -0.2236 1.1205   0.2711   0.4497   [illegible] 3.9025 1.3568  0.7214   0.0763   0.2454   [illegible] 0.4113
 [illegible] [illegible] [illegible] 1.1675 0.2514 0.4121   [illegible] 3.9207 1.3506  0.7175   [illegible] 0.2543 0.7744 [illegible]
 0.5775  [illegible] [illegible] 1.2233  0.2332   [illegible] [illegible] 3.9446 1.3444 0.7167 [illegible] [illegible] 0.7722 [illegible]
 [illegible] [illegible] [illegible] 1.1534 [illegible] [illegible] [illegible] [illegible] 1.3522 0.7000 [illegible] [illegible] [illegible] [illegible]
 [illegible] [illegible] [illegible] 1.1441 [illegible] [illegible] [illegible] [illegible] 1.3644 [illegible] [illegible] [illegible] [illegible] [illegible]
 [illegible] [illegible] [illegible] 1.1283 0.2570 [illegible] [illegible] [illegible] 1.3724 [illegible] 0.0704 0.2527 [illegible] 0.3533
 [illegible] [illegible] [illegible] [illegible] 0.2675 [illegible] [illegible] [illegible] [illegible] 0.6689 [illegible] 0.2535 [illegible] [illegible]
 [illegible] [illegible] [illegible] 1.0779 0.2702 [illegible] 0.5313 4.0538 1.3510 [illegible] 0.0653 [illegible] 0.7415 0.3017
 [illegible] [illegible] [illegible] 1.0690 0.2797 0.4058 [illegible] [illegible] 1.4036 0.6487 0.0631 0.2450 [illegible] [illegible]
 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] 1.4141 [illegible] [illegible] [illegible] [illegible] 0.3515
 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] 0.6472 [illegible] 0.2431 [illegible] [illegible]
 [illegible] [illegible] -0.3037 [illegible] 0.3095 0.4252   [illegible] [illegible] 1.4419 0.6297 [illegible] 0.2422 [illegible] [illegible]
 0.5514  [illegible] [illegible] 0.8428   0.3185   0.4271   [illegible] [illegible] 1.4509 0.6315 0.0558 [illegible] [illegible] [illegible]
 0.6553  [illegible] -0.3415 0.9171      0.3248   0.4234   [illegible] [illegible] 1.4623 0.6292 0.0544 [illegible] 0.7564 0.4032
```

```
0.6610 -1.6136 -0.3637 0.6921 0.3241 0.4355 0.4657 4.1016 1.4759 0.6275 0.0525 0.2376 0.7550 0.4057
0.6742 -1.6236 -0.3631 0.6885 0.3419 0.4567 0.4672 4.1003 1.4868 0.6263 0.0514 0.2371 0.7544 0.4094
0.6660 -1.6751 -0.3944 0.6461 0.3441 0.4496 0.4607 4.2140 1.4773 0.6203 0.0490 0.2347 0.7526 0.4116
0.6877 -1.6625 -0.4032 0.8244 0.3581 0.4591 0.4500 4.2106 1.5078 0.6167 0.0449 0.2327 0.7574 0.4118
0.6903 -1.6639 -0.4137 0.7044 0.3626 0.4561 0.4562 4.4407 1.5172 0.6171 0.0470 0.2336 0.7536 0.4123
0.7019 -1.6633 -0.4327 0.7844 0.3616 0.4558 0.4513 4.2023 1.5272 0.6385 0.0457 0.2295 0.7526 0.4127
0.7049 -1.6645 -0.4344 0.7674 0.3716 0.4414 0.4502 4.2777 1.5365 0.6131 0.0447 0.2266 0.7527 0.4126
0.7116 -1.6625 -0.4457 0.7511 0.3774 0.4635 0.4515 4.2164 1.5440 0.5936 0.0420 0.2245 0.7527 0.4116
0.7104 -1.6587 -0.4446 0.7270 0.3935 0.4644 0.4527 4.3377 1.5516 0.5529 0.0410 0.2223 0.7528 0.4115
```

MACHINE 'N' CONTINUED

4 OF/DE 4



```
DATA
   0.91    1.17    1.12    1.34    1.44    1.60    1.56    1.50    1.62    1.69    1.62    1.73    1.62    1.61    1.72    1.73
   1.46    1.6[illegible]    1.68    1.90    1.75    1.81    1.84    1.75    1.70    1.74    1.88    1.84    1.80    1.87    1.[illegible]1    1.93
   1.86    1.84    1.80    1.73    1.87    1.78    1.90

     COR    A-2SA   INTERC   A+2SA   B-2SB   SLOPE   B+2SB    XBAR    YBAR     SA      SB    STD ERR    SD X   SD Y
 MANUFACTURING PROGRESS SEQUENTIAL REGRESSION          MACHINE 'O'

  0.8603  -1.6965  0.4362  2.5689  -0.5295  0.4852  1.5079  1.2232  1.0346  1.0664  0.7394  0.1348  0.3768  0.1587
  0.9197  -0.9737  0.3954  1.7647  -0.1597  0.5744  1.2006  1.3550  1.1100  0.6451  0.3471  0.0769  0.4051  0.2218
  0.9473  -0.7155  0.3770  1.4693   0.1703  0.5441  0.9200  1.4500  1.1762  0.5462  0.2066  0.0662  0.4334  0.2523
  0.9552  -0.7429  0.3212  1.3851   0.2635  0.5881  0.8129  1.5712  1.2677  0.5330  0.1474  0.1658  0.4417  0.2778
  0.9584  -0.6205  0.3574  1.3234   0.3148  0.5462  0.7137  1.6018  1.2524  0.4860  0.1237  0.0627  0.4445  0.2876
  0.9329  -0.5642  0.4116  1.3834   0.2672  0.5212  0.7752  1.7335  1.3183  0.4929  0.1260  0.0754  0.4558  0.2697
  0.9411  -0.4874  0.4287  1.3330   0.3117  0.5140  0.7163  1.8034  1.3517  0.4549  0.1317  0.0704  0.5126  0.2815
  0.9498  -0.4458  0.4191  1.2840   0.3502  0.5158  0.7014  1.8730  1.3855  0.4326  0.0428  0.0659  0.5240  0.2773
  0.9446  -0.3811  0.4457  1.2946   0.3458  0.4572  0.6860  1.9310  1.4071  0.4195  0.2757  0.0677  0.5330  0.2123
  0.9517  -0.2616  0.4447  1.2550   0.3641  0.4572  0.5202  1.9354  1.4339  0.4067  0.0556  0.0641  0.5414  0.2781
  0.9255  -0.3227  0.4809  1.2645   0.3449  0.4753  0.5058  2.0044  1.4475  0.4018  0.0652  0.0714  0.5474  0.2671
  0.9157  -0.2913  0.5135  1.3045   0.3246  0.4549  0.5081  2.0793  1.4593  0.3975  0.0451  0.0777  0.5523  0.2[illegible]
  0.9243  -0.2509  0.5184  1.2876   0.3360  0.4515  0.5573  2.1214  1.4770  0.3946  0.0590  0.0743  0.5574  0.2416
  0.9274  -0.2224  0.5254  1.2721   0.3432  0.4677  0.5922  2.1609  1.4929  0.3734  0.0522  0.0726  0.5604  0.2455
  0.9183  -0.2259  0.5470  1.2709   0.3341  0.4345  0.5327  2.1277  1.5028  0.3566  0.0534  0.0713  0.5725  0.2456
  0.9159  -0.1510  0.5629  1.2775   0.3337  0.4257  0.5207  2.2025  1.5131  0.3576  0.0475  0.0753  0.5660  0.2418
  0.9097  -0.1210  0.5903  1.2516   0.3246  0.4197  0.5007  2.2048  1.5217  0.3506  0.0455  0.0744  0.5691  0.2476
  0.9153  -0.1120  0.5775  1.2671   0.3335  0.4177  0.5009  2.2759  1.5354  0.3444  0.0419  0.0745  0.5702  0.2437
  0.9142  -0.0995  0.5855  1.2604   0.3347  0.4128  0.4909  2.3355  1.5455  0.3375  0.0350  0.0733  0.5720  0.2467
  0.9236  -0.0794  0.5859  1.2464   0.3407  0.4138  0.4854  2.3929  1.5573  0.3322  0.0362  0.0714  0.5735  0.2471
  0.9244  -0.0769  0.5923  1.2510   0.3473  0.4267  0.5062  2.3912  1.5694  0.3295  0.0337  0.0698  0.5759  0.2422
  0.9227  -0.0535  0.5940  1.2344   0.3465  0.4188  0.4752  2.4073  1.5771  0.3232  0.0327  0.0696  0.5775  0.2454
  0.9209  -0.0330  0.6034  1.2378   0.3417  0.4073  0.4649  2.4323  1.5846  0.3192  0.0308  0.0695  0.5785  0.2433
  0.9170  -0.0118  0.6159  1.2433   0.3371  0.3949  0.4506  2.4501  1.5905  0.3139  0.0299  0.0707  0.5501  0.2424
  0.9224  -0.0136  0.6107  1.2350   0.3430  0.3895  0.4500  2.4793  1.6011  0.3122  0.0281  0.0652  0.5914  0.2421
  0.9211  -0.0057  0.6120  1.2291   0.3455  0.3588  0.4521  2.5316  1.6097  0.3106  0.0266  0.0696  0.5927  0.2419
  0.9221   0.0101  0.6191  1.2292   0.3442  0.3952  0.4462  2.5434  1.6163  0.3045  0.0255  0.0679  0.5830  0.2432
  0.9257   0.0151  0.6187  1.2224   0.3471  0.3954  0.4437  2.5640  1.6247  0.3018  0.0241  0.0667  0.5856  0.2406
  0.9286   0.0157  0.6149  1.2142   0.3513  0.3473  0.4433  2.5343  1.6337  0.3006  0.0230  0.0658  0.5661  0.2417
  0.9304   0.0291  0.6157  1.2103   0.3550  0.3908  0.4436  2.5541  1.6430  0.3003  0.0220  0.0651  0.5874  0.2434
  0.9321   0.0145  0.6133  1.2084   0.3561  0.3901  0.4401  2.6033  1.6497  0.2974  0.0210  0.0643  0.5898  0.2427
  0.9316   0.0139  0.6108  1.2047   0.3544  0.3956  0.4402  2.6219  1.6554  0.2944  0.0203  0.0641  0.5904  0.2412
  0.9325   [illegible]  0.6110  1.2455   0.3557  0.3964  0.4[illegible]  2.6[illegible]  1.6622  0.2922  0.0194  0.0632  0.5904  0.2411
  0.9141   0.0548  0.6193  1.2241   0.3442  0.3854  0.4269  2.6574  1.6640  0.2926  0.0206  0.0691  0.5915  0.2379
  0.9102   0.0648  0.6635  1.2833   0.3441  0.3937  0.4252  2.6744  1.6696  0.2895  0.0198  0.0686  0.5922  0.2370
  0.9121   0.0906  0.6562  1.2717   0.3381  0.3777  0.4173  2.6708  1.6725  0.2878  0.0198  0.0736  0.5925  0.2345
  0.9141   0.0667  0.6575  1.2287   0.3391  0.3771  0.4152  2.7000  1.6782  0.2856  0.0190  0.0696  0.5935  0.2341
```

