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A study of the relationship between the intensity of short-range and medium-range capacity management and the effectiveness of manufacturing operations

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A STUDY OF THE RELATIONSHIP BETWEEN THE INTENSITY OF SHORT-RANGE AND MEDIUM-RANGE CAPACITY MANAGEMENT AND THE EFFECTIVENESS OF MANUFACTURING OPERATIONS

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A STUDY OF THE RELATIONSHIP BETWEEN THE INTENSITY OF SHORT-RANGE AND MEDIUM-RANGE CAPACITY MANAGEMENT AND THE EFFECTIVENESS OF MANUFACTURING OPERATIONS

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The objective of this study was to examine the relationship between intensity of short-range and medium-range capacity management and effectiveness of manufacturing operations. Data were collected to test the null hypothesis which stated that intensity of short-range and medium-range capacity management does not influence manufacturing effectiveness.

Intensity of short-range and medium-range capacity management was indicated by the following variables: (1) production standards; (2) priority determination; (3) delivery dates determination; (4) material requirements planning; (5) routing information; (6) capacity utilization; and (7) backlog measurement.

Manufacturing effectiveness was indicated by the following variables: (1) delivery dates performance; (2) lead times; (3) subcontract work; (4) direct labor overtime; (5) direct labor efficiency; (6) plant and equipment utilization; and (7) work in process inventory.

The population selected to provide data for this study is the manufacturing firms in the State of Texas with five hundred or more employees. Over 42 percent of the eligible firms responded to a six-page questionnaire.

Several multivariate techniques were utilized for data analysis: (1) factor analysis; (2) canonical correlation analysis; (3) bivariate correlation; (4) multiple linear regression; (5) cross-tabulation; and (6) analysis of variance.

The results of this research did not adequately support the rejection of the null hypothesis. However, they did definitely identify a distinct group of capacity management intensity variables that influence manufacturing effectiveness in specific cases.

Intensity variables were placed in three groups that identified how influential they were over the effectiveness measures. The most influential group included the variables: production standards and material requirements planning. The indication for the manufacturing manager is to concentrate on improvements in these areas.

Effectiveness variables were also placed in three groups that identified the level at which the variables were influenced by the intensity variables. The highly influenced group included plant and equipment utilization and delivery dates performance.

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CHAPTER I

INTRODUCTION

Background

In the last fifteen years numerous articles and books have been written about the competitive vulnerability of U.S. manufacturing companies. A major part of this vulnerability arose out of the failure of these companies to develop and manage their manufacturing capability effectively.[1]

The following passage is an example of what can be frequently found in today's business publications.

> The notion that the U.S. is deindustrializing and becoming a nation of hamburger flippers, retail clerks and copying machine mechanics echoes through today's political and economic debate. High imports, plant closings and growing employment in service industries combine to generate the impression that the U.S. is losing its industrial base and its ability to manufacture goods that can compete in the world economy. "We can't afford to become a nation of video arcades, drive-in banks and McDonald's hamburger stands," warns Chrysler Corp. chairman Lee Iacocca.[2]

In order to reverse the current decline of U.S. manufacturing, the development of a proper manufacturing strategy is essential. This strategy should be integrated

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[1]Elwood S. Buffa, Meeting the Competitive Challenge (Homewood, Ill.: Richard D. Irwin, 1984), 2-19.

[2]Wall Street Journal, 5 January 1987, 1.

with the overall corporate strategy. Capacity management is an important part of any manufacturing strategy. This dissertation will focus on capacity management that despite its importance has not received appropriate research attention.

Deindustrialization and Productivity

In 1971, imports of manufactured goods into the U.S. exceeded manufactured exports for the first time in almost a century.[3] This was a clear sign that U.S. manufacturing was in decline. Although many American companies have fought back successfully, the overall problem of deindustrialization and trade deficits remains.

While there are many causes that combine to create the economic problems, one measure appears to summarize it--the productivity of the private sector. Productivity is a concept that is hard to explain and measure. Typically it is calculated by dividing a country's total "output," adjusted for inflation, by the number of labor hours required to create this output. Productivity has been used for more than thirty years as a measure of private sector vitality. It was also used as a measure of international competitiveness. After rising at an average rate of approximately 3 percent per year since World War II, U.S. productivity stopped growing after 1976. Despite produc-

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[3] Robert H. Hayes and Steven C. Wheelwright, Restoring Our Competitive Edge: Competing Through Manufacturing (New York: John Wiley & Sons, 1984), 1.

tivity gain in 1982 and 1983, it has shown little evidence of a sustained improvement. Studies of manufacturing firms in the U.S. and abroad have revealed that the productivity problem has been due less to foreign pressure and governmental interference than to the way that U.S. managers have guided their companies.[4]

The use of productivity is not limited to labor resources. It provides a useful way of measuring the efficiency with which all resources are consumed during production. Managers can increase productivity by using existing capacity more effectively.[5]

Although the terms "priority" and "capacity" have been in use for a long time, recent literature has brought increased meaning to them. Monks presented his definition of these terms as follows:

> Priority, in a broad sense, is an ordering of goals or activities in accordance with an individual's or organization's system of values. More specifically, priority refers to the ranking or importance of something--often materials. The measure of importance stems primarily from society, in other words, what customers want. Customer demands are, in turn, translated into purchase and production orders that must then be guided through operations until the desired good or service is produced. So customer orders have "priorities." Capacity is a measure of an organization's ability to accomplish its prioritized goals, or more simply, the abilty to produce. In a production facility, this "ability" usually translates into having enough human and equipment capability and time to do the job.[6]

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[4]Ibid., 1-7.

[5]Ibid., 6.

[6]Joseph G. Monks, <u>Operations Management: Theory and</u>

Monks maintained that a priority and capacity approach may be useful for analyzing productivity problems. He suggested a manufacturing strategy that included a realignment of priority principles and a commitment to better use of capacities.

Manufacturing Strategy

A manufacturing system is a competitive weapon for the firm.[7] Manufacturing capabilities such as an adaptive production system and low cost production could be considered as capacity management resources, and driven by capacity management activities.

Skinner emphasized the importance of the interrelationship between manufacturing operations and corporate strategies.

> Frequently the interrelationship between production operations and corporate strategy is not easily grasped. The notion is simple enough-namely, that a company's competitive strategy at a given time places particular demands on its manufacturing function, and, conversely, that the company's manufacturing posture and operations should be specifically designed to fulfill the task demanded by strategic plans. What is more elusive is the set of cause-and-effect factors which determine the linkage between strategy and production operations. Strategy is a set of plans and policies by which a company aims to gain advantages over its competitors.

Problems, 3d ed. (New York: McGraw-Hill Book Company, 1987), 27-28.

[7] Richard B. Chase and Nicholas J. Aquilano, Production and Operations Management: A Life Cycle Approach, 4th ed. (Homewood, Ill.: Richard D. Irwin, 1985), 781.

> Generally a strategy includes plans for products and the marketing of these products to a particular set of customers.[8]

Wheelwright suggested the development of a conceptual framework. His purpose was to determine whether a firm's manufacturing actions will be truly supportive of corporate strategy.[9]

Manufacturing decisions reflect trade-offs among different performance criteria. According to Wheelwright the following are the four most important performance criteria:

> Efficiency. This criterion encompasses both cost efficiency and capital efficiency and can generally be measured by such factors as return on sales, inventory turnover, and return on assets.
> Dependability. The dependability of a company's products and its delivery and price promises is often extermely difficult to measure. Many companies measure it in terms of the "percent of on-time deliveries."
> Quality. Product quality and reliability, service quality, speed of delivery, and maintenance quality are important aspects of this criterion. For many firms this is easy to measure by internal standards, but as with the other criteria, the key is how the market evaluates quality.
> Flexibility. The two major aspects of flexibility changes are in the product and the volume. Special measures are required for this criterion, since it is not generally measured.[10]

Capacity management is a term often found in operations management literature. A generally accepted defini-

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[8] Wickham Skinner, "Manufacturing--Missing Link in Corporate Strategy," Harvard Business Review 47 (May-June 1969): 138-39.

[9] Steven C. Wheelwright, "Reflecting Corporate Strategy in Manufacturing Decisions," Harvard Business Review 56 (February 1978): 60.

[10] Ibid., 61.

tion of capacity management is, however, quite elusive.

Schroeder developed a framework for operations decisions, in which capacity was one of the factors:

> Capacity decisions are aimed at providing sufficient output capacity for the organization--not too much and not too little. Capacity decisions include developing capacity plans long-, medium-, and short-term ranges.[11]

Manufacturing effectiveness, though a very important and broad concept, is not used as a standard term in the literature. For this study, a manufacturing effectiveness criteria was developed as a measurable result of short-range and medium-range capacity management efforts. Long-range capacity management was excluded from the study because it belongs mainly outside the domain of production and inventory management. Its main focus is capacity expansion which is part of econometrics and finance literature. Long-range capacity management decisions rest with top management, while this dissertation concentrates on capacity decisions of middle management. Capacity management is a subsystem in the production and inventory management system. It interfaces with another subsystem known as priority management. A main core of priority management is the material requirements planning (MRP). MRP was originally a computer based method for managing materials required to carry out a schedule. MRP has been expanded to become a method of

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[11] Roger G. Schroeder, Operations Management: Decision Making in the Operations Function (New York: McGraw-Hill Book Company, 1981), 11-12.

coordinating requirements for materials, capacity, and possibly other company resources. A fully expanded application of the MRP method is called manufacturing resources planning (MRPII).[12]

While MRP II was used in the U.S., the just-in-time (JIT) philosophy was used in Japan. JIT is a philosophy that encourages solving problems, not covering them up with band-aids such as excess inventory, safety stock, or padded lead times. Zero inventories is the Americanized term for the JIT. Kanban, the reorder point system used by Toyota, is one way to achieve the JIT philosophy; MRP II is another way. In recent years the JIT philosophy has become popular in the U.S.[13]

Adopting JIT philosophy constitutes a shift from the classical "push" type production system to a "pull" type system. In a push system the driving force is capacity utilization, requiring capacity to be scheduled first, with a material feasibility check being secondary. A pull system is due date driven with customer orders defining due date requirements. Therefore, the major difference between pull and push systems lies in the capacity control approach.[14]

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[12]Oliver W. Wight, MRP II: Unlocking America's Productivity Potential (Boston: CBI Publishing, 1984).

[13]R. Dave Garwood, "Explaining JIT, MRP II, Kanban," P&IM Review and APICS News 4 (October 1984): 66-69.

[14]Hans-Martin Schneeberger, "Job Shop Scheduling in Pull Type Production Environment" (Ph.D. diss., Purdue University, 1984).

Capacity control and capacity planning are the two elements that make up capacity management.

Capacity management--planning and control--plays a key role in developing and implementing a manufacturing strategy aimed at acheiving effective manufacturing operations.

Existing Approaches to Capacity Management Research

The first step in this study was a search of capacity management literature. This search revealed studies in two major areas:

1. Quantitative models for optimizing capacity management decisions

2. Subjective models promoting the alleged importance of specific capacity management tools and techniques

The work accomplished in each of these areas is reviewed in the following chapters. The quantitative approaches are contained in chapter two and the subjective approaches in chapter three.

Research Objectives

The objective of this study was to examine the relationship between the intensity of short-range and medium-range capacity management and the effectiveness of manufacturing operations. Since there are no universally accepted measures of these two sets of variables, a development of factors relating to capacity management and manufacturing effectiveness was necessary.

Importance of the Study

The process of capacity management is not only theoretically interesting but also is of practical importance. It is a major component of the production and inventory management system.

In spite of the fact that numerous relevant studies have been published, no studies were found which attempt to identify and examine the relationship between the intensity of capacity management activities and the effectiveness of manufacturing operations. The absence of this type of research has prompted the study. In this study, intensity of capacity management refers to depth, vigor, sophistication, scope and degree of activities that are concerned with capacity management.

To a great extent this is the age of naive sophistication. Many managers choose complex techniques to assist them in decision making, thinking it is good and free. The manager should recognize that increased sophistication and complexity tend to increase cost and decrease understanding and utility and can be justified only on the basis of results.[15]

Since capacity management activities represent cost, and manufacturing effectiveness represents financial

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[15] Oliver W. Wight, Production and Inventory Management in the Computer Age (Boston: Chaners Books International Inc., 1974), 85-87.

benefits, it is obvious that the relationship between them is important to a manufacturer. The knowledge of this relationship will enable the manager to better prioritize the capacity management activities and determine their intensity according to their influence on manufacturing effectiveness. The formulation and testing of a research hypothesis will facilitate the investigation of the relationship mentioned above.

Hypothesis

In order to accomplish the research goal, data was collected to test the null hypothesis:

H_o The intensity of short-range and medium-range capcity management does not influence manufacturing effectiveness.

Definition of Variables

Intensity of short-range and medium-range capacity management is indicated by the following variables:

1. Production standards--their availability and sources

2. Priority determination--its criteria, frequency of use, frequency of change and authority of assignment

3. Delivery dates--criteria of determination

4. Material requirements planning--its existence and accuracy

5. Routing information--its availibility and use

6. Capacity utilization--the use of load information and delivery date determination

7. Backlog measurement--its use in capacity planning and control

Manufacturing effectiveness is indicated by the following variables:

1. Delivery dates--percentage of the time in which they are met

2. Lead times--percentage of the time in which they are shorter than those of competitors

3. Subcontract work--as a percentage of total output

4. Direct labor overtime--as a percentage of total direct labor

5. Direct labor efficiency--calculated as a ratio between total standard time and total actual time

6. Plant and equipment utilization--measured as the number of weekly shifts of operation

7. Work in process inventory--measured as percentage of total inventory

Methodology

Research methodology includes the principles and the procedure utilized to effectively carry out research. Some of the main steps were discussed in prior sections. The following is a discusssion of the remainder of the elements in the methodology for this study.

The Data

The data used in this study are of two kinds: primary and secondary. The primary data were gathered through a research questionnaire. The secondary data were gathered through published journal articles, texts, dissertations, proceedings and reports.

Population and Sample Frame

The population selected to provide data for this study is the manufacturing firms in the State of Texas with five hundred or more employees. All firms from this group listed in the 1985 Directory of Texas Manufacturers provided the sample frame.[16] The literature and experiences of persons interviewed indicated that the larger firms provide more meaningful data.

Questionnaire Development

The questionnaire is contained in Appendix D. The cover letters are contained in Appendices A,B and C.

Intensity of Short-Range and Medium-Range Capacity Management

An attempt was made to identify the variables, within the control of management, that are believed to have an effect on manufacturing effectiveness. The identification procedure was conducted by means of a search of the litera-

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[16] Directory of Texas Manufacturers (Austin, Texas: The University of Texas at Austin, 1985).

ture, discussion with practitioners and consultation with academicians.

Intensity of short-range and medium-range capacity management is indicated by the following variables:

1. Production standards
2. Priority determination
3. Delivery dates determination
4. Material requirements planning
5. Routing information
6. Capacity utilization
7. Backlog measurement

A development of questions came next, followed by the physical construction of the questionnaire.[17] Responses to questions in sections one through seven of the questionnaire provided the data used to represent the intensity of capacity management.

By assigning numerical values to responses to questions, a measure for each response was developed. An index was developed for each of these variables. The respondent's position on that index has been calculated so that every participating firm received one value for each of the seven intensity variables. The method of calculating each value is explained in chapter four.

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[17]Charles H. Backstrom and Gerald Hursh-Cesar, Survey Research, 2nd ed. (New York: John Wiley & Sons, 1981).

Manufacturing Effectiveness

The methodological process here was very similar to the one described above. The objective in this area was to identify variables that validly measure effectiveness and are available to the researcher.

Manufacturing effectiveness is indicated by the following variables:

1. Delivery dates performance
2. Lead times
3. Subcontract work
4. Direct labor overtime
5. Direct labor efficiency
6. Plant and equipment utilization
7. Work in process inventory

Responses to questions in section eight of the questionnaire provided the data used to represent manufacturing effectiveness. The response values are explained in chapter four.

Plant Classifications

The questionnaire respondents were classified according to: (1) number of employees; (2) a two-digit Standard Industrial Code (SIC); and (3) type of operation (manufacture to stock, manufacture to order, and manufacture to stock and to order). Additional details are contained in chapter four.

Analysis of the Data

Several multivariate data analysis techniques were utilized:

1. Factor analysis
2. Canonical correlation analysis
3. Bivariate correlation
4. Multiple linear regression
5. Cross-tabulation
6. Analysis of variance

The survey analysis is contained in chapter five. The chapter includes the techniques, the analysis, and interpretation of the results.

CHAPTER II

REVIEW OF QUANTITATIVE APPROACHES

Published work in the capacity management field can be placed in two broad categories. The first category contains quantitative models for optimizing capacity management decisions; these are discussed in this chapter. The second category contains a wide range of subjective approaches that are not engaged in an optimization process, nor do they seek to justify the recommendations presented. This category is discussed in chapter three.

The two basic management functions relevant in the case of capacity management are "planning" and "control". Thus the capacity management literature can be classified as follows:

1. Capacity planning (medium-range)
    a) Aggregate capacity planning (ACP)
    b) Rough-cut capacity planning (RCCP)
    c) Capacity requirements planning (CRP)
2. Capacity control (short-range)[1]

Due to the fundamental difference between planning and control, most of the published work in the area of capacity control utilizes the subjective approach, while the capacity

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[1]Monks, Operations Management, 460.

planning literature is primarily quantitative in nature. In contribution to this dissertation, the quantitative approaches provided the philosophy of measurable justification of results.

Aggregate Capacity Planning

Aggregate capacity planning is concerned with the determination of production, inventory, and work force levels, to meet fluctuating demand requirements. Usually, the physical resources (plant and equipment) of the firm are assumed to be fixed during the planning horizon. The planning effort is directed toward the best utilization of those resources given the demand requirements. A problem usually rises because the times and quantities imposed by demand seldomly coincide with the times and quantities that make for an efficient use of the firm's resources.

Whenever the conditions affecting the production process are not stable in time due to changes in demand, cost components or capacity availability, production should be planned in an aggregate way to obtain effective resource utilization. Aggregation can take place by consolidating similar items into product families, different machines into machine centers, etc. The time horizon of aggregate capacity planning is dictated by the specific situation; for example, if demand is seasonal, a full seasonal cycle should be incorporated into the planning horizon. Commonly, the time frame of aggregate capacity planning which is medium-range in nature, varies froms six to eighteen months, twelve months being a suitable figure for most planning systems.[2]

The costs relevant to aggregate capacity planning can be categorized as follows:

1. Basic production costs. These are fixed and variable costs incurred in producing a given product type in a given time period. Included are direct and indirect labor costs, and regular as well as overtime compensations.
2. Costs associated with changes in the production rate. Typical costs in this category are those involved in hiring, training, and laying off personnel.
3. Inventory holding costs. A mojor component of the inventory holding cost is the cost of capital tied up in inventory. Other components are storing, insurance, taxes, spoilage, and obsolescence.
4. Backlogging costs. Usually these costs are very hard to measure and include costs of expediting, loss of customer good will, and loss of sales revenues resulting from backlogging.[3]

Aggregate capacity planning models can be classified according to the assumptions they make about the structure of the cost components. These models can be classified as: (1) linear cost models; (2) quadratic cost models; and (3) general cost models.

Linear Cost Models

Some of the very first models proposed to guide aggre-

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[2]James B. Dilworth, Production and Operations Management: Manufacturing and Nonmanufacturing, 3d ed. (New York: Random House, 1986), 135-66.

[3]Arnoldo C. Hax, Handbook of Operations Research: Foundations and Fundamentals, eds. Joseph J. Moder and Salah E. Elmaghraby (New York: Van Norstad Reinhold Company, 1978), 129.

gate capacity planning decisions were linear cost models. These models considered the work force to be either fixed or variable.

Fixed Work Force Model

With fluctuating sales, a manufacturer must have fluctuating production, or fluctuating inventory, or both. Bowman suggested that this problem may be placed into a transportation method framework.[4] The transportation method was extended to include multiple time periods. The problem was one of balancing production overtime costs with inventory storage costs to result in a minimum total of these costs. A major advantage of the proposed method was its calculations simplicity. The main limitation of this approach was that it did not include hiring or firing costs or back order costs.

Variable Work Force Models

Hansmann and Hess formulated the aggregate planning problem in a linear programming format.[5] Constraints such as maximum amount of overtime could also be used. The Simplex method was used for solution and sensitivity analy-

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[4]Edward H. Bowman, "Production Scheduling by the Transportation Method of Linear Programming," Operations Research 4 (February 1956): 100-103.

[5]F. Hansmann, and S. W. Hess, "A Linear Programming Approach to Production and Employment Scheduling," in Management Technology, Monograph of the Institute of Management Science, January 1960, 46-52.

sis. In cases where the costs were approximately linear this method produced better results than the early model known as the HMMS model which used quadratic costs.

O'Malley, Elmaghraby and Jeske developed a production smoothing system which combined several scheduling tools into an operational unit.[6] The input to the system was a forecasted customer demand; the outputs were the required production levels, size of labor force, planned overtime and expected inventories of classes and individual end products. Because of a varying demand, economic manufacturing quantities were calculated by the method of dynamic programming. The manufacturing progress function was used to convert units into labor requirements. The operating schedule was derived by a linear programming formulation which balanced payroll costs, the costs of labor fluctuations and inventory charges.

Lippman, Rolfe, Wagner and Yuan introduced a model that minimized the sum of production, employment, and inventory costs subject to a schedule of known demand requirements over a finite time horizon. The three decision variables were: work force producing at regular time, work force producing on overtime, and the total work force. The model produced an optimal policy when demands were monotone

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[6]Richard L. O'Malley, Salah E. Elmaghraby, and John W. Jeske, Jr., "An Operational System for Smoothing Batch-Type Production," Management Science 12 (June 1966): B433-49.

(either increasing or decreasing).[7]

Yuan proposed a multi-product model.[8] The instrumental variables in each period were regular time and overtime production for each product, and total work force. The objective was to minimize the sum of employment, work force fluctuation, production, and inventory costs subject to a schedule of known demand requirements for each product. Developing optimal production and employment policies, three types of suboptimal policies were defined as initial hiring, firing, or leveling of work force.

Von Lanzenauer suggested a model for planning optimal production and employment levels in multiproduct, multistage production systems.[9] The model determined the amount of the demand for each product that should be satisfied, be backlogged, or remain unfilled. The results were especially relevant whenever the production capacity was insufficient to produce all market demand. The model formulation was also helpful in certain dynamic market conditions where backorders and shortages were desirable.

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[7]Steven A. Lippman, Alan J. Rolfe, Harvey M. Wagner, and John S. C. Yuan, "Optimal Production Scheduling and Employment Smoothing with Deterministic Demands," Management Science 14 (November 1967): 127-58.

[8]John Shang-Chia Yuan, "Algorithms and Multi-Product Model in Production Scheduling and Employment Smoothing" (Ph.D. diss., Stanford University, 1968).

[9]Christoph Haehling von Lanzenauer, "Production and Employment Scheduling in Multistage Production Systems," Naval Research Logistics Quarterly 17 (June 1970): 193-98.

Lee and Moore showed a technique for the analysis of problems involving multiple goals and linear relationships. This technique is known as goal programming. Multiple goals, such as the following, were specified in this order:

P1=operate within the limits of productive capacity
P2=meet the contracted delivery schedule
P3=operate at a minimum level of 80 percent of regular time capacity
P4=keep inventory to a maximum of three units
P5=minimize total production and inventory costs
P6=hold overtime production to a minimum amount.[10]

This solution provided a satisfaction of these goals starting with P1 and proceeding to the lower priority goals. This technique utilized tradeoffs between goals of capacity, delivery schedules, and so on.

Quadratic Cost Models

Whenever quadratic cost models are used to solve the aggregate capacity planning problem, the decision rules generated have a linear structure because the differentiation of a quadratic function produces a linear function. Thus, the quadratic cost models are also known as linear decision rules.

The HMMS Model

The aggregate planning problem was first formulated by Holt, Modigliani, and Simon over thirty years ago.[11] This

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[10]S. M. Lee and L.J. Moore, "A Practical Approach to Production Scheduling," Production and Inventory Management 15 (1st Qtr. 1974): 79-92.

[11]Charles C. Holt, Franco Modigliani, and Herbert A.

formulation resulted in what is called the linear decision rule (LDR). The LDR model assumed four types of quadratic costs: (1) regular production costs; (2) hiring and firing costs; (3) overtime costs; and (4) cost of inventories and back orders. The objective was to minimize the total cost by choosing a production level and work force for each period.

The LDR was applied to a paint factory. It was simple to use and also had a great deal of intuitive appeal. LDR has its limitations. It is restricted to the use of quadratic costs, and it reacts to forecast changes gradually, while in reality changes such as hiring and firing are made in larger increments. In spite of the limitations and availability of many models, LDR is still used for comparisons.

The LDR was later included in a book with an additional fourth author. As a result it also became known as the HMMS model (Holt, Modigliani, Muth and Simon).[12]

Extension of the HMMS Model

Bergstrom and Smith proposed an extension to the HMMS model by generalizing the approach to a multiproduct formu-

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Simon, "A Linear Decision Rule for Production and Employment Scheduling," Management Science 2 (October 1955): 1-30.

[12]C. C. Holt, F. Modigliani, J. F. Muth, and H. A. Simon, Planning Production Inventories and Work Force (Englewood Cliffs, New Jersey: Prentice-Hall, 1960).

lation and incorporating diminishing marginal revenues in the objective function.[13] To remove the HMMS restriction of a specified demand, revenue curves were estimated for each item in each time period. This allowed the determination of optimal production, sales, inventory and work force levels so as to maximize profit over a specified time horizon. The model focused on decision variables in two seperate functional areas: production and marketing. The HMMS model on the other hand focused on the production area only.

Peterson offered an extension to the HMMS model to allow the manufacturer, at a cost, to smooth distribution orders to achieve less fluctuations in work force, production, and inventory levels.[14] The smoothing of the distribution was achieved by not requiring the manufacturer to ship exactly what is ordered. The model provided a means of balancing the costs and benefits (to the manufacturer) of smoothing shipments in response to orders and therefore could be used as an aid in establishing dynamic prices.

Gaalman introduced a method for aggregating multi-item versions of the HMMS model.[15] The resulting model could be

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[13]Gary L. Bergstrom and Barnard H. Smith, "Multi-Item Production Planning: An Extension of the HMMS Rules," <u>Management Science</u> 16 (June 1970): B614-29.

[14]Rein Peterson, "An Optimal Control Model for Smoothing Distributor Orders: An Extension of the HMMS Aggregate Production Work Force Scheduling Theory" (Ph.D. diss., Cornell University, 1969)

[15]G. J. Gaalman, "Optimal Aggregation of Multi-Item

considered as a one item production planning model, similar to the HMMS model. The disaggregation of the optimal decisions derived from the aggregated model lead to optimal decisions, to the original multi-item model. The proposed approach revealed that computational savings could be realized.

Goodman presented a linearization method which was based upon the method of goal programming.[16] The goal programming approach was applied to the HMMS quadratic model. A linear approximation to the original objective function was made, and computational results were derived. The goal programming solution was only about three percent higher in cost than optimal. This indicated that the model provided an excellent approximation to the quadratic model. The same approach was applied to higher order cost models and found to be inappropriate.