```
4025  DATA

      1.15    1.70    1.95    1.91    2.04    2.00    1.96    2.06

      R*R    A-2SA    INTERC    A+2SA    B-2SB    SLOPE    B+2SB    XBAR    YBAR     SA      SB    STD ERR    SD X SD Y

 MANUFACTURING PROGRESS SEQUENTIAL REGRESSION                    MACHINE 'P'

    0.9964  -2.6773  -1.2899   0.0975   0.6241   0.7780   0.9318   3.7161   1.6012   0.6937   0.0769   0.0349   0.5232   0.4078
    0.9539  -2.8134  -0.9033   1.0068   0.3626   0.6655   0.9684   3.8799   1.6788   0.9550   0.1515   0.0998   0.5383   0.3674
    0.9537  -2.3130  -0.7826   0.7448   0.4284   0.6315   0.8346   4.0112   1.7505   0.7637   0.1016   0.0885   0.5510   0.3563
    0.9317  -2.0119  -0.5959   0.8201   0.3988   0.5901   0.7613   4.1173   1.7925   0.7080   0.0906   0.0578   0.5572   0.3348
    0.8912  -1.7656  -0.4010   0.9636   0.3512   0.5273   0.7034   4.2047   1.8162   0.6823   0.0881   0.1127   0.5587   0.3120
    0.8924  -1.5466  -0.3281   0.8903   0.3640   0.5080   0.6519   4.2807   1.8463   0.6092   0.0720   0.1067   0.5601   0.3012
```

```
DATA

  0.32    0.36    1.11    1.06    1.59    1.41    1.33    1.71    1.77    1.87    1.93

  ROW    A-2SA   INTERC   A+2SA   B-2SB   SLOPE   B+2SB   XBAR    YBAR    SA      SB    STD ERR   SD X SD Y

MANUFACTURING PROGRESS SEQUENTIAL REGRESSION                 MACHINE 'J'

0.9061  -4.6427  -1.6933  2.0605  -0.2121  0.5101  2.0323  4.7345  0.5577  1.9759  0.5411  0.1914  0.4419  0.4414
0.9057  -4.3378  -1.6612  1.0142   0.1898  0.7904  1.3709  2.9144  0.7125  1.2880  0.2953  0.1658  0.5213  0.4275
0.8455  -3.1610  -1.7523  0.3571   0.5079  0.8622  1.2157  3.0477  0.9887  1.0899  0.1773  0.1556  0.6256  0.5424
0.9316  -3.5496  -1.4424  0.4246   0.4954  0.7825  1.0696  3.2450  0.5753  0.9535  0.1436  0.1544  0.6512  0.5240
0.6014  -3.2432  -1.3577  0.5278   0.4465  0.7097  0.9720  3.3597  1.0266  0.9428  0.1316  0.1722  0.6695  0.5237
0.9205  -3.1639  -1.4063  0.3494   0.5230  0.7263  0.9307  3.4673  1.1122  0.8773  0.1122  0.1593  0.6915  0.5231
0.9336  -3.2456  -1.4175  0.2744   0.5775  0.7701  0.9627  3.5649  1.1552  0.8260  0.0813  0.1476  0.7095  0.5241
0.9436  -3.1124  -1.4275  0.1578   0.6008  0.7333  0.8657  3.6507  1.2541  0.7526  0.0663  0.1932  0.7251  0.5512
0.9512  -3.1537  -1.4161  0.1133   0.4206  0.7305  0.8413  3.7418  1.3151  0.7664  0.0552  0.1334  0.7472  0.5535
```

```
DATA

  1.07   1.48   1.22   1.59   0.74   1.60   1.72   1.79   1.64   1.85   1.80   1.79   1.88   1.84   1.85   2.00

  2.00   1.97

   RHO    A-2SA   INTERC   A+2SA    B-2SB    SLOPE    B+2SB    XBAR     YBAR     SA       SB    STD ERR    SD X SD Y

MANUFACTURING PROGRESS SEQUENTIAL REGRESSION                    MACHINE 'B'

  0.5391  -6.2221   0.3303   5.9220  -1.0222   0.2888   1.5499   3.2147   1.2288   2.2613   0.6555   0.1490   0.3911   0.1540
  0.7332  -3.3168  -0.1738   2.9711  -0.3605   0.4452   1.2500   3.3549   1.3196   1.5725   0.4928   0.1398   0.4250   0.2210
  0.8042  -5.4022  -1.0558   7.4718  -1.6328   0.0684   1.7509   3.4992   1.2038   3.2180   0.8400   0.3712   0.4188   0.2221
  0.3825  -6.6022   1.4180   5.6683  -1.0587   0.2296   1.5019   3.5293   1.2701   2.5501   0.6407   0.3543   0.4287   0.2218
  0.2869  -4.2104   0.5603   6.3332  -0.6380   0.3529   1.3439   3.6104   1.3342   2.1252   0.4355   0.3278   0.4483   0.3463
  0.1235  -1.9121  -0.2237   3.4546  -0.3377   0.4381   1.2138   3.6164   1.2915   1.7892   0.4879   0.4191   0.5564   0.3352
  0.4372  -3.4759  -0.4226   2.6517  -0.1290   0.4479   1.1750   3.7302   1.4410   1.5261   0.4099   0.3001   0.5658   0.3474
  0.4947  -2.1120  -0.4454   2.1601   0.0112   0.5102   1.0092   3.8256   1.4924   1.3249   0.2455   0.2915   0.5852   0.3722
  0.5959  -2.7953  -0.4499   1.9853   0.0910   0.5046   0.9101   3.8065   1.5112   1.1676   0.2165   0.2459   0.5502   0.3640
  0.5418  -2.5058  -0.4391   1.6871   0.1419   0.4921   0.8442   3.9417   1.5341   1.0482   0.1786   0.2528   0.5316   0.3541
  0.5744  -2.3327  -0.4171   1.4590   0.1028   0.4043   0.7975   3.9929   1.5606   0.9577   0.1512   0.2410   0.5414   0.3535
  0.5958  -2.1535  -0.4123   1.3660   0.2265   0.4511   0.7351   4.0149   1.5821   0.8831   0.1321   0.2355   0.5454   0.3435
  0.4165  -2.1005  -0.4091   1.2738   0.2472   0.4387   0.7154   4.0051   1.5556   0.8209   0.1165   0.2225   0.5572   0.3435
  0.4434  -1.9558  -0.4120   1.1517   0.2824   0.4905   0.7093   4.1279   1.6245   0.7769   0.1047   0.2150   0.5448   0.3455
  0.6646  -1.5463  -0.4195   1.0557   0.3086   0.4057   0.6020   4.1664   1.6448   0.7476   0.0935   0.2008   0.5715   0.3477
  0.6605  -1.8133  -0.4109   0.5914   0.3243   0.4034   0.7024   4.2066   1.6644   0.7012   0.0945   0.2014   0.5780   0.3457
```

```
DATA :

    1.93   1.91   1.88   1.98   1.88   1.92   1.85   1.85   1.90   1.89   1.74   1.91   1.93   1.93   1.94   1.92
    5.21   5.24   5.26   5.29   5.32   5.34   5.37   5.39   5.41   5.43   5.45   5.47   5.49   5.51   5.52   5.54

   RSQ    A-2SA   INTERC   A+2SA   B-2SB   SLOPE   B+2SB    XBAR    YBAR     SA      SB    STD ERR    SD X   SD Y

 MANUFACTURING PROGRESS SEQUENTIAL REGRESSION                 MACHINE 'S'