Chang and Jones proposed a model that dealt with multiproduct and long production cycle time that included several production periods.[17] As a result, production could not be started and completed in a given time period. The

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Production Smoothing Models," Management science 24 (December 1978): 1733-39.

[16]David A. Goodman, "A Goal Programming Approach to Aggregate Planning of Production and Work Force," Management Science 20 (August 1974): 1569-75.

[17]Robert H. Chang and Charles M. Jones, "Production and Workforce Scheduling Extensions," AIIE Transactions 2 (December 1970): 326-33.

product cycle time was defined as the time for one unit of production to be fabricated, assembled, and delivered to inventory or the customer. Consideration of the long production cycle time was made by integrating a labor set-back technique into the solution. Labor set-back was defined as the percentage of total unit labor required during each production period.

Most aggregate planning models utilized a constant work force productivity factor; the expected rate of output capability per employee was kept unchanged over time. Productivity rates in many organizations are known to change with additional manufacturing experience. Ebert extended the HMMS model to include the productivity factor.[18] This extension resulted in optimal aggregate solutions under conditions of changing productivity. It could also assist in product pricing decisions and workforce planning. A major limitation to the model was the need to estimate learning curve parameters.

Fisk and Seagle suggested an extension of the HMMS model that yielded a production rate for each work center in each time period.[19] Each production rate achieved an optimal balance between inventory costs and costs of chang-

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[18]Ronald J. Ebert, "Aggregate Planning with Learning Curve Productivity," Management Science 23 (October 1976): 171-82.

[19]John C. Fisk and J. Peter Seagle, "The Integration of Aggregate Planning with Resource Requirements Planning," Production and Inventory Management 19 (3d Qtr.1978): 81-91.

ing capacity. The model integrated aggregate planning with rough-cut capacity planning. It gave the production planner a capacity target for each work center and each time bucket. If planned order releases could fit the targets, cost minimization could have been achieved.

General Cost Models

The linear and quadratic cost models, although appropriate for a great number of applications, impose several restrictions on the nature of the cost functions to be used. Realistic industrial situations tend to exhibit cost functions which are nonlinear and discontinuous and therefore, cannot be treated by any of the methods outlined previously. Buffa and Taubert reported the following factors as mainly responsible for this cost behavior: supply and demand interactions, manufacturing or purchasing economies of scale, learning curve effects, quantum jumps in costs with addition of a new shift, technological and productivity changes, and labor slowdown.[20]

Several aggregate capacity planning methods have been suggested which attempt to be more responsive to the complexities introduced by the specific decision environment. Generally, these more realistic approaches do seek an optimal solution, but do not guarantee that such will be

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[20] E. S. Buffa and W. H. Taubert, Production-Inventory Systems: Planning and Control (Homewood, Illinois: Richard D. Irwin, 1972).

found. These methods can be classified according to the following categories: (1) nonlinear analytical models; (2) heuristic decision rules; (3) search decision rules; and (4) simulation.

Nonlinear Analytical Models

These models provide a mathematical treatment of general nonlinear cost functions. Much of the work in this area attempted to decompose the multiperiod planning problem. Linear approximation to a high order cost function is an option that will enable the use of a linear model. The range programming linear approximation to a fourth order cost function, subject to linear constraints, was shown by Laurant.[21] A satisficing range was introduced for each variable, a range in which all the values of the variable were considered to entail the same minimal cost.

In order to overcome some of the limitations of early models Akinc and Roodman introduced a mixed integer programming model for aggregate planning.[22] The model was based on an analytical framework that allowed the user to specify a set of production options. The model was one that a production manager should find useful. It made a provision

[21]Gilles Laurant, "A Note on Range Programming: Introducing A 'Satisficing Range' in a L.P.," Management Science 22 (February 1976): 713-16.

[22]Umit Akinc and Gary M. Roodman, "A New Approach to Aggregate Production Planning," IIE Transactions 18 (March 1986): 88-94.

for approximating a wide variety of cost structures. It could incorporate factors such as union contract provisions and compulsory maintenance schedules.

In order to facilitate a further discussion of the nonlinear analytical models additional classification is needed. These models can be classified into two categories: convex cost models and concave cost models.

Convex cost models

Modigliani and Hohn analyzed an aggregate planning problem for a convex and nondecreasing production cost function and linear inventory holding cost without production or storage limits.[23] They also assumed that production costs were unchanged for each period of the total time horizon. They proposed an algorithm based on fundamental solutions that can be implemented graphically. The most important results of Modigliani and Hohn's work are the qualitative properties associated with planning horizons. They proved that the total planning interval could be partitioned into subintervals, defined by planning horizons, within which the optimal plan was independent of requirements and costs during other periods. If inventory holding costs were negligible, a constant rate of production within each interval was the optimum.

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[23]F. Modigliani and F. E. Hohn, "Production Planning Over Time and the Nature of the Expectation and Planning Horizon," Econometrica 23 (January 1955): 46-66.

Veinott considered the problem of determining the optimum production quantities of a single product over a finite number of time periods so as to minimize convex production and inventory costs.[24] His model did not penalize changes in the production rate. He performed a parametric analysis to study the changes on the optimum production levels resulting from variations in demand requirements, and inventory and production bounds. From the results of his analysis, he developed simple and intuitive computational procedures for finding optimum production schedules for a range of parameter values.

Johnson studied a case where no backlogging was allowed, no storage limits were permitted, and inventory carrying costs were linear.[25] The key point of departure from previous analyses is that he identified each unit of production with its ultimate destination or period when it was to be used. Johnson proved a very simple optimum rule: requirements should be satisfied sequentially in order of their due dates by the cheapest available means.

Concave cost models

Zangwill showed how to determine minimum cost flows in

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[24] Arthur F. Veinott, Jr., "Production Planning with Convex Costs: A Parametric Study," Management Science 10 (April 1964): 441-60.

[25] S. M. Johnson, "Sequential Production Planning Over Time at Minimum Cost," Management Science 3 (July 1957): 435-37.

certain types of concave cost networks.[26] Although concave functions can be minimized by an exhaustive search, such an approach is impractical for all but the simplest of problems. Zangwill developed theorems which explicitly characterized the extreme points for certain networks. By using this characterization, algorithms were developed to determine the minimum concave cost solution. This approach was applied to a single product production and inventory model, and a multiple product production and inventory model.

Veinott used a different approach to solve the problem for multi-facility inventory systems.[27] He showed how to formulate this problem by minimizing a concave function over the solution set of a Leontief substitution system. The search of the extreme points to find an optimal solution was aided by dynamic programming. The algorithms that were presented were those whose computational effort increased by no more than the increase in the size of the problem.

Sobel considered start-up and shut-down costs in his model.[28] These fixed smoothing costs were caused by produc-

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[26]Willard I. Zangwill, "Minimum Concave Cost Flows in Certain Networks," Management Science 14 (March 1968): 429-50.

[27]Arthur F. Veinott, Jr., "Minimum Concave Cost Solution of Leontief Substitution Models of Multi-Facility Inventory Systems," Operations Research 17 (March-April 1969): 262-91.

[28]Matthew J. Sobel, "Smoothing Start-Up and Shut-Down Costs: Concave Case," Management Science 17 (September 1970): 78-91.

ing in a period but not in the one preceeding it, and/or producing in a period but not in the one following it. Such costs incurred if, for example, the start-up and the shut-down decisions caused the transfer of employees from one activity to another. Inventory, holding costs, and production costs were assumed to be concave. The algorithms developed for optimal policies used some features of the economic lot size problem.

Heuristic Decision Rules

These rules attempt to bring in the decision maker's intuition of the problem under consideration, by incorporating "rules of thumb" that contribute to the solution of the problem.

Bowman proposed an approach which was quite a departure from previous thinking.[29] He suggested that management's own past decisions could be incorporated into a system of improving their present decisions. Decision rules were developed, with the coefficients in the rules derived from management's past decisions, rather than from a cost model. The assumption was that management's decisions were good, but the use of mathematical decision rules would make them more consistent. Several cases were presented to test the theory.

[29] E. H. Bowman, "Consistency and Optimality in Managerial Decision Making," Management Science 9 (January 1963): 310-21.

Jones developed a heuristic approach to the determination of two basic parameters: work force and production level.[30] His method was called parametric production planning. Two rules, one for each parameter, were developed. The four dimensional universe was searched in order to find a set of parameters which would result in maximum profit or minimum cost. In complex and realistic situations the results of this approach could be superior to results achieved by HMMS or linear programming.

Masud and Hwang combined a heuristic approach and analytical decision methods to present a multiple objective formulation of the multi-product, multi-period aggregate planning problem.[31] In their model, conflicting multiple objectives were treated explicitly. It provided a more realistic modeling approach and afforded the production manager an opportunity to make intelligent trade-off decisions about the different objectives. The fundamental problem with the traditional single objective approach was it concealed the issue of conflicting objectives and the necessity of making informed trade-offs to arrive at an acceptable solution.

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[30]Curtis H. Jones, "Parametric Production Planning," Management Science 13 (July 1967): 843-66.

[31]Abu S. M. Masud and C. L. Hwang, "An Aggregate Production Planning Model and Application of Three Multiple Objective Decision Methods," International Journal of Production Research 18 (November 1980): 741-52.

Holt formulated a production decision framework (PDF); an easy to use algorithm for aggregate planning decision.[32] The algorithm was developed for the typical manager who does not take too seriously the search for optimality, but rather seeks to find logical decision rules that provide satisfying short-term solutions. The planning problem was subdivided into nine mutually exclusive and exhaustive subproblems. Each subproblem had a predetermined action statement. Simple calculations were necessary to identify the subproblem on hand and the optimal planning horizon so that the appropriate action could be taken.

Search Decision Rules

These rules consist of the application of hill climbing techniques to the response surface defined by a nonlinear cost function and the problem constraints.

Taubert developed a search decision rule (SDR).[33] This method could use any cost function. The cost function was minimized using a pattern search technique. Production and work force decisions made by the SDR were comparable to those of the HMMS and total costs were almost identical. SDR eliminated some of the restrictions imposed by HMMS and

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[32] Jack A. Holt, "A Heuristic Method for Aggregate Planning: Production Decision Framework," Journal of Operations Management 2 (October 1981): 41-51.

[33] William H. Taubert, "The Search Decision Rule Approach to Operations Planning" (Ph.D. diss., University of California, Los Angeles, 1968).

therefore was more realistic. Taubert used his method to evaluate decision rules with twenty variables and obtained good results.

Mellichamp and Love utilized a search technique in their production switching model.[34] They argued that the available mathematical models were seldom used in planning situations in industry. They observed that managers favored one large change in work force over a series of smaller and more frequent changes. As a result, they proposed a modified random walk production-inventory heuristic that was simple as well as efficient. It had a three level production and work force rule. Production was switched from one level to another depending on sales forecast and level of inventory. Utilizing a search procedure, the production switching points were determined in a way that minimized any given cost function. In spite of the simplicity of this technique it produced schedules which exceeded optimal schedules by only one to two percent of the total production cost.

Goodman explored a sectioning search approach as an alternative method of solving nonlinear aggregate planning models. After applying the search method to a relatively large and complex test model, Goodman stated the following subjective advantages:

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[34] Joseph M. Mellichamp and Robert M. Love, "Production Switching Heuristic for the Aggregate Planning Problem," Management Science 24 (August 1978): 1242-51.

1. The method is simple and can be understood by managers as well as technicians.
2. The method is flexible since it does not depend on any particular mathemetical structures.
3. Dimensionality offers little problem. In terms of memory, only the cost model and the previous solution need to be stored. Computational requirements increase only linearly, not exponentially, as the size of the problem grows.
4. The method supplies an integer solution.
5. The method is free of parameters. Hence, simulations or other experiments are not needed in order to obtain parameter settings to solve a given model.[35]

Simulation

For a long time simulation has been recognized as an important modeling tool to deal with situations where analytical models either provide a too simplified representation of a real world problem or the necessary compuations were not feasible.

Vergin supplied a classical example of the use of simulation to select parameters for aggregate planning decision rules.[36] Using simulation, any cost function or other objectives could be evaluated. The evaluation of each decision rule required a seperate simulation run. Any cost structure was allowed; a departure from the restricted cost functions used in prior methods.

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[35]David Allen Goodman, "A Modified Sectioning Search Approach to Aggregate Planning" (Ph.D. diss., Yale University, 1972).

[36]R. C. Vergin,"Production Scheduling Under Seasonal Demand," Journal of Industrial Engineering 17 (May 1966): 264-66.

Cruickshanks, Drescher, and Graves considered a job shop operation in which all production was for contracted orders, and no uncommitted finished goods inventory were stocked.[37] A planning window was implemented as a production smoothing approach. It required that the planned production time be reduced or the promised delivery time be increased or both. A simulation was used to find the best course of action based on the costs and benefits associated with each possible choice.

Aggregate capacity planning models were presented and discussed in this chapter. In order for the review to be complete, a critical evaluation of these models is necessary.

Evaluation of Aggregate Capacity Planning Models

Aggregate capacity planning has received substantial theoretical treatment in the literature for the last thirty years, widespread implementation of available analytical techniques, however, has not occured. The HMMS model has been used as the standard for comparison for new approaches to aggregate planning. In addition, many extensions to this model have been published. Yet, it remains an implementation failure.

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[37]Allan B. Cruickshanks, Robert D. Drescher, and Stephen C. Graves, "A Study of Production Smoothing in a Job Shop Environment," Management Science 30 (March 1984): 368-80.

Although the HMMS model was developed in 1955, as recently as 1978 no company is reported to be using it. Several possible reasons for implementaion failure of the HMMS were suggested: (1) its inability to handle integer variables and/or constraints; (2) the difficulty of constructing realistic aggregate cost functions; and (3) a substantial portion of the cost savings of the HMMS model could be achieved by improved aggregate inventory management alone.[38]

A study done by Shearon shed some light on aggregate planning in industry.[39] The study indicated that production managers were usually responsible for aggregate planning decisions, but general managers often reviewed and approved large changes in inventory or work force. Aggregate decisions were found to be fragmented, with marketing controlling variables which influenced demands and operations controlling supply variables. Most of the participants in the survey preferred to maintain a level work force whether the demand was fluctuating, seasonal, or uncertain. In periods of increasing demand, operations managers added overtime first, followed by increase in the work force.

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[38]Leroy B. Schwartz and Robert E. Johnson, "An Appraisal of the Empirical Performance of the Linear Decision Rule for Aggregate Planning," Management Science 24 (April 1978): 844-49.

[39]Winston T. Shearon, Jr., "A Study of the Aggregate Production Planning Problem" (Ph.D. diss., University of Virginia, 1974).

Meeting schedules was the most important criterion by which operations managers' job performance was evaluated. It was followed in order of importance by controlling direct costs, controlling indirect costs, inventory turnover, and labor relations.

Lee and Khumawala developed a simulation model of the aggregate operation of a firm.[40] They compared the performance of four aggregate planning models that were reviewed above. The models they compared were: (1) the HMMS model; (2) Bowman's management coefficients model; (3) Jones' parametric production planning model; and (4) Taubert's SDR. Past data pertaining to actual demand were used so that comparisons could be made between performance on demand forecasts and performance on perfect forecasts. Under perfect forecasts, all four methods performed well, with the search decision rule being slighlty better than the HMMS model. A more realistic comparison was obtained under imperfect forecasts. In this case, a wider variation among the four methods occured. The search decision rule performed best, followed by the parametric planning model, the HMMS model, and the management coefficients model.

Quantitative approaches that were reviewed in this chapter attempt to optimize capacity management decisions.

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[40]William B. Lee and Basheer M. Khumawala, "Simulation Testing of Aggregate Production Planning Models in an Implementation Methodology," Management Science 20 (February 1974): 903-11.

The main reason these approaches are not used in industry is their complexity. The subjective approaches to capacity management are presented in chapter three.

CHAPTER III

REVIEW OF SUBJECTIVE APPROACHES

The subjective approaches to capacity management were less scientific than were the quantitative models. Published work in this category focused on the promotion of capacity management tools and techniques, that did not seek to find an optimum solution to the problem at hand. In contribution to this dissertation, the subjective approaches enhanced the development of the following measures: (1) the intensity of capacity management; and (2) the effectiveness of manufacturing operations. It also formed a framework for questionnaire development.

Capacity Planning

Capacity planning techniques can be divided into three major groups. The three groups are: (1) aggregate capacity planning (2) rough-cut capacity planning; and (3) capacity requirements planning.

Aggregate Capacity Planning (ACP)

Aggregate capacity planning determines timing and quantity for total output of manufacturing processes by establishing a desirable level for each of the controllable variables: work force levels, production rates, and finished goods inventory levels. Subjective approaches to aggregate capacity planning are used when the decision maker is either unaware of mathematical solutions to the problem, or does not believe that the mathematical models are representative enough of the actual situation.

Top management should provide guidance for the aggregate planning activity because the planning decisions often reflect basic company policy. Monks outlined some possible aggregate planning policy guidelines:

1. Determine corporate policy regarding controllable variables.
2. Use a good forecast as a basis for planning.
3. Plan in appropriate units of capacity.
4. Maintain as stable a work force as is practical.
5. Maintain needed control over inventories.
6. Maintain flexibility to change.
7. Respond to demand in a controlled manner.
8. Evaluate planning on a regular basis.[1]

Five subjective approaches to aggregate capacity planning were identified: (1) nonquantitative haggling; (2) constant turnover ratio; (3) adjustment of last year's plan; (4) decision options; and (5) graphing and charting methods.

Nonquantitative Haggling

Silver observed that conflicting objectives are held by different departments of an organization when it comes to aggregate capacity planning.[2] He also observed that a

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[1]Monks, Operations Management, 315.

[2]Edward A. Silver, "Medium-Range Aggregate Production Planning: State of the Art," Production and Inventory Management 13 (1st Qtr. 1972): 15-22.

compromise of the conflicting desires was achieved by bargaining in a noneconomic manner. The policy was usually dictated by the most persuasive individual rather than being set in an objective manner.

Constant Turnover Ratio

Another approach commonly used by managers was the constant turnover ratio. Their performances were often measured by the turnover ratios they achieved. Turnover ratio could be defined as total sales divided by average inventory. As a result it became appealing to set production rates so as to achieve a constant desirable tunover ratio, despite the fact that this was not the most economical choice.[3]

Adjustmemt of Last Year's Plan

The weakness of this approach was similar to that of the constant turnover ratio. Silver identified another common approach often used in industry.[4] In this approach a previous plan was slightly adjusted so as to meet current conditions. The implicit assumption that the previous plan was optimal or close to optimal could get management locked into a series of poor plans.

Decision Options

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[3]Ibid.

[4]Ibid., 23.

The decision options available in aggregate capacity planning can be divided into two types: (1) those modifying demand; and (2) those modifying supply. The modification of demand is considered as outside the domain of the operational focus and inside that of marketing, finance, and administration, and therefore will not be discussed here. Modification of the supply can be achieved through:

1. Changing work force size which:
   a) increases hiring and training costs;
   b) results in lower productivity of new employees;
   c) increases costs associated with terminating workers; and
   d) increases the risk of losing skilled workers during periods of decreased demand.
2. Changing inventory level which:
   a) may cause excessive inventory holding costs during periods of inventory buildup; and
   b) may cause back-order or lost-sales costs when peak demand exceeds the capacity of the system to build up inventory.
3. Changing production rate through:
   a) overtime, which increases per-hour labor rates and probably decreases labor efficiency;
   b) underutilization of labor, which either increases per-unit labor cost (if all workers are paid for a standard number of hours and for lower output) or results in worker dissatisfaction (when work hours are reduced below the standard number workers have come to expect);
   c) subcontracting, which often increases per-unit cost and may increase quality-control costs; and
   d) adding additional shifts, which is a commitment to a permanent change in production requirements.
4. Making simple adjustments to physical facilities, such as warehousing and storage space.[5]

Additional decision options that were suggested

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[5]William J. Sawaya, Jr. and William C. Giauque, Production and Operations Management (New York: Harcourt Brace Jovanovich, 1986), 239.

include: the use of alternate routings, additional tooling, changing make/buy decisions, and the reallocation of the work force to different jobs.[6] Most of the decision options listed above are applicable to capacity control.

The use of any single decision option mentioned above constitutes a pure strategy. The use of two or more of the decision options constitutes a mixed strategy. Varying only the inventory level or varying only the work force are examples of a pure strategy. Varying work force and inventory levels is an example of a mixed strategy. Strategies can be combined in an infinite number of ways to arrive at an operating plan that managers feel is feasible and desirable. The use of the decision options approach can be aided by the use of graphic and charting methods.

Graphic and Charting Methods

The graphic and charting techniques basically work with a few variables at a time on a trial-and-error basis. Charts are used in the development of the cost of each of the strategies that are considered. Cost minimization is the criterion for strategy selection. Since a limited number of strategies are considered, an optimal solution usually cannot be achieved. The use of histograms and

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[6] Roger Ahrens, "Capacity Management: Who is Accountable?," in Proceedings of the 25th Annual International Conference of the American Production and Inventory Control Society, October, 1982, 396-400.

cumulative graphs of forecasts can also aid the decision making process.[7]

Rough-Cut Capacity Planning (RCCP)

Rough-cut capacity planning is also known as resource requirements planning (RRP). It is an approach to obtain a rough-cut analysis of the impact that a master production schedule (MPS) will have on the capacity of a company. It can be used to sum and evaluate the work load that the MPS imposes either on all work centers or on only selected work centers where resources are limited, expensive, or difficult to obtain.

Campbell summarized the fundamentals of RCCP:

1. Determine the capacity of the resources (work centers) involved.
2. Determine the load by the time period, represented by the products and quantities in the master schedule.
3. Compare the capacity and load, time period by time period, noticing any significant differences.
4. Report the differences.[8]

Clark presented this type of planning as one which can utilize a variety of techniques, such as load profile simulations, and bills of labor.[9] Rough-cut capacity planning

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[7]Dilworth, Productions and Operations, 145-51.

[8]Kenneth L. Campbell, "Rough-Cut Capacity Planning: What it is and How to Use it," in Proceedings of the 25th International APICS Conference, October, 1982, 406-9.

[9]James T. Clark, "Capacity Management," in Proceedings of the 22d International APICS Conference, October, 1979, 191-95.

techniques utilize MPS information, but do not utilize detailed low level information produced by the material requirements planning system (MRP).

The rough-cut capacity planning techniques were: (1) capacity planning using overall factors; (2) capacity bills; (3) resource profiles; (4) bill of resource; (5) family bill of labor; (6) load profiles; and (7) capacity planning performance factor.

Capacity Planning Using Overall Factors (CPOF)

Berry, Schmitt, and Vollmann offered the CPOF technique:

> The CPOF technique is based upon planning factors involving direct labor standards for end products in the MPS. When these planning factors are applied to the MPS data, overall manpower capacity requirements are estimated. This overall estimate is frequently allocated to individual work centers on the basis of historical data on shop work loads. CPOF plans are usually stated in terms of weekly or monthly time periods, and are periodically revised as the firm makes changes to the MPS.
>
> The CPOF technique, or variants of it, are found in a number of manufacturing firms. The data requirements are minimal, involving principal accounting system data instead of information such as product routing files and detailed time standards. As a consequence, CPOF plans produce only approximations of the actual time-phased capacity requirements at individual work centers.[10]

The CPOF technique resulted in a capacity plan. The plan was based upon the same historical ratio of load in the

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[10] William L. Berry, Thomas J. Schmitt, and Thomas E. Vollmann, "Capacity Planning Techniques for Manufacturing Control Systems: Information Requirements and Operational Features," Journal of Operations Management 3 (November 1982): 15-16.

work center for each time period.

Capacity Bills (CB)

Osgood introduced the capacity bills technique which provided a much more direct linkage between individual end products in the MPS and the capacity required at individual work centers than did the CPOF.[11] This technique required more data. Routing, operation time standards, and bills of material were utilized to develop a capacity plan using the capacity bills technique. The bill of capacity indicated the total standard time per unit required to produce an end product in each work center used in its manufacturing. After the bill of capacity for each end product was prepared, the MPS could be used to estimate the total requirements at each of the work centers. The capacity plan that was developed reflected the actual period to period differences in product mix.

Resource Profiles (RP)

This technique provided a time-phasing dimension not available in the CPOF and CB techniques. In the resource profiles technique, production lead time data were added to the capacity bills data base in order to provide a time-phased profile of resource usage by end product, by work center, and by period. The profile was used to generate the

[11] William R. Osgood, "How to Plan Capacity Using The Bill of Labor," in Proceedings of the 19th International APICS Conference, October, 1976, 281-88.

capacity plan. The technique accommodated both product mix variations and operation lead times as part of the prepera- tion of capacity plans.[12]

Bill of Resource

Bechler suggested the use of a bill of resource that was similar to RP technique though the structure used was different.[13] The product groups that were covered by the MPS were defined using a bill of resource. The products were structured in a bill of material format but using resource requirements instead of part requirements. The resources could represent any measure of capacity desired. Some examples were: man hours, machine hours, test fixtures, floor space, and electricity. As a result time-phased resource requirements plans were developed for all resources that were included in the bill.

Family Bill of Labor

Erhorn emphasized the use of the family bill of labor in situations where only the labor resource was considered. In companies producing a large number of end items, family summarization was the only efficient way to achieve rough-

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[12]W. L. Berry, T. G. Schmitt, and T. E. Vollmann, "A Tutorial on Different Procedures for Planning Work Center Capacity Levels," Indiana University Discussion Paper 155 (September 1980): 1-8.

[13]Robert E. Bechler, "Resoource Requirements Planning," in Proceedings of the 23d International APICS Conference, October, 1980, 332-34.

cut capacity planning. The process used for classification of product families was described in the following steps:

1. First, classify all end items into broad categories, based on similarities of application.
2. Further classify within each application category, those end items with similar or common components. Note: similar in this case means components that are essentially of identical design, but which may differ in terms of size or finish.
3. Do not consider purchased components in the classification process, since these have no effect on your capacity requirements.
4. Finally, establish families by further classifying your groupings from step 2. This is accomplished using the additional criteria of similarity of manufacturing process. Each family will contain end items whose components look the same, and are produced on the same machinery.[14]

Load Profiles

Clark advocated the use of load profiles as a planning tool.[15] This technique was similar to the RP technique but did not provide end product information. A load profile was prepared for each of the work centers for which requirements were indicated. The load profile showed weekly work loads and normal available capacity. If a load profile was unacceptable, a revision of the MPS was executed. The revision process could be repeated more than one time until a desirable production plan was found, one that appeared to be the best way to achieve a match between resources and demand for

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[14]Craig R. Erhorn, "Developing and Using Rough-Cut Capacity Planning," in Proceedings of the 26th International APICS Conference, November, 1983, 238-41.

[15]James T. Clark, "Capacity Management,: Part Two," in Proceedings of the 23rd International APICS Conference, October, 1980, 335-41.

resources. If by using this procedure the load profile could not be leveled within the current capacity level, the problem had to be brought to management's attention for a selection of corrective action(s).