  0.4930  -1.6448  1.4609  4.5665  -0.4329  0.1912  0.8153  4.1944  1.9927  1.5529  0.3121  0.0414  0.2434  0.0377
  0.5561  -0.0411  1.4597  2.9605  -0.2425  0.0940  0.4305  4.2772  1.9519  0.7554  0.1692  0.0293  0.2443  0.0358
  0.4376   0.5024  1.4567  2.4111  -0.1112  0.0923  0.2958  4.3518  1.8596  0.4772  0.1017  0.0239  0.2074  0.0344
  0.7298   0.6490  1.3929  2.1367  -0.0433  0.1076  0.2586  4.4152  1.8690  0.3720  0.0755  0.0228  0.3080  0.0389
  0.4200   0.7117  1.5318  2.3519  -0.0927  0.0746  0.2419  4.4691  1.8451  0.4100  0.0836  0.0302  0.3152  0.0362
  0.2658   0.8708  1.6115  2.3521  -0.0932  0.0547  0.2027  4.5162  1.8632  0.3680  0.0740  0.0314  0.3238  0.0340
---------------------------------------------------------------------------------------------------------------------
  0.3445   0.8674  1.5812  2.2950  -0.0592  0.0616  0.1823  4.5630  1.8675  0.3796  0.0606  0.0357  0.3277  0.0363
  0.3924   1.0573  1.5819  2.1065  -0.0368  0.0627  0.1621  4.5997  1.8702  0.2623  0.0497  0.0278  0.3238  0.0338
  0.5100   0.9297  1.7005  2.4713  -0.1537  0.0143  0.1834  4.6352  1.8535  0.4839  0.0843  0.0527  0.2376  0.0503
  0.3334   0.9460  1.7380  2.5300  -0.1216  0.0266  0.1749  4.6683  1.8624  0.3960  0.0741  0.0514  0.3414  0.0490
  0.3498   1.0159  1.7195  2.4231  -0.0983  0.0309  0.1600  4.6901  1.8645  0.3518  0.0646  0.0492  0.3456  0.0493
  0.3777   1.0436  1.6674  2.2913  -0.0769  0.0411  0.1590  4.7292  1.8675  0.3195  0.0574  0.0470  0.3491  0.0470
---------------------------------------------------------------------------------------------------------------------
  0.1342   1.0152  1.6256  2.2360  -0.0552  0.0519  0.1591  4.7563  1.8727  0.3052  0.0536  0.0496  0.3530  0.0503
  0.1591   1.0407  1.6015  2.1623  -0.0390  0.0573  0.1537  4.7930  1.8757  0.2804  0.0482  0.0472  0.3531  0.0500
  0.2737   1.0162  1.5533  2.0904  -0.0220  0.0680  0.1580  4.8094  1.8494  0.2686  0.0450  0.0475  0.3621  0.0522
  0.1492   1.0890  1.6017  2.1145  -0.0276  0.0573  0.1423  4.9326  1.8797  0.2564  0.0425  0.0491  0.3660  0.0511
  0.2093   1.0833  1.5703  2.0572  -0.0146  0.0642  0.1431  4.9552  1.9322  0.2435  0.0394  0.0476  0.3683  0.0523
  0.2574   1.0487  1.5252  2.0017  -0.0012  0.0741  0.1495  4.8779  1.8968  0.2382  0.0377  0.0433  0.3733  0.0545
---------------------------------------------------------------------------------------------------------------------
  0.3156   0.9881  1.4561  1.9241   0.0126  0.0866  0.1606  4.9092  1.8923  0.2490  0.0370  0.0503  0.3767  0.0537
  0.3494   0.9872  1.4453  1.9033   0.0225  0.0914  0.1605  4.9145  1.8956  0.2290  0.0345  0.0474  0.3717  0.0545
  0.3743   0.9798  1.4205  1.8615   0.0322  0.0969  0.1616  4.9379  1.9001  0.2204  0.0324  0.0471  0.3714  0.0534
  0.4344   0.9665  1.3959  1.8253   0.0412  0.1023  0.1633  4.9867  1.9027  0.2131  0.0305  0.0467  0.3863  0.0519
  0.4951   0.9877  1.3953  1.8029   0.0474  0.1045  0.1617  4.9747  1.9053  0.2038  0.0285  0.0478  0.3558  0.0519
  0.5513   0.9927  1.3743  1.7559   0.0533  0.1063  0.1594  5.0031  1.9079  0.1957  0.0268  0.0479  0.3932  0.0529
---------------------------------------------------------------------------------------------------------------------
  0.4753   0.9699  1.3519  1.7340   0.0607  0.1117  0.1627  5.0399  1.9113  0.1911  0.0255  0.0467  0.3917  0.0436
  0.5030   0.9367  1.3186  1.7005   0.0691  0.1193  0.1695  5.0259  1.9155  0.1910  0.0248  0.0474  0.3942  0.0441
  0.5731   0.9351  1.3059  1.6767   0.0744  0.1215  0.1686  5.0414  1.9194  0.1854  0.0235  0.0479  0.3956  0.0467
  0.5421   0.9329  1.2935  1.6541   0.0794  0.1241  0.1688  5.0549  1.9219  0.1803  0.0224  0.0464  0.3924  0.0473
  0.5030   0.9693  1.3242  1.6792   0.0739  0.1177  0.1615  5.0719  1.9208  0.1772  0.0219  0.0473  0.4097  0.0442
  0.5255   0.9691  1.3140  1.6589   0.0782  0.1198  0.1614  5.0863  1.9232  0.1724  0.0209  0.0466  0.4026  0.0464
```

```
DATA

 0.84   1.26   1.64   1.74   1.62   1.86   1.68   1.65   1.67   1.84   1.79   1.46   1.89   1.88   1.58   1.90

 1.94   1.92   1.92   1.92   1.92   1.94   1.93   1.94   1.00   1.97   1.97   1.92   1.97   1.95   2.00

   COR    A-2SA   INTERC   A+2SA   B-2SB   SLOPE   B+2SB   XBAR    YBAR     SA      SB    STD.ERR   SC-X    SC-Y
 MANUFACTURING PROGRESS SEQUENTIAL REGRESSION             MACHINE 'T'

 0.9646  -2.9667  -0.3341  2.2996 -0.0789  0.4886  1.0561  3.2340  1.2463  1.3163  0.2838  0.1002  0.9026  0.3984
 0.9766  -2.1574  -0.5564  1.4446  0.2136  0.4966  0.7735  3.4707  1.3700  0.9005  0.1415  0.0717  0.8146  0.4087
 0.9843  -1.8166  -0.2646  1.1157  0.3157  0.4939  0.7730  3.6601  1.4591  0.7341  0.0896  0.0587  0.8160  0.4062
 0.9883  -1.6394  -0.4470  0.9453  0.3663  0.4934  0.4265  3.8073  1.5315  0.6462  0.0475  0.0505  0.8146  0.4042
 0.9851  -1.4994  -0.3874  0.9136  0.3644  0.4801  0.5422  3.9270  1.5912  0.6195  0.0557  0.0524  0.8087  0.3518
 0.9755  -1.4737  -0.2475  1.0778  0.3444  0.4623  0.5601  4.0294  1.6154  0.6126  0.0589  0.0634  0.8015  0.3754
 0.9673  -1.3321  -0.1064  [illegible] 0.3118  0.4449  0.4960  4.1109  1.6826  0.5580  0.0576  0.0657  0.7741  0.3615
 0.9536  -1.3278  -0.1303  1.1450  0.3116  0.4287  0.5476  4.1706  1.6633  0.5936  0.0590  0.0761  0.7847  0.3461
 0.9291  -1.2729  -0.0695  1.1160  0.2819  0.4064  0.5360  4.2583  1.6752  0.6022  0.0637  0.0935  0.7744  0.3307
 0.9709  -1.1919  -0.0200  1.1719  0.2797  0.3983  0.5170  4.3100  1.6503  0.5759  0.0563  0.0543  0.7722  0.3197
 0.9109  -1.1902  -0.0352  1.0897  0.2832  0.3513  0.4195  4.3720  1.7156  0.5475  0.0541  0.1924  0.7615  0.3110
 0.9113  -1.0221   0.0257  1.0666  0.2794  0.3418  0.4643  4.4199  1.7163  0.5279  0.0512  0.0834  0.7527  0.3215
 0.9154  -0.9893   0.0231  1.0344  0.2905  0.3434  0.4703  4.4022  1.7339  0.5057  0.0475  0.0600  0.7445  0.2347
 0.9141  -0.9711   0.0403  1.1116  0.2523  0.3796  0.4550  4.5338  1.7445  0.4857  0.0434  0.0944  0.7357  0.2714
 0.9152  -0.8332   0.0506  0.9841  0.2961  0.2759  0.4597  4.5507  1.7557  0.4668  0.0355  0.0666  0.7276  0.2859
 0.9130  -0.9306   0.0663  0.9796  0.2568  0.3717  0.4163  4.5702  1.7747  0.4510  0.0374  0.0846  0.7231  0.2735
 0.9120  -0.7916   0.0624  0.9963  0.2986  0.2673  0.4380  4.6017  1.7727  0.4370  0.0354  0.0837  0.7133  0.2743
 0.9107  -0.7563   0.1296  0.9612  0.2962  0.3612  0.4206  [illegible] 1.7801  0.4242  0.0325  0.0726  0.7566  0.2756
 0.9071  -0.7135   0.1154  0.9413  0.2547  0.3556  0.4220  4.6595  [illegible] 0.4129  0.0325  0.0825  0.7354  0.2738
 0.9059  -0.6746   0.1291  0.9324  0.2943  0.3551  0.4157  4.6609  1.7933  0.4019  0.0304  0.0816  0.6954  0.2544
 0.9034  -0.6352   0.1450  0.9257  0.2929  0.3510  0.4092  4.7123  1.7997  0.3921  0.0251  0.0912  0.6924  0.2559
 0.9021  -0.6073   0.1584  0.9230  0.2921  0.3476  0.4028  4.7373  1.8057  0.3877  0.0278  0.0894  0.6462  0.2517
 0.8917  -0.5703   0.1652  0.9414  0.2855  0.3469  0.3962  4.7607  1.8081  0.3781  0.0277  0.0830  0.6821  0.2452
 0.8922  -0.5448   0.2020  0.9312  0.2864  0.3350  0.3915  4.7136  1.8144  0.3692  0.0263  0.0616  0.6764  0.2429
 0.8824  -0.5147   0.2173  0.9743  0.2845  0.3367  0.3906  4.8057  1.8201  0.3510  0.0251  0.0805  0.6750  0.2436
 0.8892  -0.4887   0.2211  0.9308  0.2931  0.3320  0.3809  4.8204  1.8238  0.3746  0.0244  0.0817  0.6715  0.2395
 0.8873  -0.4551   0.2121  0.9256  0.2830  0.3262  0.3700  4.8474  1.8400  0.3477  0.0234  0.1101  0.6650  0.2363
 0.8887  -0.4467   0.2352  0.9172  0.2837  0.3284  0.3731  4.8673  1.8344  0.3409  0.0224  0.0795  0.6643  0.2321
 0.8901  -0.4281   0.2411  0.9104  0.2844  0.3272  0.3699  4.8805  1.8398  0.3346  0.0214  0.0777  0.6633  0.2332
```

DATA

```
   1.06    1.36    1.64    1.70    1.87    1.93    1.91    2.04

   R*R   A-2SA   INTERC    A+2SA   B-2SB   SLOPE   B+2SB    XBAR    YBAR     SA      SB , STD ERR   SD X  SD Y
MANUFACTURING PROGRESS SEQUENTIAL REGRESSION               MACHINE 'U'

  0.9654 -1.4494 -0.0195  1.4105  0.1534  0.4022  0.6509  3.4136  1.3534  0.7190  0.1244  0.0764  0.7094  0.2904
  0.9773 -1.0706 -0.0327  1.0051  0.2827  0.4066  0.5305  3.6239  1.4406  0.5189  0.0620  0.0543  0.7159  0.2544
  0.9740 -1.1578 -0.1240  0.9098  0.3315  0.4354  0.5393  3.7921  1.5270  0.5169  0.0519  0.0596  0.7252  0.3199
  0.9786 -1.1120 -0.1555  0.8009  0.3691  0.4450  0.5209  3.9303  1.5934  0.4782  0.0379  0.0538  0.7316  0.3291
  0.9803 -1.0184 -0.1331  0.7523  0.3790  0.4383  0.4976  4.0409  1.6380  0.4427  0.0297  0.0495  0.7292  0.3228
  0.9808 -1.0418 -0.1687  0.7044  0.3974  0.4486  0.4998  4.1391  1.6881  0.4365  0.0256  0.0494  0.7300  0.3206
```

DATA

```
1.14    1.38    1.45    1.44    1.64    1.78    1.46    1.74    1.78    1.85    1.88    1.72    1.93    1.93    1.94

 DMO    A=25A   INTERC  F=25A   R=25R   SLOPE   R=25R   XBAR    YBAR    SA      SB      STD COR     SD X SD.Y
MANUFACTURING PROGRESS SEQUENTIAL REGRESSION                  MACHINE [illegible]

0.9441  -2.4481  -0.2149   2.3345  -0.0421   0.4797   0.0095   3.3399   1.1779   1.1757   0.2604   0.0860   0.5229   0.2571
0.7472  -2.1939   0.1769   2.5410  -0.2071   0.3492   0.0064   3.4809   1.3051   1.1325   0.2781   0.1307   0.5252   0.2122
0.3194  -1.5591   0.0749   1.8296   0.0121   0.3529   0.7129   3.6118   1.4441   0.8668   0.1752   0.1275   0.5315   0.2149
0.3596  -1.4355   0.0165  [illegible]  0.1346   0.3293   0.6631   3.7196   1.4995   0.7259   0.1321   0.1316   0.5427   0.2747
0.5315  -1.3344   0.2039   1.0222  -0.0301   0.3151   0.6103   3.3328   1.4012   0.9147   0.1576   0.1632   0.5439   0.2154
0.6459  -1.1905   0.2254   1.4593   0.0915   0.2951   0.5906   3.9778   1.5247   0.7124   0.1269   0.1337   0.5450   0.2239
0.5909  -1.0912   0.1903   1.4514   0.1330   0.3467   0.5545   3.9453   1.5531   0.6332   0.1039   0.1350   0.5492   0.2235
0.7495  -1.0457   0.1243   1.2955   0.1971   0.3439   0.5437   4.1073   1.5831   0.5953   0.0686   0.1150   0.5537   0.2319
0.7991  -1.0267   0.0034   1.1990   0.2330   0.3455   0.5270   4.0444   1.6916   0.5662   0.0750   0.1141   0.5505   0.2363
0.8177  -0.9990   0.0491   1.0791   0.2551   0.3375   0.5199   4.1177   1.6164   0.5151   0.0467   0.1107   0.5674   0.2495
0.2902  -0.9535   0.1154   0.0931   0.2794   0.3042   0.5101   4.1573   1.6592   0.4975   0.0570   0.1064   0.5605   0.2567
0.3419  -0.9192   0.0054   0.9306   0.2943   0.3963   0.4098   4.2125   1.6778   0.4626   0.0510   0.1318   0.5732   0.2475
0.9567  -0.8936  -0.0074   0.3782   0.3096   0.4004   0.4912   4.2571   176969   0.4429   0.0454   0.0900   0.5773   0.2497
```

DATA

-0.17 0.66 0.99 1.08 1.47 1.63 1.47 1.19 1.73 1.91 1.50 1.91 1.84 1.88 1.85 1.92
1.93 1.81 1.96 1.88 2.01

MANUFACTURING PROGRESS SEQUENTIAL REGRESSION MACHINE [illegible]

OBS	A-2SA	INTERC	A+2SA	B-2SB	SLOPE	B+2SB	XBAR	YBAR	SA	SB	STD ERR	SD X	SD Y
[illegible]	-2.3183	-0.9[illegible]	0.5183	0.4029	0.5910	0.4906	2.3555	0.4025	0.7091	0.0401	0.0226	1.0036	0.5235
0.9976	-2.2381	-0.9730	0.4063	0.4048	0.5769	0.4572	2.4234	0.6354	0.4921	0.0457	0.0331	0.0757	0.5526
0.9952	-2.1044	-0.9556	0.7773	0.4391	0.6187	0.7093	2.9449	0.9014	[illegible]	0.0530	0.0811	0.0927	0.6128
[illegible]	-2.[illegible]	-1.0007	0.7253	0.4021	0.6433	0.7724	3.0340	0.9401	0.8725	0.0751	0.0366	[illegible]	0.6462
0.9874	-2.4732	-1.[illegible]	0.8478	0.5304	0.6635	0.7562	3.1049	1.0444	0.8392	0.0543	0.3299	1.0038	0.4551
0.9171	-2.[illegible]	-0.[illegible]	1.1451	0.3382	0.5788	0.9104	3.3230	1.0621	1.0047	0.1207	0.1356	[illegible]	0.4039
0.3209	-2.7876	-0.9158	1.0163	0.3384	0.5080	0.7903	3.6337	1.1360	0.3510	0.1097	0.1[illegible]	0.0987	0.4640
0.1293	-2.7312	-0.9178	0.9157	0.4272	0.5173	0.7475	3.5347	1.2038	0.9117	0.1[illegible]	0.1734	0.0955	0.4110
0.[illegible]	-2.[illegible]	-0.8[illegible]	0.8837	0.4242	0.5735	0.7347	3.4277	1.2186	0.8222	0.0776	0.1749	0.0703	0.5310
0.0964	-2.4947	-0.9327	0.8904	0.4029	0.5578	0.7377	3.4906	1.2609	0.9440	0.0759	0.1324	0.0798	0.5487
0.2130	-2.4526	-0.9157	0.9319	0.4304	0.5436	0.6956	3.7796	1.3351	0.8183	0.0[illegible]	0.1760	0.0443	0.5576
0.2199	-2.4163	-0.9216	0.7628	0.4473	0.5443	0.6954	3.8343	1.3440	0.7947	0.0505	0.1509	0.0585	0.5443
0.2240	-2.3819	-0.9329	0.7161	0.4540	0.5551	0.6772	3.9073	1.3703	0.7205	0.0524	0.1615	0.0533	0.5407
0.0251	-2.3028	-0.9163	0.6019	0.4434	0.5619	0.6586	3.9537	1.4071	0.7460	0.0610	0.1574	0.0402	0.5530
0.3249	-2.2672	-0.7[illegible]	0.7[illegible]	0.4449	0.5565	0.6662	4.0060	1.4320	0.7240	0.0460	0.1573	0.0432	0.5452
0.0268	-2.1511	-0.7391	0.6326	0.4670	0.5506	0.6341	4.0547	1.4531	0.7059	0.0410	0.1506	0.0359	0.5365
0.[illegible]	-2.1404	-0.7834	0.6011	0.4747	0.5529	0.6291	4.1009	1.4809	0.6924	0.0706	0.1457	0.0335	0.5353
0.0312	-2.1252	-0.7714	0.5973	0.4761	0.5491	0.6201	4.1443	1.5009	0.6759	0.0360	0.1422	0.0222	0.5377
0.0341	-2.1064	-0.7768	0.5564	0.4827	0.5427	0.6167	4.1357	1.5243	0.6665	0.0315	0.1364	0.0261	0.5263

```
DATA

     0.79   1.04   1.17   1.32   1.55   1.64   1.64   1.67   1.77   1.85   1.88   1.84   1.82   1.81   1.84   1.92

     1.99   1.94   1.96   2.32

        R*R     A-2SA   INTCPC   A+2SA    B-2SB    SLOPE    B+2SB    XBAR     YBAR      SA       SB     STD ERR     SD X SD Y
MANUFACTURING PROGRESS SEQUENTIAL REGRESSION              MACHINE  'X'

S3 IS NEGATIVE    -0.3755093E-05
DMS IS NEGATIVE SO SL IS WRONG    -0.3635843E-05
     1.0001**********  -0.5407********************  0.46708833.2300  3.3442   1.0010**********4416.3820 999.9993   0.4134   0.1930
     0.9954  -1.4375  -0.6550   0.1674   0.3899   0.4969   0.6339   3.4333   1.0807   0.4112   0.0535   0.0197   0.4504   0.2243
     0.9712  -2.2871  -0.6939   0.4      0.3432   0.5700   0.7908   3.6282   1.1741   0.6966   0.1134   0.0559   0.4931   0.2952
     0.9774  -2.2259  -0.9759   0.2774   0.4304   0.5956   0.7608   3.7479   1.2523   0.6286   0.0826   0.0536   0.5296   0.3199
     0.9767  -2.0636  -0.9265   0.2105   0.4538   0.5600   0.7302   3.8512   1.3077   0.5585   0.0431   0.0538   0.5553   0.3254
     0.9890  -1.9433  -0.6739   0.1422   0.4607   0.5540   0.7091   3.9416   1.3528   0.5330   0.0521   0.0500   0.5742   0.3277
     0.9436  -1.8805  -0.6747   0.1311   0.4824   0.5542   0.6479   4.0233   1.3991   0.5029   0.0414   0.0463   0.5905   0.3365
     0.9857  -1.9497  -0.4931   0.0835   0.5016   0.5793   0.6389   4.0385   1.4441   0.4883   0.0343   0.0440   0.6053   0.3477
     0.9877  -1.6463  -0.8065   0.0532   0.5139   0.5711   0.6204   4.1076   1.4640   0.4769   0.0286   0.0415   0.6185   0.3554
     0.9880  -1.7043  -0.9483   0.0971   0.5020   0.5563   0.6150   4.2337   1.5134   0.4737   0.0282   0.0455   0.6290   0.3734
     0.9794  -1.7436  -0.7719   0.1599   0.4842   0.5431   0.6023   4.2000   1.5373   0.4759   0.0296   0.0424   0.6371   0.3444
     0.9718  -1.6881  -0.7315   0.2252   0.4652   0.5271   0.5871   4.3414   1.5570   0.4783   0.0310   0.0401   0.6432   0.3439
     0.9473  -1.6297  -0.6148   0.2600   0.4547   0.5149   0.5730   4.3731   1.5757   0.4724   0.0303   0.0437   0.6479   0.3392
     0.9439  -1.5925  -0.6714   0.2489   0.4548   0.5115   0.5663   4.4339   1.5973   0.4604   0.0274   0.0619   0.6522   0.3389
     0.9212  -1.5836  -0.6784   0.2267   0.4638   0.5122   0.5627   4.4793   1.6205   0.4526   0.0247   0.0599   0.6563   0.3419
     0.9713  -1.5447  -0.6559   0.2330   0.4612   0.5075   0.5538   4.5201   1.6381   0.4444   0.0231   0.0597   0.6599   0.3399
     0.9715  -1.5123  -0.6379   0.2332   0.4805   0.5034   0.5409   4.5567   1.6552   0.4365   0.0215   0.0549   0.6630   0.3397
     0.9731  -1.4949  -0.6368   0.2231   0.4633   0.5027   0.5421   4.5955   1.6733   0.4300   0.0197   0.0572   0.6660   0.3334
```