Capacity Planning Performance Factor (CPPF)

Lunz argued that a fundamental factor was not commonly considered while performing calculations of capacity requirements and available capacity in conjunction with techniques such as those that were presented above.[16] Consideration of this factor, he stated, was necessary in order to successfully execute the capacity planning process. The CPPF had to be utilized in order to determine how many standard hours per day had to be used for each direct labor person, or for each machine. Factors such as allowable rest periods, machine break downs, efficiency percentage, rework, etc. reduced the available hours and did not contribute to the accomplishment of direct labor standards. These factors were used to calculate the appropriate CPPF.

Strengths and Weaknesses

Ahrens listed the following strengths and weaknesses of rough-cut capacity planning.

The strengths were:

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[16] Alfred G. Lunz, "The Missing Factors: The Real Keys to Effective Capacity Requirements Planning and Control," Production and Inventory Management 22 (2d Qtr. 1981): 1-12.

It does not require a computer although the process is enhanced if assisted by a computer.

Routings are not essential for every item.

It is simpler. Only key or critical work centers are considered.

Quick simulation of capacity requirements prior to MRP is provided.

Rescheduling the MPS for capacity over/under loads is made easier. When using more detailed methods of determining capacity requirements the relationship between the capacity required and the MPS item is not clear.

It aids production planning in allocating capacity to product families by providing quick answers to "what if" questions.

The weaknesses were:

It is not precise.

Component and work-in-process inventory are ignored.

RCCP only considers critical work centers. It assumes the non-critical work center capacities can be manipulated as required.

Lead time offsets are not considered.

It does not track performance to plan.[17]

Evaluation Criteria

Njus examined the effectiveness of a RCCP model after its implementation.[18] Credibility and turnaround time were the major considerations in the evaluation. The accuracy of

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[17] Roger Ahrens, "Basics of Capacity Planning and Control," in Proceedings of the 24th International APICS Conference, October, 1981, 232-35.

[18] John Njus, "Resource Requirements Planning: The Sundstrand Model," in Proceedings of the 26th International APICS Conference, November, 1983, 480-83.

the RCCP model was established by comparing its results with an existing standard for planning. The existing standard for planning was the gross current work standard direct labor load report. This report was calculated by exploding the detail part requirements for a given MPS. The turn-around time for the RCCP report was compared to that for the existing gross labor report.

Capacity Requirements Planning (CRP)

Plossl and Wight proposed the term "capacity requirements planning" to replace what was previously called "infinite loading" or "loading to infinite capacity."[19] CRP utilized the low-level detailed MRP information. It actually went beyond infinite loading, however, for it included planned orders as well as released orders and involved an iterative plan-replan process. Replanning continued until a realistic load was developed.

> CAPACITY REQUIREMENTS PLANNING (CRP)--The function of establishing, measuring, and adjusting limits or levels of capacity. The term capacity requirements planning in this context is the process of determining how much labor and matching resources are required to accomplish the tasks of production. Open shop orders, and planned orders in the MRP system, are input to CRP which "translates" these orders into hours of work by work center by time period.[20]

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[19] George W. Plossl and Oliver W. Wight, "Capacity Planning and Control," Production and Inventory Management 14 (3d Qtr. 1973): 31-67.

[20] Thomas F. Wallace, ed., APICS Dictionary, 5th ed. (Falls Church, Virginia: American Production and Inventory Control Society, 1984), 4.

Loading

Loading refers to the assigning of work load to a work center. There are two types of loading methods. The first is called infinite loading and the other is called finite loading.

Infinite loading

The capacity requirements planning (CRP) technique that was discussed above is classified as an infinite loading technique.

> INFINITE LOADING--Showing the work behind work centers in the time periods required regardless of the capacity available to perform this work. The term infinite loading is considered to be obsolete today, although the specific computer programs used to do infinite loading can now be used to perform the technique called capacity requirements planning. Infinite loading was a gross misnomer to start with, implying that a load could be put into a factory regardless of its availability to perform. The poor terminology obscured the fact that it is necessary to generate capacity requirements and compare these with available capacity before trying to adjust requirements to capacity.[21]

Finite loading

The second type of loading is finite loading.

> FINITE LOADING--Conceptually the term means putting no more work into a factory than the factory can be expected to execute. The specific term usually refers to a computer technique that involves automatic shop priority revision in order to level load operation by operation.[22]

Finite loading does not usually work well at the CRP

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[21] Ibid., 14.

[22] Ibid., 11.

stage because it forces changes back onto the master production schedule that are not always the best solutions to the scheduling problem. Finite loading is a useful technique for single work centers in the priority control stage where jobs are being scheduled.

The information manual for CAPOSS-E an IBM finite and infinite loading system provides a list of the benefits of capacity management:

Adherence to scheduled due dates.
Reduction of delivery time.
Increased customer confidence.
More efficient machine loading, which releases additional capacity.
Easier control of schedules.
Recognition of overloads in time to take action.[23]

The CRP Process

End item requirements arising from the aggregate plan and MPS are exploded into tentative planned orders for components by the MRP system. The CRP system then converts these orders into standard labor and machine hours of load on the appropriate workers and/or on the machines as identified from the work center status and shop routing files. The output is a load projection report by work center. If work center capacities are adequate, the planned order releases are verified for the MRP system, and released orders become purchase and shop orders. Workload reports

[23] International Business Machines, Capacity Planning and Operation Sequencing System--Extended: General Information Manual, GH12-5119-0, (White Plains, New York., 1977), 13-14.

are also made for use in input/output control. If some initial load projection reports reveal inadequate capacity, either the capacity must be modified or the master schedule revised.[24]

In the process described above, the master production schedule drives an MRP system, which passes planned orders to CRP. Wright suggested an alternative to this approach.[25] In his proposal the master production schedule directly drove the CRP while in the classical approach CRP was driven by the MRP.

Karni developed a systematic methodology to characterize and analyze the flow of work through a work station and related this flow to the nominal capacity of the station.[26] Operation of the station was measured by work-in-process, delay, and underload. Flow between stations was measured by queue length and lead times. Performance was evaluated by the degree of underload and overload planned for the station, and the degree to which MRP imposed lead times could be achieved. To complete the discussion of the CRP, its strengths and weaknesses will be presented.

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[24]Ray Plossl and Tom Moore, "Job-Shop Scheduling: A Case Study," in Proceedings of the 25th International APICS Conference, October, 1982, 97-104.

[25]Allan B. Wright, "How to Use a Detailed Scheduling System to Plan Materials," in Proceedings of the 25th International APICS Conference, October, 1982, 85-86.

[26]Reuven Karni, "Capacity Requirements Planning: A Sytematization," International Journal of Production Research 20 (November 1982): 715-39.

Strengths and Weaknesses

Behling provided a detailed list of CRP strengths and weaknesses.

The strengths were:

> Net capacity required is accurately depicted since on-hand and work-in-process inventories are considered in determining the requirements plan, and completed operations are considered in determining the hours required.
>
> Capacity requirements are developed for all work centers on resources which are defined by the routing information.
>
> Time-phased visibility of bottlenecks and unbalanced loads is provided for the horizon represented by the production plan or master schedule less the lead time offset.

The weaknesses were:

> Data requirements are extensive since accurate information is required at a minimum for routings, order status, and operation status.
>
> Extensive computer assistance is required due to the voluminous number of records processed and calculations performed.
>
> Visibility for corrective action is difficult because the pegging of capacity requirements to specific master schedules is limited.
>
> Predefined scheduling rules don't always represent actual shop operation, thus limiting the accuracy of the time phasing in the net capacity required.[27]

Input/Output Planning

Belt proposed a technique called input/output (I/O) planning as a replacement for capacity requirements planning

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[27]Richard L. Behling, "Supply Chain Management with Capacity Constraints," in Proceedings of the 25th International APICS Conference, October, 1982, 379-83.

(CRP).[28] The proposal constituted an integration of capacity planning and capacity control. While CRP is a load vs. capacity method the input/output planning method utilizes a different approach which is similar to the one used by the capacity control technique called input/output control. Belt pointed out that load and capacity cannot be directly compared. In the CRP, it is invalid to match up load which is measured in hours, to capacity which is a rate expressed in units per hour.

In the proposed input/output planning method, planned input is used instead of load, and planned output is used instead of capacity. This terminological transformation eliminates the invalid comparison mentioned above. The input/output plan shows the planned input, planned output, planned queue, and planned queue in weeks of output all on a weekly basis. The proposed format is concise and understandable. Action recommended by input/output planning is based upon a comparison of planned queue in weeks of output and planned lead time. Employing the input/output techniques for both capacity planning and capacity control means that a single report format can serve both functions.

The input/output planning technique is superior to machine loading (utilized by CRP) for the following reasons:

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[28]Bill Belt, "Integrating Capacity Planning and Control," Production and Inventory Management 17 (1st Qtr. 1976): 9-25.

1. It focuses on stabilizing the planned queue or backlog as the primary capacity planning objective, thus recognizing the true role of backlog in the shop. Backlog is stabilized to a preplanned level equivalent to planned lead time by adding capacity, reducing input, or some combination of the two, and true capacity needs are defined easily as a result. Machine loading tries only to match input ("load") with output, and ignores queue fluctuations.
2. I/O planning validates the lead time used in inventory planning, by seeking to stabilize queues around the inventory-control system's planned lead time value. Machine loading does not try to do this.
3. I/O planning recognizes that backlogs will always vary somewhat and seeks stability within a certain tolerable range of variation. Machine loading, in trying to equate input with output, attempts to keep the backlog size rigidly fixed and not permit it to fulfill its proper function of a physical and psychological buffer.
4. I/O planning offers more flexible alternatives to the capacity planner by giving him visibility as to future input, future output, and future queue variations by time period. Capacity planning becomes more precise and more realistic than the numbers-matching approach of machine loading.
5. I/O planning is useful for intermediate as well as starting work centers since it clearly shows the evolution of backlog time period by time period, based on the scheduled input rate from MRP. Directly modifying the input rate to intermediate work centers remains a difficult proposition. But seeing the peaks and valleys of input and queues, rather than an average input for all time periods, helps the planner to decide when to change the planned output rate. Machine loading offers only the possibility of equating "load" with capacity for both intermediate and starting work centers.
6. Changes to planned lead times are easier to implement with I/O planning, which will show the results clearly, in terms of queue variations, by time period. Machine loading has no provision for showing this.
7. An integrated I/O format may be used for both capacity planning and control functions in production control systems, both tailor-made as well as standard packages, rather than having machine load reports for the one and input/output reports for the other.[29]

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[29] Ibid., 23-24.

In order to further facilitate the understanding of capacity planning methods, some comparisons and evaluations will be presented.

Capacity Requirements Planning (CRP) Vs. Rough-Cut Capacity Planning (RCCP).

Sari provided a comparison between CRP and RCCP using manufacturing and product charac-teristics similar to those utilized by Everdell in the development of a MPS.[30] Review of the respective strengths and weaknesses of CRP and RCCP revealed that the two tools very much complemented each other in many respects. In addition certain characteristics of the manufacturing environment or product tend to favor one tool or the other.

The following were some of Sari's considerations:

1. Type of manufacturer and facility. Flow-like manufacturers frequently rely exclusively on RCCP. Very little beyond loading to process capacity is needed. Discrete manufacturers, particularly those with common use equipment and facilities, do not rely exclusively on RCCP. The load profiles of RCCP assume a manufacturing flow that does not depict well the effects of lead time variability.

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[30]F. John Sari, "Resource Requirements Planning and Capacity Requirements Planning: The Case for Each and Both," in Proceedings of the 24th International APICS Conference, October, 1981, 229-31, and Romeyn Everdell, "Planning Bills of Materials: Tools for Master Scheduling," in Proceedings of the 26th International APICS Conference, November, 1983, 265-68.

Even though CRP suffers from the same problem it does provide additional visibility into the situation.

2. Lower level independent demand. Manufacturers with significant spare part business, interplant component supply situations, etc., may utilize CRP to reflect this lower demand.

Performance Comparison of Four Capacity Planning Techniques

Schmitt, Berry, and Vollmann used a simulation model of a two stage fabrication/assembly process to compare the performance of four capacity planning procedures. The procedures were aimed at developing work center capacity plans designed to ensure the production of components and assemblies as specified by MRP. Three of the procedures examined were rough-cut capacity planning procedures. The procedures in this group were: capacity planning using overall factors (CPOF), capacity bills (CB), and resource profiles (RP). The fourth procedure was the capacity requirements planning (CRP). The conclusions of the comparison were:

> The results indicate that the performance of a procedure when measured against the MPS depends on the operating conditions of the manufacturing system. The results also indicate that the choice of a particular procedure often represents a compromise among the benefits of improved MPS performance, the costs of preparing and processing data, and the premium expenses required for more frequent adjustments in work center capacity levels.[31]

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[31]Thomas G. Schmitt, William L. Berry, and Thomas E. Vollman, "An Anlysis of Capacity Planning Procedures for a

A control step always follows the planning step. This statement is true in regard to the capacity function. After the completion of capacity planning, the stage is set for capacity control.

Capacity Control

APICS Dictionary defines capacity control as:

> CAPACITY CONTROL--The process of measuring production output and comparing it with the capacity requirements plan determining if the variance exceeds preestablished limits, and taking corrective action to get back on plan if limits are exceeded.[32]

Capacity control complements priority control. Priority control activities include order release, dispatching, and status control, while capacity control activities include lead time control and input/output control.[33]

Lead Time Control

An effective lead time control can be an important step towards meeting the production and inventory control objectives of customer service, minimum inventory investment and planned operating efficiency.

Belt introduced a modern concept of lead time

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material Requirements Planning System," Decisions Sciences 15 (October 1984): 522-41.

[32]Wallace, APICS Dictionary, 4.

[33]G. W. Plossl, "Tactics for Manufacturing Control," Production and Inventory Management 15 (3d Qtr. 1974): 21-34.

control.[34] Traditionally, lead time was thought as given and uncontrollable. The new concept suggested that lead time is a controllable resource and should be managed like any other resource in order to maximize return on investment. Lead time should be allocated sparingly. It should be balanced with other productive resources such as man/machine resources. Lack of balance will make it impossible for the shop to run smoothly. Lead time should also be controlled so that actual lead times are approaching the planned lead times using input/output control. Before discussing the principles of lead time control the term must be defined.

Lead Time Definition

Lankford presented a detailed anatomy of lead time.[35] As defined for production control, lead time is the elapsed time between the release of an order for manufacturing and the receipt of that order into stores. This is the definition of manufacturing lead time (MLT), the time required for production or processing activities. It does not include pre-manufacturing activities such as engineering, design and material purchasing. Each manufactured item in the bill of materials has its individual MLT and each purchased item has its procurement lead time.

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[34] Bill Belt, "The New ABC's of Lead-Time Management," Production and Inventory Management 15 (3d Qtr.1974): 81-91.

[35] R. L. Lankford, "Short-Term Planning of Manufactuirng Capacity," in Proceedings of the 21st International APICS Conference, October, 1978, 37-39.

When quoting a delivery date to customers total lead time must be used. Total lead time includes pre-manufacturing activities, MLT, and post-manufacturing activities such as crating or waiting for shipment.

Manufacturing lead time consists of operation times and inter-operation times. Operation time consists of set-up and run time. Inter-operation time consists of queue time and transit time. Queue time is the time a job spends in a backlog waiting for another job to be finished. Transit time includes wait time and move time. Wait time is the time a job spends waiting to be moved, while move time is the actual traveling time of the job. The dominant element of MLT is queue time, which is estimated to account for seventy to ninety percent of the total. Studies suggested that ten percent or less of the MLT in an average company is actual run time.[36]

Lead Time Variability

Heard focused on the importance of the variability in lead times.[37] He observed that the significance of lead time variability was not as evident as that of lead time length. Manufacturing control systems were notoriously one

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[36]Oliver W. Wight, "Input/Ouput Control. A Real Handle on Lead Time," Production and Inventory Management 11 (3d Qtr. 1970): 9-30.

[37]Ed Heard, and George Plossl, "Lead Time Revisited," Production and Inventory Management 25 (3d Qtr. 1984): 33-47.

sided with respect to completion date. Early completion of orders were neither appreciated nor understood, though they caused an unnecessary increase in finished goods inventory. Materials and capacity devoted to completing unneeded orders early could not be used to complete needed orders on time.

Wight described five situations providing evidence of poor lead time control.[38] The situations were: (1) excessive inventories of parts and finished material combined with poor customer service; (2) an inability to make realistic delivery promises and meet them; (3) excessive expediting; (4) a chronic lack of space in the plant; and (5) plants that are always behind schedule. The root of the problem was large backlogs caused by a surge in lead time, erratic plant input, and inability to plan and control output rates.

Moghaddam and Bimmerle identified nineteen factors influencing manufacturing lead time.[39] They ranked those factors according to the importance placed on them by the manufacturers. The ten most important factors in descending order were: (1) commitment to customer on shipping date; (2) ability to plan and control capacity; (3) the number of resource constraints; (4) shop utilization (load);

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[38]Wight, "Input/Output Control," 9-30.

[39]John M. Moghaddam, and Charles F. Bimmerle, "Managing Manufacturing Lead Time: A Research Report," in Proceedings of the 24th International APICS Conference, October, 1981, 163-64.

(5) ability to plan and control inventory level; (6) the variety of products; (7) priority rules; (8) labor flexibility; (9) the degree of assembly work; and (10) engineering order change.

Control Techniques

Lead time variability is influenced by the control technique used. Moghaddam and Bimmerle determined that the techniques used by manufacturers to reduce MLT were not of equal importance.[40] The ten most important techniques in descending order were: (1) increase the output rate by extra manning; (2) increase shop floor control; (3) reduction of rework and scrap; (4) increase the output rate by overtime; (5) replan production output level; (6) combine the planning and control of capacity with the planning and control of mix; (7) plan capacity requirements in the largest possible groups of items; (8) increase input/output control; (9) increase expediting (stock chasing); and (10) removing work for subcontracting.

Young introduced a cost based control technique.[41] He presented an overview of the costs associated with manufacturing lead time. Although many of the costs were difficult to document or even unmeasurable, they existed. Pulling

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[40] Ibid., 164-65.

[41] Jan B. Young, "Understanding Shop Lead Times," in Proceedings of the 22d International APICS Conference, October, 1979, 177-79.

together enough of the costs formed a management judgement on the extension or contraction of lead times. After changes in lead times were implemented, the formation of the management judgement was repeated in order to evaluate the change.

Input/Output Control

Wight introduced input/output control as a technique aimed at reducing and controlling lead time.[42] The reduction and control of backlogs, and thus lead times, can be achieved by following one simple rule: the input to a shop must be equal or less than the output. In spite of the clarity of this rule, more times than not, the exact opposite occurs. The input/output control technique facilitates control in three main ways: (1) projecting capacity requirements into the future; (2) showing planned input and output at the level rate; and (3) showing the relationship between input and output.

In the input/output control report, a production rate has been planned and then leveled out. This level rate is projected into the future so that a plant foreman would have enough time to make any necessary adjustments to capacity. The report shows the planned input, actual input, planned output, actual output, and cumulative deviations all on a weekly basis. The integration of capacity planning and con-

[42] Wight, "Input/Output Control," 9-30.

trol using input/output planning and control was discussed in the I/O planning section.

Overview

The literature review that was presented in chapters two and three identified a research topic and contributed to the research design.

A review of quantitative models in chapter two identified a very low degree of implementation due to complexity and difficulty in developing input data. It indicated a need for improvement. The quantitative models provided the fundamental concept that a measurement of results is necessary in order to justify recommendations.

A review of the subjective models identified their basic limitations. These models do not provide an optimal solution, nor do they attempt to justify their recommendations. These models, however, contributed to development of intensity and effectiveness measures and the questionnaire. These topics are presented in chapter four.

CHAPTER IV

DATA COLLECTION SURVEY

The selection of the population and sample frame for this study was described in chapter one. The completed mailing list included 296 manufacturing plants in the State of Texas.

Design of Questionnaire

Selection of variables, development of questions and the assignment of numerical values to potential responses were the next steps performed. The final step in the design of the questionnaire was its physical construction.

Selection of Variables

Both the intensity variables and the effectiveness variables were selected by means of a literature review, consultation with academicians and practitioners, and personal experience. Detailed lists and explanations of the two variable groups appeared in chapter one. These lists represent a reduction of original lists. During a pilot study and consultation with practitioners, it became evident that the number of variables, and subsequently the number of questions had to be reduced. Some of the main reasons were: (1) not all desirable information was readily available to potential participants; (2) a lengthy, time consuming questionnaire would discourage participation; and (3) the confidential nature of part of the information would result in incomplete questionnaires.

Development of Questions

For the effectiveness measures, one question per variable was developed. However, for the intensity measures several questions per variable were necessary. A list of the variables (intensity and effectiveness) and their corresponding questions are shown in appendix E. The survey questionnaire is contained in appendix D.

Numerical Value Assignment

The assignment of numerical values to potential responses to all questions was a subjective, judgemental process. The main consideration was that the assignment would provide a relative measurement--a measurement that would indicate the respondent's position on each variable scale. The response values for all the questions are shown in appendix D.

Questionnaire Construction

The questionnaire layout was designed especially for ease of use. It also was aimed at improving participation and completeness. The ease of completion was achieved by providing check-off blanks and spaces for responses.

The importance of the research and the individual participation were stressed in the cover letters. The letters also promised confidential handling of the information. A summary of results was promised too. A name and mailing address on the questionnaire, to request a summary, was provided by 86 percent of the repondents.

Survey Implementation

Pilot Study

The initial questionnaire was distributed to members of the North Texas Chapter of the American Production and Inventory Control Society, in order to conduct a pilot study. This study was aimed at increasing question reliability, relevance and understanding. Based on the results of the pilot study several changes in the questionnaire were made.

Questionnaire Mailing and Follow-Up

The cover letters for the first, second, and third mailings are contained in appendices A, B, and C. A subsequent mailing went to those not responding to an earlier request. The third mailing utilized certified letters in order to improve the rate of return. The first mailing included 296 questionnaires. Sixteen questionnaires were returned unfilled due to plant closing, lack of applicability and inability to participate.

All efforts of mailings and telephone calls yielded a return of 137 questionnaires (48.9 percent of the 280 eligible plants). Numerous phone calls were made in order to complete and correct questionnaires. As a result there were 119 usable returns (42.5 percent). Responses to the mailings are shown in table 1.

TABLE 1

QUESTIONNAIRE RATE OF RETURN

Mailing	Number of Usable Responses	Percentage of Respondents	Percentage of Eligible Plants
First	70	58.8	25.0
Second	31	26.1	11.1
Third	18	15.1	6.4
Total	119	100.0	42.5

Summary of Participants

This section contains tables which provide basic characteristics of the participants and basic statistics concerning the intensity and effectiveness variables.

Tables 2, 3, and 4 classify the respondents according to their demographic characteristics. Tables 5 and 6 provide the value of statistics for intensity and effectiveness variables respectively. Table 5 contains seven intensity variables and a total intensity score. The total intensity score for each respondent was developed by summing the scores for each of the seven variables. For all the seven variables scores were positive integers. For all variables, a higher score indicated higher intensity. A total effectiveness score was not developed due to: (1) six of the effectiveness scores were measured in percents while one was measured in positive integers; and (2) a higher percent indicated higher effectiveness in some variables and lower in others. A full spectrum of scores occured in six of the seven effectiveness variables and only in three of the seven intensity variables, possibly due to different levels of interdependence within the two variable groups. Further analysis of the information contained in tables 2 through 6 is found in chapter five.

Appendix F provides the questionnaire response frequencies. In the questionnaire there were several places in which "other" was a possible choice. In question I B, ten of the respondents answered in this manner. Some of the specific responses were: estimates, MTM, ratio delay, and video analysis. In question II B the category "other" was used sixty-one times. Some of the more frequent responses were: customer requirements (14), FIFO (7), and marketing (5). In question II D there were sixteen responses in the "other" category. The frequent responses were: production control (4), joint decision (4), and customer (3). In question III A there were five such responses, three were lead time and two were contract requirements. The "other" catgory drew fifty-nine responses in question V C. Thirty of the respondents provided "not applicable" as an answer and were assigned a score of zero. Some of the remaining responses were: material availability (5), machine availability (3), and efficiency (3). In question VII B "other" was marked thirty-one times. Twenty of those were indicated as "not applicable" (zero score). Of the remaining eleven reponses, capacity (2) and rescheduling (2) were the most frequent.

TABLE 2

RESPONDENTS CLASSIFIED BY A TWO-DIGIT STANDARD INDUSTRIAL CODE

Two-Digit Standard Industrial Code	Number of Respondents	Percentage of Respondents
20	11	9.2
21	0	0.0
22	3	2.5
23	9	7.6
24	1	0.8
25	2	1.7
26	1	0.8
27	2	1.7
28	4	3.4
29	1	0.8
30	3	2.5
31	1	0.8
32	2	1.7
33	9	7.6
34	18	15.1
35	4	3.4
36	19	16.0
37	9	7.6
38	1	0.8
39	19	16.0
Total	119	100.0

Note: See Appendix D, question IX B.

TABLE 3

RESPONDENTS CLASSIFIED BY
NUMBER OF EMPLOYEES

Number of Employees	Number of Respondents	Percentage of Respondents
500-1000	101	84.9
1001-1500	5	4.2
1501-2000	3	2.5
2001-2500	4	3.4
Over 2500	6	5.0
Total	119	100.0

TABLE 4

RESPONDENTS CLASSIFIED BY
TYPE OF OPERATION

Type of Operation	Number of Respondents	Percentage of Respondents
Manufacture to stock only	6	5.0
Manufacture to order only	33	27.7
Manufacture to stock and to order	80	67.2
Total	119	100.0

TABLE 5

VALUE OF STATISTICS FOR INTENSITY VARIABLES

Variable	Possible Min-Max	Actual Min-Max	Mean	Median	Mode	Standard Deviation	Number of Cases
Production standards	0-9	1-9	4.6	5.0	5.0	2.0	119
Priority determination	0-13	0-9	4.7	5.0	3.0	2.2	119
Delivery dates determination	0-6	1-6	3.6	4.0	3.0	1.5	119
Material requirements planning	0-11	0-11	7.7	9.0	11.0	3.6	119
Routing information	0-9	0-9	4.7	5.0	6.0	1.9	119
Capacity utilization	0-7	0-7	4.4	4.0	7.0	2.4	119
Backlog measurement	0-13	0-12	7.5	9.0	10.0	3.7	119
Total of intensity scores	0-68	12-53	37.3	38.0	44.0	8.4	119

TABLE 6

VALUE OF STATISTICS FOR EFFECTIVENESS VARIABLES

Variable	Possible Min-Max	Actual Min-Max	Mean	Median	Mode	Standard Deviation	Number of Cases
Delivery dates performance (%)	40-97	40-97	87.5	93.0	97.0	11.9	119
Lead times (%)	25-97	25-97	60.0	55.0	55.0	22.5	119
Subcontract work (%)	5-67	5-67	7.0	5.0	5.0	8.6	119
Direct labor overtime (%)	5-72	5-30	8.7	10.0	5.0	5.3	119
Direct labor efficiency (%)	50-97	57-97	83.0	80.0	80.0	11.1	119
Plant and equipment utilization	3-18	3-18	9.9	10.0	5.0	5.1	119
Work in process inventory (%)	15-87	15-87	35.5	22.0	15.0	23.2	119

CHAPTER V

SURVEY ANALYSIS

The data obtained from the questionnaires was analyzed utilizing several multivariate data analysis techniques. The statistical analysis was performed on a Honeywell main frame computer, using the SPSS^{x} Information Analysis System.[1] The different tools are briefly described and followed by the results of each phase of the analysis. In the final section, a synthesis of the overall analysis is presented.