```
DATA
     -0.32   0.85   1.26   1.30   1.56   1.64   1.51   1.80   1.88   1.92   1.92   1.99   1.98   1.86   1.94   1.96

      1.98   1.96   2.04

     R*R    A-2SA    INTERC    A+2SA    B-2SB    SLOPE    B+2SB    XBAR     YBAR      SA       SB     STD ERR    SD X SD Y

 MANUFACTURING PROGRESS SEQUENTIAL REGRESSION              MACHINE   'Y'

   0.9995  -3.4035  -1.5202   0.3632   0.5938   0.6728   0.7516   3.1449   0.5959   0.9417   0.0395   0.0269   1.2146   0.8175
   0.9958  -3.4203  -1.4634   0.4935   0.5188   0.6485   0.7702   3.4473   0.7721   0.9785   0.0649   0.0599   1.1616   0.7549
   0.9964  -3.2849  -1.4779   0.3291   0.5662   0.6541   0.7420   3.6735   0.9290   0.9035   0.0439   0.0510   1.1321   0.7419
   0.9969  -3.1696  -1.4711   0.2264   0.5875   0.6517   0.7156   3.8657   1.0480   0.8488   0.0321   0.0447   1.1105   0.7248
   0.9849  -3.3191  -1.3945   0.4300   0.5111   0.6250   0.7333   4.0128   1.1133   0.9123   0.0569   0.0919   1.0359   0.6839
   0.9844  -3.1521  -1.4099   0.3372   0.5270   0.6300   0.7231   4.1415   1.1994   0.8711   0.0465   0.0854   1.0692   0.6783
   0.9377  -3.0997  -1.4203   0.2578   0.5559   0.6135   0.7112   4.2560   1.2753   0.8394   0.0398   0.0799   1.0575   0.6741
   0.9888  -3.0435  -1.4200   0.2007   0.5677   0.6332   0.6988   4.3503   1.3398   0.8103   0.0378   0.0749   1.0487   0.6675
   0.9890  -2.9760  -1.4038   0.1685   0.5704   0.6284   0.6865   4.4478   1.3926   0.7861   0.0290   0.0726   1.0397   0.6573
   0.9896  -2.9257  -1.3953   0.1351   0.5750   0.6260   0.6770   4.5329   1.4422   0.7652   0.0255   0.0694   1.0323   0.6496
   0.9891  -2.8728  -1.3751   0.1227   0.5728   0.6203   0.6678   4.6033   1.4834   0.7489   0.0237   0.0699   1.0253   0.6344
   0.9914  -2.8317  -1.3243   0.1832   0.5501   0.6061   0.6622   4.6766   1.5104   0.7537   0.0240   0.0883   1.0176   0.6226
   0.9789  -2.7737  -1.2737   0.1862   0.5429   0.5977   0.6520   4.7390   1.5390   0.7400   0.0274   0.0923   1.0047   0.6133
   0.9749  -2.7192  -1.2668   0.1846   0.5375   0.5905   0.6434   4.7953   1.5653   0.7257   0.0265   0.0943   1.0021   0.5987
   0.9752  -2.6658  -1.2425   0.1808   0.5331   0.5840   0.6349   4.8495   1.5836   0.7117   0.0254   0.0958   0.9947   0.5882
   0.9723  -2.6139  -1.2143   0.1852   0.5266   0.5766   0.6265   4.9088   1.6102   0.6998   0.0250   0.0990   0.9874   0.5774
   0.9722  -2.5715  -1.1995   0.1719   0.5258   0.5728   0.6198   4.9451   1.6328   0.6859   0.0235   0.0977   C.9806   0.5497
```

```
DATA

   0.94    1.23    1.21    1.40    1.42    1.53    1.50    1.58    1.58    1.61    1.58    1.64    1.68    1.68    1.63    1.62

   1.64    1.66    1.63    1.63    1.64    1.61    1.65    1.61    1.56    1.85    1.78    1.89    1.85    1.84    1.89    1.96

   1.95    1.88    1.93    1.98    2.00

   R*R    A-2SA   INTERC   A+2SA    B-2SB   SLOPE    B+2SB    XBAR     YBAR      SA      SB    STD ERR    SD X SD Y

MANUFACTURING PROGRESS SEQUENTIAL REGRESSION              MACHINE  'Z'

 0.8339 -6.8053 -0.7131  5.3792 -1.1343  0.5312  2.1968  3.4627  1.1264  3.0461  0.8329  0.0936  0.2792  0.1424
 0.9123 -3.9938 -0.8664  2.2610 -0.1924  0.5771  1.3467  3.5707  1.1943  1.5437  0.3849  0.0698  0.3141  0.1898
 0.9318 -2.8539 -0.7654  1.3231  0.0931  0.5475  1.0120  3.6630  1.2401  1.0443  0.2322  0.0593  0.3414  0.1936
 0.9527 -2.3813 -0.8048  0.7716  0.2502  0.5588  0.8675  3.7461  1.2866  0.7482  0.1543  0.0510  0.3670  0.2151
 0.9455 -2.0739 -0.6765  0.7209  0.2652  0.5224  0.7797  3.8188  1.3186  0.6987  0.1286  0.0529  0.3363  0.2075
 0.9547 -1.8378 -0.6499  0.5380  0.3186  0.5150  0.7114  3.8645  1.3507  0.5939  0.0782  0.0487  0.4032  0.2125
 0.9565 -1.6627 -0.5941  0.4746  0.3368  0.4976  0.6624  3.9444  1.3765  0.5344  0.0814  0.0474  0.4177  0.2133
 0.9549 -1.5301 -0.5537  0.4227  0.3514  0.4886  0.6257  3.9702  1.3996  0.4882  0.0686  0.0458  0.4289  0.2140
 0.9478 -1.4305 -0.4708  0.4889  0.3326  0.4661  0.5995  4.0472  1.4156  0.4798  0.0667  0.0504  0.4382  0.2092
 0.9510 -1.3369 -0.4443  0.4482  0.3435  0.4590  0.5745  4.0923  1.4340  0.4463  0.0577  0.0486  0.4461  0.2095
 0.9562 -1.2800 -0.4428  0.3944  0.3589  0.4586  0.5583  4.1344  1.4531  0.4186  0.0498  0.0464  0.4532  0.2125
 0.9586 -1.2175 -0.4235  0.3705  0.3652  0.4535  0.5417  4.1736  1.4692  0.3970  0.0441  0.0450  0.4595  0.2125
 0.9493 -1.1560 -0.3665  0.4230  0.3504  0.4385  0.5267  4.2099  1.4797  0.3947  0.0441  0.0489  0.4446  0.2091
 0.9372 -1.0953 -0.3079  0.4795  0.3342  0.4232  0.5122  4.2437  1.4803  0.3737  0.0445  0.0531  0.4599  0.2049
 0.9337 -1.0333 -0.2641  0.5048  0.3264  0.4119  0.4974  4.2754  1.4970  0.3645  0.0428  0.0548  0.4723  0.2017
 0.9298 -0.9789 -0.2364  0.5061  0.3250  0.4048  0.4845  4.3053  1.5063  0.3713  0.0399  0.0545  0.4754  0.1976
 0.9210 -0.9234 -0.1931  0.5372  0.3157  0.3937  0.4717  4.3335  1.5130  0.3652  0.0390  0.0567  0.4781  0.1941
 0.9113 -0.8694 -0.1503  0.5689  0.3058  0.3826  0.4594  4.3602  1.5188  0.3594  0.0383  0.0590  0.4805  0.1927
 0.9032 -0.8174 -0.1120  0.5933  0.2987  0.3731  0.4475  4.3857  1.5244  0.3527  0.0372  0.0605  0.4827  0.1895
 0.8869 -0.7654 -0.0641  0.6373  0.2862  0.3610  0.4358  4.4099  1.5281  0.3507  0.0374  0.0630  0.4845  0.1858
 0.8839 -0.7205 -0.0383  0.6440  0.2834  0.3546  0.4257  4.4331  1.5325  0.3411  0.0356  0.0649  0.4862  0.1934
 0.8683 -0.6712  0.0049  0.6809  0.2729  0.3434  0.4140  4.4552  1.5365  0.3380  0.0355  0.0669  0.4877  0.1803
 0.8393 -0.6219  0.0592  0.7403  0.2569  0.3303  0.4037  4.4761  1.5376  0.3405  0.0367  0.0722  0.4898  0.1742
 0.8342 -0.6887  0.0105  0.7097  0.2685  0.3423  0.4162  4.4967  1.5498  0.3496  0.0369  0.0759  0.4903  0.1735
 0.8435 -0.6932 -0.0061  0.6810  0.2764  0.3464  0.4164  4.5150  1.5584  0.3435  0.0350  0.0769  0.4917  0.1855
 0.8405 -0.7582 -0.0536  0.6509  0.2876  0.3580  0.4284  4.5359  1.5703  0.3523  0.0352  0.0785  0.4932  0.1926
 0.8456 -0.7825 -0.0809  0.6207  0.2968  0.3647  0.4325  4.5545  1.5800  0.3538  0.0339  0.0786  0.4949  0.1963
 0.8519 -0.7912 -0.0984  0.5945  0.3042  0.3789  0.4535  4.5733  1.5887  0.3464  0.0323  0.0779  0.4968  0.1996
 0.8562 -0.8175 -0.1256  0.5664  0.3129  0.3754  0.4380  4.5915  1.5983  0.3460  0.0313  0.0792  0.4988  0.2024
 0.8559 -0.8722 -0.1676  0.5370  0.3233  0.3855  0.4477  4.6096  1.6094  0.3523  0.0311  0.0807  0.5012  0.2099
 0.8587 -0.9158 -0.2037  0.5083  0.3326  0.3934  0.4542  4.6274  1.6197  0.3545  0.0304  0.0818  0.5038  0.2139
 0.8643 -0.9063 -0.2074  0.4914  0.3372  0.3950  0.4528  4.6447  1.6272  0.3494  0.0289  0.0806  0.5064  0.2152
 0.8693 -0.9221 -0.2268  0.4686  0.3440  0.3996  0.4551  4.6617  1.6359  0.3477  0.0279  0.0807  0.5090  0.2182
 0.8724 -0.9527 -0.2545  0.4437  0.3520  0.4061  0.4602  4.6787  1.6455  0.3491  0.0271  0.0808  0.5118  0.2225
 0.8751 -0.9842 -0.2824  0.4195  0.3599  0.4126  0.4654  4.6953  1.6551  0.3509  0.0264  0.0815  0.5147  0.2270
```