Factor Analysis

Factor analysis is a class of multivariate statistical techniques. The main objective of these techniques is to condense the information contained in several variables into a smaller set of factors where the loss of information is minimal. Factor analytic techniques are interdependence techniques in which all variables are simultaneously considered. The differentiation between dependent and independent variables is not required. While there are a variety of types of factor analysis, this dissertation utilized the principle factor solution, with iteration and the varimax orthogonal rotation. The selection of the type of factor

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[1] SPSS^{x} User's Guide, 2d ed. (New York: McGraw-Hill, 1986).

analysis is based on the specific research objectives. The technique employed was primarily aimed at defining relationships between variables.

Factor Analysis Applications

Factor analysis was applied three times. The first application was done on both the intensity and effectiveness variables (fourteen variables). The second application was done on the intensity variables alone (seven variables). The third application was done on the effectiveness variables alone (seven variables).

Correlation Matrices

The principle factor analysis was applied to a matrix of correlation coefficients among all the variables. The correlation matrix used in the fourteen-variable factor analysis is presented in table 7.

The principle diagonal of the matrix contains communality estimates. The estimate used here was the squared multiple correlation coeffcient (SMC) of one variable with all others. The SMC multiplied by 100 measures the percentage of variation that could be explained for one variable from all others. For routing information, the SMC is 0.45. This means that 45 percent of the routing information data can be predicted from data on the remaining thirteen variables.

The correlation matrix was used in the first step of the analysis. Table 8 shows the correlation matrix used in the factor analysis of the seven-variable intensity data. Table 9 shows the correlation matrix used in the factor analysis of the seven-variable effectiveness data. Additional intermediary statistics are required for factor solution but are not normally interpreted. They are presented in appendix G (tables 39-43).

Unrotated Factor Matrices

Two different factor matrices are presented for each of the three factor analyses. The first set includes the unrotated factor matrices which are normally shown without interpretational comments. The second set includes the rotated factor matrices which are subjected to interpretation.

The fourteen-variable, seven intensity variables, and seven effectiveness variables unrotated factor loadings matrices are shown in tables 10, 11, and 12 respectively. Table 10 is used in the following conceptual explanation.

Columns define the factors while rows refer to variables. At the intersection of rows and columns are the loadings for the row variables on the column factor. The factors are meaningful independent patterns of relationship among variables. The number of factors extracted was a variable controlled by the researcher. The criterion utilized in stopping the iterative procedure of factor extraction was a minimum value allowed for the eigenvalue of a subsequent factor. A minimum eigenvalue of 1.4 was selected for the fourteen-variable analysis. For the seven intensity variables analysis the eigenvalue was 1.0, and for the seven effectiveness variables analysis it was set at 1.2. If the eigenvalue was less than the value set by the researcher factoring was terminated and rotation was commenced. Three factors were extracted from the fourteen-variable analysis (table 10), two factors were extracted from the seven intensity variables analysis (table 11), and two factors were extracted from the seven effectiveness variables analysis (table 12).

Loadings, that can be interpreted like correlation coefficients, measure which variables were invloved in which factor pattern and to what degree. The column headed "h^2" is refered to as the communality. This is the proportion of a variable's total variation that is involved in the factor patterns. It is the sum of the squared factor loadings. The complement of communality ($1 - h^2$) represents the proportion of unique variance of a variable, the proportion not explained by the factors or any other variable in the analysis.

The ratio of the sum of the values in the h^2 column to the number of variables, multiplied by 100, equals the percentage of total variation in the data that is explained by the three factors. In table 10 the three factors involved 35.9 percent of the data variation.

TABLE 7

FOURTEEN-VARIABLE FACTOR ANALYSIS
CORRELATION MATRIX

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Production standards	.66													
2. Priority determination	-.03	.54												
3. Delivery dates determination	-.03	.00	.52											
4. Material requirements planning	-.17	.00	-.19	.47										
5. Routing information	-.09	-.10	-.07	-.10	.45									
6. Capacity utilization	-.09	-.24	-.12	-.00	.07	.56								
7. Backlog measurement	-.15	-.17	-.05	.13	.04	-.03	.50							
8. Delivery dates performance	-.07	.00	.12	-.30	.00	-.07	-.04	.49						
9. Lead times	-.05	-.07	-.02	.02	.11	-.05	.14	-.13	.49					
10. Subcontract work	-.02	.00	-.13	-.04	-.04	.12	.00	.01	.02	.44				
11. Direct labor overtime	.10	-.02	-.03	-.05	.12	.16	-.10	.04	-.21	-.14	.46			
12. Direct labor efficiency	-.19	.06	-.06	.00	.04	-.12	.06	-.15	-.09	-.10	.13	.57		
13. Plant and equipment utilization	.00	.07	-.15	.21	-.25	-.02	.25	-.34	.03	.11	.19	.07	.40	
14. Work in process inventory	.06	-.00	-.07	-.04	.10	-.13	-.06	.00	.06	-.20	.02	.11	-.11	.40

Note: These are product moment correlation coefficients. Elements in the principal diagonal are the squared multiple correlation coefficient (SMC) of the variable with all the others. These elements, in factor analysis terminology, are the estimates of communality.

TABLE 8

SEVEN INTENSITY VARIABLES FACTOR ANALYSIS
CORRELATION MATRIX

Variable	1	2	3	4	5	6	7
1. Production standards	.56						
2. Priority determination	-.08	.51					
3. Delivery dates determination	-.01	.01	.61				
4. Material requirements planning	-.23	.02	-.16	.56			
5. Routing information	-.07	-.16	-.10	-.14	.52		
6. Capacity utilization	-.15	-.25	-.11	-.02	.08	.54	
7. Backlog measurement	-.14	-.21	-.04	.11	.11	.01	.47

Note: These are product moment correlation coefficients. Elements in the principal diagonal are the squared multiple correlation coefficient (SMC) of the variable with all the others. These elements, in factor analysis terminology, are the estimates of communality.

TABLE 9

SEVEN EFFECTIVENESS VARIABLES FACTOR ANALYSIS
CORRELATION MATRIX

Variable	1	2	3	4	5	6	7
1. Delivery dates performance	.50						
2. Lead times	-.14	.50					
3. Subcontract work	.00	.03	.40				
4. Direct labor overtime	.05	-.19	-.16	.42			
5. Direct labor efficiency	-.10	-.12	-.10	.19	.46		
6. Plant and equipment utilization	-.30	.03	.09	-.15	.00	.45	
7. Work in process inventory	.00	.05	-.19	.02	.11	-.00	.49

Note: These are product moment correlation coefficients. Elements in the principal diagonal are the squared multiple correlation coefficient (SMC) of the variable with all the others. These elements, in factor analysis terminology, are the estimates of communality.

TABLE 10

FOURTEEN-VARIABLE UNROTATED
FACTOR LOADINGS MATRIX

Variable	Factors			h^2
	F_1	F_2	F_3	
1. Production standards	.58	.35	-.18	.49
2. Priority determination	.04	.56	.28	.39
3. Delivery dates determination	.33	.09	.52	.39
4. Material requirements planning	.63	-.07	.19	.44
5. Routing information	.30	-.06	.47	.31
6. Capacity utilization	.38	.46	.06	.36
7. Backlog measurement	-.18	.59	.04	.38
8. Delivery dates performance	.62	-.36	-.08	.52
9. Lead times	.23	-.20	-.25	.16
10. Subcontract work	.08	.02	.21	.05
11. Direct labor overtime	-.26	-.29	.23	.20
12. Direct labor efficiency	.50	.11	-.41	.43
13. Plant and equipment utilization	.16	-.59	.42	.55
14. Work in process inventory	-.11	.23	.53	.35
Total variance (%)	13.60	12.10	10.20	35.90
Common variance (%)	37.88	33.70	28.42	
Eigenvalues	1.91	1.69	1.43	

TABLE 11

SEVEN INTENSITY VARIABLES UNROTATED FACTOR LOADINGS MATRIX

Variable	Factors		h^2
	F_1	F_2	
1. Production standards	.59	-.03	.35
2. Priority determination	.50	.51	.51
3. Delivery dates determination	.49	-.25	.30
4. Material requirements planning	.53	-.54	.56
5. Routing information	.42	-.40	.34
6. Capacity utilization	.54	.35	.41
7. Backlog measurement	.22	.65	.47
Total variance (%)	23.20	18.80	42.00
Common variance (%)	55.24	44.76	
Eigenvalues	1.62	1.31	

TABLE 12

SEVEN EFFECTIVENESS VARIABLES UNROTATED FACTOR LOADINGS MATRIX

Variable	Factors		h^2
	F_1	F_2	
1. Delivery dates performance	.76	.01	.58
2. Lead times	.56	.10	.32
3. Subcontract work	-.07	.13	.02
4. Direct labor overtime	.14	.70	.51
5. Direct labor efficiency	.43	-.57	.51
6. Plant and equipment utilization	.46	.53	.49
7. Work in process inventory	-.34	.42	.30
Total variance (%)	20.50	18.50	39.00
Common variance (%)	52.56	47.44	
Eigenvalues	1.43	1.30	

The "percent total variance" values reflect the percentage of total variation among the variables that is related to each factor. The first unrotated factor delineated the largest pattern of relationships in the data. Subsequent factors depicted decreasing patterns. In table 10, factor 1 explained 13.6 percent of the total variance among the variables. This is 37.88 percent of the variance involved in all the three factors and is shown as a "percent common variance" value. The eigenvalues equal the sum of the column of square loadings for each factor, and measure the amount of variation accounted by the factor pattern.

Rotated Factor Matrices

In the next step, factors were allowed to rotate. The orthogonal rotation used in this research positioned factor vectors, so that they have relatively high loadings from relatively few variables. The rotation made it easier to depict conceptual properties of each factor if they did in fact exist. It should be noted though, that the amount of explained variance was not altered by the rotation. The varimax rotation was utilized to simplify the factors.

The fourteen-variable, the seven intensity variables, and the seven effectiveness variables varimax rotated matrices are placed in tables 13, 14, and 15 respectively. By comparing the unrotated and rotated matrices (tables 10 and 13 for the fourteen-variable analysis; tables 11 and 14 for the seven intensity variables analysis; and tables 12

TABLE 13

FOURTEEN-VARIABLE VARIMAX ROTATED FACTOR LOADINGS MATRIX

Variable	Factors			h^2
	F_1	F_2	F_3	
1. Production standards	.68	.06	.12	.49
2. Priority determination	.25	-.52	.25	.39
3. Delivery dates determination	.09	-.07	.61	.39
4. Material requirements planning	.34	.31	.47	.44
5. Routing information	-.00	.05	.56	.31
6. Capacity utilization	.51	-.21	.23	.36
7. Backlog measurement	.20	-.58	-.08	.38
8. Delivery dates performance	.26	.63	.25	.52
9. Lead times	.14	.35	-.10	.16
10. Subcontract work	-.01	-.05	.22	.05
11. Direct labor overtime	-.44	.03	.08	.20
12. Direct labor efficiency	.58	.29	-.11	.43
13. Plant and equipment utilization	-.40	.43	.46	.55
14. Work in process inventory	-.15	-.41	.40	.35
Total variance (%)	12.49	12.28	11.13	35.90
Common variance (%)	34.79	34.20	31.01	
Eigenvalues	1.75	1.72	1.56	

TABLE 14

SEVEN INTENSITY VARIABLES VARIMAX ROTATED FACTOR LOADINGS MATRIX

Variable	Factors		h^2
	F_1	F_2	
1. Production standards	.48	.34	.35
2. Priority determination	.07	.71	.51
3. Delivery dates determination	.54	.11	.30
4. Material requirements planning	.74	-.09	.56
5. Routing information	.58	-.05	.34
6. Capacity utilization	.20	.61	.41
7. Backlog measurement	-.23	.65	.47
Total variance (%)	21.43	20.57	42.00
Common variance (%)	51.02	48.98	
Eigenvalues	1.50	1.44	

TABLE 15

SEVEN EFFECTIVENESS VARIABLES VARIMAX ROTATED FACTOR LOADINGS MATRIX

Variable	Factors		h^2
	F_1	F_2	
1. Delivery dates performance	.67	-.35	.58
2. Lead times	.54	-.18	.32
3. Subcontract work	.01	.15	.02
4. Direct labor overtime	.45	.56	.51
5. Direct labor efficiency	.11	-.70	.51
6. Plant and equipment utilization	.65	.25	.49
7. Work in process inventory	-.11	.53	.30
Total variance (%)	20.00	19.00	39.00
Common variance (%)	51.29	48.71	
Eigenvalues	1.39	1.32	