```
DATA
  1.03   1.67   1.78   1.82   1.85   1.88   1.88   1.93   1.93   1.93   1.92   1.96   1.98   1.84   1.90   1.81
  1.92   1.86   1.98   2.01

     R*R    A-2SA   INTERC   A+2SA    B-2SB    SLOPE    B+2SB    XBAR     YBAR     SA       SB      STD ERR   SD X SD Y
  MANUFACTURING PROGRESS SEQUENTIAL REGRESSION              MACHINE 'AA'

  0.9742  -5.3591  -1.7920  1.7751   0.1196   0.7469   1.3742   4.3995   1.4940   1.7835   0.3137   0.0917   0.5333   0.6034
  0.9512  -4.3458  -1.4469  1.4519   0.1886   0.6429   1.1372   4.5603   1.5759   1.4494   0.2371   0.0995   0.5414   0.3680
  0.9427  -3.6378  -1.2036  1.2366   0.2299   0.6043   0.9788   4.6852   1.6307   1.2196   0.1872   0.1021   0.5457   0.3414
  0.9217  -3.1077  -1.0277  1.0523   0.2642   0.5642   0.8659   4.7874   1.6728   1.0400   0.1499   0.1007   0.5485   0.3223
  0.9043  -2.7325  -0.8630  1.0365   0.2676   0.5264   0.7851   4.8731   1.7022   0.9347   0.1294   0.1030   0.5498   0.3363
  0.9311  -2.4158  -0.7645  0.8866   0.2888   0.5042   0.7147   4.9476   1.7301   0.8254   0.1077   0.0993   0.5509   0.2876
  0.8940  -2.1672  -0.6666  0.8341   0.2154   0.4824   0.6695   5.0133   1.7570   0.7503   0.0935   0.0979   0.5517   0.2814
  0.8553  -1.9609  -0.5751  0.8107   0.2960   0.4623   0.6236   5.0717   1.7697   0.6929   0.0831   0.0974   0.5520   0.2712
  0.8729  -1.7835  -0.4936  0.8162   0.2908   0.4474   0.5941   5.1243   1.7835   0.6499   0.0758   0.0982   0.5519   0.2612
  0.8709  -1.6344  -0.4265  0.7815   0.2550   0.4301   0.5633   5.1723   1.7982   0.6039   0.0676   0.0958   0.5518   0.2543
  0.8713  -1.5049  -0.3721  0.7457   0.2998   0.4207   0.5415   5.2165   1.8122   0.5639   0.0604   0.0931   0.5519   0.2497
  0.8234  -1.3945  -0.2550  0.8849   0.2679   0.3937   0.5145   5.2560   1.8145   0.5698   0.0629   0.1046   0.5511   0.2331
  0.9044  -1.2717  -0.1783  0.9151   0.2295   0.1775   0.4906   5.2936   1.8203   0.5467   0.0595   0.1041   0.5501   0.2315
  0.7499  -1.1597  -0.0607  1.0373   0.2308   0.3529   0.4750   5.3276   1.8194   0.5490   0.0516   0.1160   0.5485   0.2237
  0.7430  -1.0570  -0.0155  1.0270   0.2303   0.3435   0.4567   5.3593   1.8254   0.5212   0.0566   0.1141   0.5469   0.2139
  0.7176  -0.9533   0.0454  1.0649   0.2200   0.3287   0.4375   5.3809   1.8274   0.5045   0.0544   0.1159   0.5453   0.2115
  0.7246  -0.9418   0.0477  1.0272   0.2241   0.3263   0.4264   5.4170   1.8352   0.4797   0.0501   0.1126   0.5439   0.2045
  0.7343  -0.8495   0.0683  0.9852   0.2336   0.3242   0.4187   5.4439   1.8439   0.4584   0.0463   0.1094   0.5428   0.2066
```

```
DATA

    0.64   0.96   1.05   1.41   1.42   1.34   1.85   1.79   1.87   1.93   1.83   1.83

    R*R    A-2SA   INTERC   A+2SA   B-2SB   SLOPE   B+2SB   XBAR    YBAR    SA      SB     STD ERR   SD X SD Y
MANUFACTURING PROGRESS SEQUENTIAL REGRESSION                    MACHINE 'BB'

  0.9789  -3.0309  -1.3136  0.4038  0.2285  0.5548  0.8810  3.9564  0.8816  0.8587  0.1631  0.0438  0.3802  0.2132
  0.9596  -3.8832  -1.8265  0.2302  0.3434  0.6896  1.0357  4.1182  1.0132  1.0283  0.1731  0.0776  0.4484  0.3156
  0.9688  -3.2712  -1.7136 -0.1559  0.4491  0.6606  0.8721  4.2521  1.0952  0.7788  0.1058  0.0670  0.4905  0.3291
  0.9315  -3.0257  -1.4225  0.1808  0.3620  0.5869  0.8119  4.3547  1.1364  0.8016  0.1125  0.0980  0.5118  0.3112
  0.9552  -2.5597  -1.1639  0.2318  0.3922  0.5255  0.6587  4.5722  1.2391  0.6979  0.0666  0.0911  0.7310  0.3780
  0.9568  -2.3535  -1.0299  0.2937  0.3889  0.4938  0.5987  4.7353  1.3085  0.6618  0.0524  0.0928  0.8190  0.4135
  0.9646  -2.2685  -1.0125  0.2434  0.4079  0.4897  0.5715  4.8658  1.3703  0.6280  0.0409  0.0862  0.8603  0.4290
  0.9698  -2.2504  -1.0317  0.1870  0.4268  0.4942  0.5617  4.9736  1.4264  0.6093  0.0337  0.0813  0.8799  0.4414
  0.9692  -2.1672  -0.9897  0.1879  0.4243  0.4844  0.5446  5.0543  1.4636  0.5888  0.0301  0.0807  0.8923  0.4364
  0.9683  -2.0941  -0.9548  0.1845  0.4218  0.4763  0.5308  5.1419  1.4941  0.5697  0.0272  0.0802  0.8876  0.4294
```

DATA

0.80	1.34	1.50	1.61	1.70	1.72	1.78	1.79	1.78	1.85	1.82	1.77	1.80	1.66	1.82	1.85
1.81	1.90	1.91	1.85	1.82	1.79	1.78	1.91	1.84	1.97	1.93	1.71	1.91	1.76	2.01	

MANUFACTURING PROGRESS SEQUENTIAL REGRESSION

MACHINE 'CC'

R*R	A-2SA	INTERC	A+2SA	B-2SB	SLOPE	B+2SB	ROAR	YHAT	SA	SB	STD ERR	SD X	SD Y
0.9866	-4.7124	-1.7515	1.2095	0.1837	0.7339	1.2841	4.0443	1.2167	1.4805	0.2751	0.0532	0.4979	0.3679
0.9914	-3.8181	-1.5435	0.7212	0.3122	0.6804	1.0467	[illegible]	1.3157	1.1548	0.1841	[illegible]	0.5239	0.3578
0.9797	-3.2899	-1.4203	0.4503	0.3807	0.6475	0.9143	4.3434	1.3924	0.9350	0.1334	0.0583	0.5456	0.3556
0.9722	-3.0132	-1.2776	0.4580	0.3774	0.6118	0.8462	4.4544	1.4477	0.8678	0.1172	0.0643	0.5572	0.3457
0.9710	-2.7442	-1.1908	0.3625	0.3987	0.5905	0.7823	4.5499	1.4958	0.7767	0.0954	0.0534	0.5649	0.3413
0.9656	-2.5543	-1.0938	0.3667	0.3952	0.5670	0.7388	4.6332	1.5332	0.7302	0.0859	[illegible]	[illegible]	0.3373
0.9530	-2.4104	-0.9518	0.4467	0.3734	0.5403	0.7072	4.7357	1.5606	0.7143	0.0835	0.0739	0.5413	[illegible]
0.9532	-2.2515	-0.9263	0.3989	0.3821	0.5272	0.6724	4.7712	[illegible]	0.6626	0.0726	0.0724	0.5455	0.3143
0.9452	-2.1229	-0.8456	0.4316	0.3715	0.5034	0.6453	4.8300	1.6101	0.6336	0.0685	0.0759	0.5449	0.3043
0.9253	-2.0155	-0.7416	0.5364	0.3445	0.4944	0.6243	4.8829	1.6238	0.6390	0.0649	0.0453	0.5767	0.2975
0.9134	-1.9013	-0.6641	0.5730	0.3330	0.4667	0.6004	4.9316	1.6372	0.6116	0.0669	0.0927	0.5917	0.2839
0.8943	-1.8417	-0.5205	0.8007	0.2801	0.4343	0.5890	4.9745	1.6307	0.6606	0.0773	0.1133	0.5212	0.2776
0.8539	-1.7279	-0.4311	0.7658	0.2849	0.4252	0.5554	5.0148	1.6511	0.6234	[illegible]	0.1073	0.5507	0.2785
0.8550	-1.6322	-0.4522	0.7277	0.2909	0.4187	0.5465	5.0525	1.6633	0.5900	0.0639	0.1047	0.5412	0.2671
0.8495	-1.5354	-0.4040	0.7274	0.2882	0.4080	0.5278	5.0876	1.6718	0.5657	0.0599	0.1046	0.5476	0.2613
0.8561	-1.4771	-0.3985	0.6802	0.2973	0.4068	0.5163	5.1210	1.6447	0.5393	0.0547	0.1013	0.5972	0.2570
0.8613	-1.4207	-0.3886	0.6436	0.3040	0.4046	0.5053	5.1526	1.6963	0.5161	0.0504	0.0984	0.5449	0.2558
0.8573	-1.3484	-0.3519	0.6449	0.3016	0.3956	0.4916	5.1824	1.7037	0.4983	0.0475	0.0979	0.5355	0.2521
0.8444	-1.2766	-0.3073	0.6625	0.2957	0.3870	0.4782	5.2106	1.7093	0.4848	0.0456	0.0987	[illegible]	0.2473
0.8339	-1.2057	-0.2555	0.6947	0.2868	0.3759	0.4650	5.2372	1.7130	0.4751	0.0446	0.1010	0.5873	0.2417
0.8176	-1.1369	-0.2040	0.7290	0.2775	0.3648	0.4522	5.2624	1.7160	0.4665	0.0437	0.1035	[illegible]	0.2366
0.8228	-1.1034	-0.1986	0.7038	0.2818	0.3637	0.4455	5.2856	1.7241	0.4512	0.0409	0.1111	0.5354	0.2348
0.8179	-1.0480	-0.1680	0.7100	0.2789	0.3572	0.4355	5.3097	1.7287	0.4390	0.0372	0.1094	[illegible]	0.2319
0.8247	-1.0334	-0.1773	0.6787	0.2853	0.3592	0.4330	5.3321	1.7378	0.4290	0.0369	0.1099	0.5942	0.2311
0.8171	-0.9809	-0.1437	0.6935	0.2806	0.3521	0.4236	5.3535	1.7413	0.4146	0.0357	[illegible]	0.5835	0.2273
0.7808	-0.9223	-0.0781	0.7662	0.2643	0.3394	0.4124	5.3738	1.7403	0.4221	0.0370	0.1065	0.5626	0.2231
0.7851	-0.8943	-0.0725	0.7494	0.2669	0.3372	0.4075	5.3934	1.7462	0.4109	0.0358	0.1046	0.5918	0.2215
0.7628	-0.8388	-0.0239	0.7909	0.2570	0.3271	0.3973	5.4122	1.7465	0.4074	0.0351	0.1079	0.5869	0.2176
0.7760	-0.8470	-0.0436	0.7598	0.2639	0.3312	0.3985	5.4306	1.7549	0.4017	0.0336	0.1069	0.5962	0.2192

DATA

```
   0.93   1.15   1.40   1.58   1.67   1.72   1.83   1.79   1.88   1.91   1.82   1.90   1.96   1.97   1.99   1.93
   2.80

   RSQ    A-2SA    INTERC    A+2SA    B-2SB    SLOPE    B+2SB    XBAR    YBAR     SA      SB     STD ERR    SQ X SS Y

MANUFACTURING PROGRESS SEQUENTIAL REGRESSION.                     MACHINE [illegible]

  0.4781  -3.8721  -1.3839   1.1050   0.1755   0.6517   1.2278   3.7220   1.1912   1.2444   0.2379   0.0627   0.4095   0.2842
  0.5855  -3.2074  -1.5217   0.1550   0.4733   0.7318   0.9904   3.8619   1.3146   0.8402   0.1293   0.0499   0.4595   0.3187
  0.5787  -3.6070  -1.8344   0.2542   0.4494   0.6767   0.9051   4.0000   1.3950   0.7903   0.1142   0.0401   0.4855   0.3329
  0.6811  -2.6159  -1.2935   0.0666   0.5191   0.6672   0.8204   4.1280   1.4572   0.6641   0.0776   0.0347   0.5258   0.3454
  0.5787  -2.4305  -1.2653   0.0596   0.5981   0.6393   0.7700   4.2163   1.5163   0.7226   0.0656   0.0552   0.5364   0.3440
  0.4675  -2.3344  -1.2044   0.1751   0.4753   0.6078   0.7404   4.2946   1.5460   0.6149   0.0662   0.0542   0.5430   0.3351
  0.3665  -2.1595  -0.9961   0.1664   0.4766   0.5901   0.7037   4.3070   1.5827   0.5817   0.0564   0.0548   0.5547   0.3330
  0.4465  -2.0272  -0.9335   0.1702   0.4744   0.5745   0.6743   4.4308   1.6152   0.5515   0.0499   0.0645   0.5842   0.3324
  0.9414  -1.9439  -0.9300   0.3468   0.4296   0.5411   0.6527   4.4475   1.6339   0.5704   0.0558   0.0913   0.5125   0.3145
  0.5330  -1.9148  -0.7161   0.3488   0.4198   0.5205   0.6254   4.5330   1.6540   0.5515   0.0528   0.0863   0.5186   0.3125
  0.5371  -1.7376  -0.6914   0.3547   0.4229   0.5144   0.6004   4.6056   1.6779   0.5230   0.0440   0.0818   0.5443   0.3113
  0.5353  -1.6594  -0.6586   0.3422   0.4242   0.5045   0.5800   4.6530   1.6946   0.5314   0.0411   0.0796   0.5511   0.3052
  0.9404  -1.5608  -0.6079   0.3450   0.4249   0.4962   0.5735   4.6996   1.7180   0.4814   0.0371   0.0778   0.5565   0.3271
  0.6335  -1.5411  -0.5702   0.3714   0.4140   0.4854   0.5567   4.7414   1.7314   0.4708   0.0357   0.0795   0.6071   0.3215
  0.9356  -1.4615  -0.5517   0.3581   0.4158   0.4910   0.5462   4.7741   1.7472   0.4449   0.0326   0.0764   0.6114   0.2931
```

APPENDIX III

SOME FEATURES OF A PROBLEM SOLVING, STARTUP MODIFICATION, GROUP STRUCTURE

day, the means which have been considered in the search. This will prevent recycling of the search process up the same blind alley, repeatedly. Where the problem solver feels that one or several sets of means will achieve a goal shown on the factorization chart, these will be recorded as sub-goals, on the chart. These in turn become ends or goals, for which a further sub-set of means must be found. The decision is made by the searcher problem solver to tell the Search-Screen Recording Sub-group that a given set provides a suitable factorization of a goal for entry on the factorization hierarchy chart. This can be challenged by the Screening Sub-group of the problem solvers, but can only be deleted by agreement between the two. The Search-Screen Recording Sub-group, by daily recording the search and screen process, makes explicit the communication exposures, search findings and rejections, as well as the screening acceptances.

The main problem solving group will be divided into four sections: (1) Searchers; (2) Screeners; (3) Implementers; and (4) Process Oriented. The process oriented section will observe very specifically "How It Is" in each section of the production process. This will include data on process, product, equipment, people and information. This will be provided to the Searchers and Screeners to compare with "How It Should Be". The observations will have to be precise and detailed, and will require fine

"Organizations" by March and Simon[1] was chosen as the behavioral knowledge base because it is an oft quoted, highly regarded work, which is represented by the authors as fully describing human behavior in organizations. Since problem solving for plant startup is done by people in organizations, their pertinent behavioral characteristics should be described in March and Simon. Secondly, the choice was narrowed to Chapter 6: "Cognitive Limits on Rationality" and Chapter 7: "Planning and Innovation." This was done in order to obtain all the positive benefits of rational thought and action rather than dealing with the many effects which can be caused by emotions, personality, attitudes and similar non-rational behavior. This is not to belittle the potential effects of such behavioral phenomena, but rather an effort to accentuate the positive rational characteristics. It is thought that if the most rational behavior is dominant, effects from the other areas will tend to be minimized.

Finally, several propositions were chosen from these two chapters of March and Simon, which were believed to be most valuable in arranging the modifications group structure*, and the procedure, to take maximum advantage of rational behavior. These propositions are listed in Exhibit

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[1] James G. March and Herbert Simon, "Organizations", (New York: John Wiley and Sons, 1958).

*See Exhibit II.

I, with the March and Simon page and proposition identification shown. They are numbered 1. to 16. in the Exhibit, and will be referred to by these numbers.

These propositions have been accepted as being entirely true for the purposes of this paper. March and Simon do not make such strong claims for them, but rather suggest that they should be proved by empirical testing. The literature which they do cite does not generally provide ironbound proof of the statement. For example, Newell, Shaw and Simon, 1958, show that a computer can derive the "Principia Mathematica" of Bertrand Russell through a certain problem solving process. This lends credence to the sixth proposition, but doesn't prove it. This often seems to be the case with behavioral knowledge. It is likely that such principles, as the ones shown, will be subject to empirical testing and confirmation in the future, as recommended by March and Simon, but are never likely to be completely proved. What literature support the authors have been able to find is indicated by the footnote numbers at the end of the propositions. In spite of the lack of any more rigorous proof, it seems well worth while not to wait for such proof, take March and Simon at face value, and proceed to make some pragmatic use of their propositions.

The selection of an individual proposition is not defended as being the very best choice from the total universe of behavioral science. Rather it is represented as being better than the alternative of not selecting it. This provides only a very low level criterion, but if it is found to provide a substantial step forward, it may be satisficing.

The first proposition chosen in Gresham's Law, that programmed work drives out unprogrammed work. Forming a project group whose only duty is to solve problems so as to make startup modifications, uses this law for programming the problem solving. Such a project group also takes advantage of the second, third and fourth propositions, which should all lead to great effectiveness in problem solving, for such a structure. The fifth proposition is coupled with the first four, by making the objective of the project group an increasing productivity defined by the Manufacturing Progress Ratio[2], which might be in the range of 1.20 to 1.50. A secondary objective from this same proposition would be number of modifications or innovations completed per time period. These programmed stimuli provide clear objectives for the problem solving project group to achieve.

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[2] During startup, the productivity 'Y' in units per hour has been shown to follow the relationship:

$$Y = aX^b$$

where 'a' is the productivity in units per hour for the first unit,
X is the cumulative number of units produced,
$b = \text{Log } M/\text{Log } 2.0$,
M = Manufacturing Progress Ratio, as shown by Nicholas Baloff, "Startups in Machine-Intensive Production Systems, *The Journal of Industrial Engineering* XVII, January 1966, p. 30.

The sixth and seventh propositions require that the people for the project group be carefully chosen to have experience in solving problems in a 'productive' fashion. Careful recording of past experience will be required before selection, to obtain the 'productive' rather than strictly 'reproductive' problem solvers.

The eighth and ninth propositions can be utilized by forming a sub-unit in the project group for promoting and recording factorization of the major problem of inadequate production, into smaller and smaller sub-problems. The factorization permits more simultaneous activity and hence speedier problem solving. Programming this activity through a communicative, clerical sub-group, similar to an organization chart, but with a numbering scheme to identify successive levels, and sets of factored sub-goals, would be used by this group. The objective of the group would be to achieve many successive levels, for minute factorization. This group also takes advantage of propositions one through four, as do all the other sub-groups established in the group structure.

Speed of problem solving through factorization will be further speeded by establishing a sub-group whose specific job is to schedule the solving of each sub-problem, and as a result end up scheduling the solution of the problem as a whole. This group will feed back information to the factorization sub-group, requesting more or different factorization when the schedule is too slow. It will use PERT among its scheduling tools.

A further feature of the group structure will be a Communication Interface Sub-group. This sub-group takes advantage of propositions ten through fourteen. Since most innovation is the result of borrowing, and the rate and type of borrowed innovation is a function of exposure and communication system of the organization, such a sub-group should increase the amount of innovation. The objective of this group will be to define a very broad interface of sources from which solutions to sub-problems may be borrowed. The interface definition matrix will include dimensions of geography, corporations, scientific disciplines, institutional groups, industry segments, as well as recorded sources such as libraries. It will arrange specific contacts on this interface for the problem solver search sub-group, and work with the scheduling and factorization sub-groups to scan this interface so as to become cognizant of tentative solutions which may be borrowed as quickly as possible.

A Search-Screen Recording Sub-group will also be established. Searching for means to achieve a goal, and screening these means to decide whether a given set of means found in the search will achieve the goal is an important part of problem solving. The Search-Screen Recording Sub-group will make this process explicit by recording each day, the means which have been considered in the search. This will prevent recycling of the search process up the same blind alley, repeatedly. Where the problem solver feels that one or several sets of means will achieve a goal shown on the factorization chart, these will be recorded as sub-goals, on the chart. These in turn become ends or goals, for which a further sub-set of means must be found. The decision is made by the searcher problem solver to tell the Search-Screen Recording Sub-group that a given set provides a suitable factorization of a goal for entry on the factorization hierarchy chart. This can be challenged by the Screening Sub-group of the problem solvers, but can only be deleted by agreement between the two. The Search-Screen Recording Sub-group, by daily recording the search and screen process, makes explicit the communication exposures, search findings and rejections, as well as the screening acceptances.

The main problem solving group will be divided into four sections: (1) Searchers; (2) Screeners; (3) Implementers; and (4) Process Oriented. The process oriented section will observe very specifically "How It Is" in each section of the production process. This will include data on process, product, equipment, people and information. This will be provided to the Searchers and Screeners to compare with "How It Should Be". The observations will have to be precise and detailed, and will require fine instruments in many cases, to do the job. Implementers will take action to complete, or put into action, the lowest set of sub-goals on the factorization hierarchy chart. These should be defined in terms of elements which are readily available to the firm by purchase of goods, or inside or outside services. Factorization down to this level of simplicity takes advantage of the fifteenth proposition. Where this condition is not met, the implementers will feed back a sub-goal revision request to the Searchers, which will be recorded on the Factorization Hierarchy chart.

It is expected that this organizational structure will provide faster, better modifications than an unstructured or professional functionally structured group. It utilizes Gresham's Law by programming the specific activity which will speed problem solution, and thus startup. The overall group objective of a high Manufacturing Progress Ratio and number of innovations, points the whole group in that direction. Factorization should proceed faster because the factorization recording sub-group is programmed to do just that. The greater factorization, the greater the speed of problem solving. The problem solving Scheduling Sub-group reinforces this speed. The Communication Interface Sub-group should increase the rate and quality of borrowing innovation, by scheduling communication on a very broad, high information quality, interface. Most innovation is the result of borrowing, so this explicit, scheduled exposure of the Searchers and Screeners in the problem solving group should increase innovation, which both improves the quality and speed of problem solving. The Search-Screen Recording Sub-group should remove a good deal of recycling and dead ends from the search process, by explicit exposure of any such repetitions. The implementers, dealing with only the lowest factorization hierarchy of commonly available element sub-goals, should be able to implement cheaply and economically. The manager should be able to review the modification progress easily by seeing the factorization chart, the problem solving schedule, the search-screen record, along with increasing productivity as measured by the Manufacturing Progress Ratio.

The formal record keeping, particularly in the search and screen process, simplifies, speeds and makes more explicit the interchange between individual and group. The individual obtains clear-cut, short cycle tasks with clear goals which should take the frustration and lack of productivity out of his problem solving work, and make him feel as if he is really accomplishing a great deal. The group is motivated in the correct direction to increase productivity during startup. Its job is well defined, between people and along the time scale. Communication interchange with the environment is expressly broadspread and well defined through the Communication Interface Sub-group. These features should create harmony, efficiency and speed in interaction between individual, project group and environment.

An important feature developed by this structure is the economy of the division of mental labor. The economy of division of physical labor is commonly utilized by dividing physical tasks into well defined, repetitive, short cycle jobs. The difficulty of observing mental labor has prevented its division, particularly in the problem solving area. The explicit exposure of each step of the problem solving process, and the short cycle tasks guaranteed by the structure of sub-groups should give better defined, repetitive mental tasks. This should create the recurrence of thought which speeds the task, just as does the recurrence of physical motion, and so lead to the economy of division of mental labor, and utilize the sixteenth proposition.

The foregoing features which are recommended for the structure of a problem solving, startup modification group are not intended to wholly define the group and its procedures. It is only claimed that valid behavioral propositions have been chosen and applied, so that the structure indicated will solve problems faster and better than a structure which doesn't consider the propositions. This makes practical use of theoretical behavioral knowledge. Applying truth seems much less frequent than generating more of such knowledge. Despite the lack of rigorous proof, which lack can be easily queried, this is an effort to make a pragmatic application of the truths in order to speed startup.

EXHIBIT III-1

PERTINENT PROPOSITIONS:
from "Organizations" by March and Simon.

1. "Gresham's Law" of planning: Daily routine drives out planning. When an individual is faced both with highly programmed and highly unprogrammed tasks, the former take precedence over the latter. (P. 185)[1]

2. (A-7.6) Creating a new organizational unit charged with the task first of elaborating a new program, and then carrying it out when elaborated, provides for a spurt of innovative, program developing activity. (P. 187)[2]

3. (7.27:7.13) Vigorous innovative activity will occur in organizational units not assigned substantial responsibilities for programmed activity, so the level at which innovation occurs depends on the levels at which there are individuals or units having planning responsibilities without heavy operating responsibilities. (P. 199)

4. (7.12:7.13) The average rate of innovation will be higher, the greater the institutionalization of innovation. (P. 185)

5. (A-7.5) The failure of the existing program to attain satisfactory levels of the criteria, where these criteria are natural stimuli to innovation, can be supplemented by two additional programmed stimuli:
   (a) criteria expressed as the rate of change; and
   (b) criteria expressed as the rate of innovation.

6. (7.10:7.6,7:11) The type of problem solving used, i.e. the extent to which productive elements are present, depends on both the characteristics of the

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[1] J. T. Lanzetta, and T. B. Roby. "Group Performance as a Function of Work Distribution Patterns and Task Loan", Sociometry XIX, 1956, pp. 95-104.

[2] Philip Selznick, "Leadership in Administration: A Sociological Interpretation", (New York: Harper & Row, 1957).

problem and on the past experience of the problem solver. (P. 177)[3,4]

7. The boundaries of specialization of individual jobs tend to be determined by the training employees bring to it from learning some trade or profession in the broader social environment. (P. 161)

8. (7.23:7.21) The more detailed the factorization of the problem, the more simultaneous activity is possible, hence the greater the speed of problem solving. (P. 193)

9. (A-6.13) The principal way to factor a problem is to construct a means-end analysis, with the means becoming sub-goals assigned to individual organizational units. (P. 152)

10. (A-7.10) Most innovations in an organization are the result of borrowing rather than invention, which borrowing saves the cost of actual invention, testing, and risk of error in evaluation. (P. 188)[5,6]

11. (7.12,7.20:7.18) To the extent that innovation does occur through borrowing, both the rate of innovation and the type of innovation will be functions of exposure, thus of the communication structure of the organization. (P. 188)

12. (6.11:6.31) The existing pattern of communication will determine the relative frequency with which particular members of the organization will encounter particular stimuli, or kinds of stimuli, in their search processes. (P. 168)

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[3] A. Newell, J. C. Shaw and H. A. Simon, "Elements of a Theory of Human Problem Solving", *Psychological Review* LXV, 1958, pp. 151-166.

[4] A. D. de Groot, *"Het Denken van den Schaker"*, (Amsterdam: 1946.) English translation, Adrianus Dingeman de Groot, *"Thought and Choice in Chess"*, (The Hague: Mouton, 1965).

[5] W. H. Brown, "Innovation in the Machine Tool Industry," *Quarterly Journal of Economics* LXXI, 1957, pp. 406-425.

[6] J. Coleman, E. Katz and H. Menzel, "Diffusion of an

13. (A-6.14) Our knowledge of fact is gained via filtering through either in-group members of a particular organizational unit, or in-group members of a common profession. (P. 153)[7,8]

14. (A-6.15) In organizational communication, evidence is replaced with conclusions drawn from that evidence, and these conclusions then become 'facts' on which the rest of the organization acts. (P. 155)[9]

15. (A-6.11) Adaptation takes place through a recombination of lower-level programs that are already in existence.[10]

16. (A-6.17) The economies of individual specialization arise principally from opportunities for using programs repetitively. (P. 158)

Innovation Among Physicians", Sociometry XX, 1957, pp. 253-270.

[7] D. C. Dearborn and H. A. Simon, "Selective Perception: A Note on the Departmental Identification of Executives", Sociometry XXII, 1958, pp. 140-144.

[8] Howard S. Leven, "Office Work and Automation", (New York: John Wiley & Sons, 1956), p. 136.

[9] W. G. Gore, "Administrative Decision Making in Federal Field Offices", Public Administration Review XVI, 1956, pp. 281-291.

[10] Herbert A. Simon, "Birth of an Organization: The Economic Cooperation Administration", Public Administration Review XIII, 1953, pp. 227-236.

EXHIBIT III-2

SOME FEATURES OF ORGANIZATION STRUCTURE