TABLE 16

SUMMARY PRESENTATION OF FACTOR LOADINGS

Variable	Fourteen-Variable Analysis						Intensity Variables Analysis				Effectiveness Variable Analysis			
	Unrotated Loadings			Rotated Loadings			Unrotated Loadings		Rotated Loadings		Unrotated Loadings		Rotated Loadings	
	F1	F2	F3	F1	F2	F3	F1	F2	F1	F2	F1	F2	F1	F2
1. Production standards	.50	.35	-.10	.60	.06	.12	.59	-.03	.40	.34				
2. Priority determination	.04	.56	.20	.25	-.52	.25	.50	.51	.07	.71				
3. Delivery dates (1)	.33	.09	.52	.09	-.07	.61	.49	-.25	.54	.11				
4. Material requirements planning	.63	-.07	.19	.34	.31	.47	.52	-.54	.74	-.09				
5. Routing information	.30	-.06	.47	-.80	.05	.56	.42	-.40	.58	-.05				
6. Capacity utilization	.30	.46	.06	.51	-.21	.23	.54	.35	.20	.61				
7. Backlog measurement	-.10	.59	.04	.20	-.58	-.08	.22	.65	-.23	.65				
8. Delivery dates (2)	.62	-.36	-.08	.26	.63	.25					.76	.01	.67	-.35
9. Lead times	.23	-.20	-.25	.14	.35	-.10					.56	.10	.54	-.10
10. Subcontract work	.08	.82	.21	-.81	-.05	.22					-.27	.13	.81	.15
11. Direct labor overtime	-.26	-.29	.23	-.44	.03	.08					.14	.70	.45	.56
12. Direct labor efficiency	.50	.11	-.41	.58	.29	-.11					.43	-.57	.11	-.70
13. Plant and equipment utilization	.16	-.59	.42	-.40	.43	.46					.46	.53	.65	.25
14. Work in process inventory	-.11	.23	.53	-.15	-.41	.40					-.34	.42	-.11	.53
Total variance (%)	13.60	12.10	10.20	12.49	12.28	11.13	23.20	18.80	21.43	20.57	20.50	18.50	20.00	19.00
Common variance (%)	37.88	33.70	28.42	34.79	34.20	31.01	55.24	44.76	51.02	48.98	52.56	47.44	51.29	48.71
Eigenvalues	1.91	1.69	1.43	1.75	1.72	1.56	1.62	1.31	1.50	1.44	1.43	1.30	1.39	1.32

Notes: (1) = Determination, (2) = Performance and 15 for the seven effectiveness variables analysis), it was determined that the h^2 values, the number of factors, and the sum of the eigenvalues do not change with orthogonal rotation.

Results and Conclusions

Table 16 is a summary of the rotated and unrotated loadings in the three analyses. It is presented in order to make the six-way comparison easier. Table 17 was developed from the rotated factor loadings in the fourteen-variable analysis. It lists the variables in descending order of magnitude. Tables 18 and 19 contain similar information for the two seven-variable analyses.

The fourteen-variable factor analysis contained more data and resulted in a more meaningful output. The following conclusions were drawn from that analysis (table 17):

1. Of the three factors depicted by the analysis, factors 1 and 3 were heavily loaded by intensity variables, and only slightly loaded by effectiveness variables. In factor 2 the situation was reversed. It described heavy loading by effectiveness variables, while the intensity variables loadings were very light. The analysis apparently confirmed the distinction between the intensity variables and the effectiveness variables.

2. In factor 1, three of the four highest loadings belonged to the following intensity variables: production standards (0.68), capacity utilization (0.51), and material

TABLE 17

FOURTEEN-VARIABLE ROTATED LOADINGS
LISTED BY MAGNITUDE

Factor 1		Factor 2		Factor 3	
Production standards	.68	Delivery dates (2)	.63	Delivery dates (1)	.61
Direct labor efficiency	.58	Plant and equipment utilization	.43	Routing information	.56
Capacity utilization	.51	Lead times	.35	Material requirements planning	.47
Material requirements planning	.34	Material requirements planning	.31	Plant and equipment utilization	.46
Delivery date (2)	.26	Direct labor efficiency	.29	Work in process inventory	.40
Priority determination	.25	Production standards	.06	Priority determination	.25
Backlog measurement	.20	Routing information	.05	Delivery dates (2)	.25
Lead times	.14	Direct labor overtime	.03	Capacity utilization	.23
Delivery dates (1)	.09	Subcontract work	−.05	Subcontract work	.22
Routing information	−.00	Delivery dates (1)	−.07	Production standards	.12
Subcontract work	−.01	Capacity utilization	−.21	Direct labor overtime	.08
Work in process inventory	−.15	Work in process inventory	−.41	Backlog measurement	−.08
Plant and equipment utilization	−.40	Priority determination	−.52	Lead times	−.10
Direct labor overtime	−.44	Backlog measurement	−.58	Direct labor efficiency	−.11
Eigenvalue 1.75		Eigenvalue 1.72		Eigenvalue 1.56	

Notes: (1) = Determination, (2) = Performance

TABLE 18

SEVEN INTENSITY VARIABLES ROTATED LOADINGS
LISTED BY MAGNITUDE

Factor 1		Factor 2	
Material requirements planning	.74	Priority determination	.71
Routing information	.58	Backlog measurement	.65
Delivery dates determination	.54	Capacity utilization	.61
Production standards	.48	Production standards	.34
Capacity utilization	.20	Delivery dates determination	.11
Priority determination	.07	Routing information	-.05
Backlog measurement	-.23	Material requirements planning	-.09
Eigenvalue 1.50		Eigenvalue 1.44	

TABLE 19

SEVEN EFFECTIVENESS VARIABLES ROTATED LOADINGS LISTED BY MAGNITUDE

Factor 1		Factor 2	
Delivery dates performance	.67	Direct labor overtime	.56
Plant and equipment utilization	.65	Work in process inventory	.53
Lead times	.54	Plant and equipment utilization	.25
Direct labor overtime	.45	Subcontract work	.15
Direct labor efficiency	.11	Lead times	-.18
Subcontract work	.01	Delivery dates performance	-.35
Work in process inventory	-.11	Direct labor efficiency	-.70
Eigenvalue 1.39		Eigenvalue 1.32	

requirements planning (0.34). In factor 3 the three highest loadings also belonged to intensity variables: delivery dates determination (0.61), routing information (0.56), and material requirements planning (0.47). The fact that the variable material requirements planning was common to both factors made the conceptual properties of each factor less discernible. In spite of that, a thorough examination of the meaning of the other two heavy loading variables in each factor resulted in the identification of two patterns. Factor 1 was labeled intensity of capacity management--internal factors, while factor 3 was labeled intensity of capacity management--external factors.

3. In factor 2, the three heaviest loadings belonged to effectiveness variables: delivery dates performance (0.63), plant and equipment utilization (0.43), and lead times (0.35). The labeling of factor 2 as manufacturing effectiveness was obvious.

The two seven-variable factor analyses contained less data input and less meaningful output. The following conclusions were drawn from the intensity variables analysis (table 18):

1. Comparing the two factors in this analysis revealed that the order of the variables in them was basically reversed. The three variables at the top of the list in factor 1, were the same variables as those at the bottom of the list in factor 2. At the same time the top three

variables in factor 2 were at the bottom of the list in factor 1.

2. The comparison of factor 1 in this analysis to factor 3 in the fourteen-variable analysis, revealed that the three variables loading heaviest on both factors were identical. The comparison of factor 2 in this analysis with factor 1 in the fourteen-variable analysis, revealed the following: three of the four variables loading heaviest on factor 2 in this analysis and three of the four intensity variables loading heaviest on factor 1 in the fourteen-variable analysis were identical. As a result the factors in this analysis were labeled in the same manner as the corresponding factors in the fourteen-variable analysis. Factor 1 in this analysis was labeled intensity of capacity management--external factors while factor 2 was labeled intensity of capacity management--internal factors.

A comparison between the fourteen-variable application and the seven intensity variables application was made. It was recognized that both delineated similar results.

The following conclusions were drawn from the effectiveness variables analysis (table 19):

1. Comparing the two factors in this analysis revealed that the order of the variables in them was basically reversed. Two of the three variables at the top of the list in factor one, were the same variables as two of the three at the bottom of the list in factor 2.

2. The comparison of factor 1 in this analysis to factor 2 in the fourteen-variable analysis revealed that the three variables loading heaviest on both factors were identical and in exactly the same order. The comparison of factor 2 in this analysis to factor 2 in the fourteen-variable analysis revealed that the order of their effectiveness variables were basically reversed. Factor 1 in this analysis was labeled manufacturing effectiveness--external factors, while factor 2 was labeled manufacturing effectiveness--internal factors. The fact that the variable plant and equipment utilization loaded heavy on both factors in this analysis, made their conceptual properties less discernible.

Factor analysis will be discussed again in this dissertation. When mentioned, reference will always be made to the fourteen-variable application.

Canonical Correlation

Canonical correlation is a technique used to predict several dependent variables form several independent variables. The main objective of canonical correlation is to simultaneously correlate the two sets of variables producing a canonical function. In this study the intensity variables were the independent set and the effectiveness variables were the dependent set.

The results of the analysis indicated that the inde-

TABLE 28

FIRST (SIGNIFICANT) CANONICAL CORRELATION STATISTICS AND COEFFICIENTS

Statistics	Value	Coefficients	Value
Eigenvalue	.28	Production standards	.55
Canonical correlation	.47	Priority determination	-.03
Wilkes' Lambda	.51	Delivery dates determination	-.13
F	1.55	Material requirements planning	.71
Hypoth. D.F.	49.00	Routing information	-.30
Significance	.01	Capacity utilization	.29
		Backlog measurement	.18
		Delivery dates performance	.69
		Lead times	.19
		Subcontract work	.04
		Direct labor overtime	-.13
		Direct labor efficiency	.36
		Plant and equipment utilization	-.48
		Work in process inventory	-.02

pendent set had a significant impact on the dependent set. The canonical correlation statistics are contained in table 20. The canonical correlation was moderate (0.47). The highest coefficients in the canonical function in the independent set, belonged to material requirements planning (0.71) and production standards (0.55). In the dependent set, the highest coefficient belonged to delivery dates performance (0.69) and plant and equipment utilization (0.48). The two intensity variables that were identified had the highest influence on the effectiveness variables. The two effectiveness variables that were identified had the highest association with the intensity variables.

Bivariate Correlation

The Pearson product moment correlation coefficients are contained in table 21. Only coefficients having a significance of 0.05 or better will be discussed. The primary attention was given to significant correlation coefficients between intensity variables and effectiveness variables. Significant coefficients within each variable group was of a secondary importance.

The production standards (an intensity variable) had a 0.159 correlation coefficient with delivery dates performance and a 0.259 correlation coefficient with direct labor efficiency (both effectiveness variables). Material requirements planning (intensity variable) had a 0.358

correlation coefficient with delivery dates performance (effectiveness variable). Routing information (intensity variable) had a 0.211 correlation coefficient with plant and equipment utilization (effectiveness variable). Capacity utilization (intensity variable) had a -0.184 correlation coefficient with direct labor overtime (effectiveness variable). Backlog measurement (intensity variable) had a -0.264 correlation coefficient with plant and equipment utilization (effectiveness variable).

The capacity utilization variable showed the strongest relationship to other variables within the seven intensity variable group. As could be expected, the total intensity score was consistently significantly correlated with the seven intensity variables. The direct labor efficiency exhibited the strongest relationship within the seven effectiveness variable group.

Tables 22 through 24 contain similar coefficients calculated from data supplied by plants from three different industries. These tables identified more significant relationships between intensity and effectiveness variables than the total data.

Table 22 relates to the eighteen respondents that are classified under fabricated metal products, except machinery and transportation equipment (SIC 34). Production standards (an intensity variable) had a -0.695 correlation coefficient with work in process inventory (an effectiveness variable).

TABLE 21

PEARSON CORRELATION COEFFICIENTS

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Production standards	1.00														
2. Priority determination	.070 .200	1.00													
3. Delivery dates determination	.005 .170	.046 .309	1.00												
4. Material requirements planning	.240 .004	-.001 .496	.195 .017	1.00											
5. Routing information	.090 .146	.133 .075	.131 .077	.105 .022	1.00										
6. Capacity utilization	.171 .031	.260 .002	.120 .003	.061 .254	-.007 .469	1.00									
7. Backlog measurement	.122 .093	.209 .011	.020 .416	-.091 .163	-.005 .179	.060 .233	1.00								
8. Total intensity score	.510 .000	.491 .000	.369 .000	.540 .000	.352 .000	.479 .000	.490 .000	1.00							
9. Delivery dates performance	.159 .042	-.107 .124	.001 .494	.350 .000	.031 .360	.009 .160	-.115 .107	.149 .054	1.00						
10. Lead times	.059 .262	.011 .455	.009 .461	.041 .320	-.114 .109	.053 .205	-.109 .119	-.023 .402	.166 .035	1.00					
11. Subcontract work	.037 .344	-.070 .201	.140 .054	.000 .194	.000 .466	-.099 .143	.026 .391	.034 .350	-.017 .426	-.002 .490	1.00				
12. Direct labor overtime	-.146 .056	-.030 .371	.031 .360	-.026 .389	-.104 .130	-.104 .023	.101 .137	-.001 .189	-.016 .432	.165 .036	.124 .090	1.00			
13. Direct labor efficiency	.259 .002	-.060 .259	.061 .255	.061 .257	-.039 .330	.150 .052	-.051 .291	.096 .150	.100 .020	.125 .000	.134 .073	-.160 .041	1.00		
14. Plant and equipment utilization	-.122 .093	-.100 .140	.112 .113	-.025 .396	.211 .011	-.020 .416	-.264 .002	-.123 .092	.272 .001	.031 .369	-.077 .202	.141 .063	-.076 .206	1.00	
15. Work in process inventory	-.071 .222	.110 .117	.115 .107	-.004 .484	-.045 .312	.110 .100	.006 .176	.093 .150	-.092 .161	-.000 .194	.165 .036	.020 .302	-.114 .110	.050 .294	1.00

Note: (coefficient/significance)

TABLE 22

PEARSON CORRELATION COEFFICIENTS
SIC 34

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Production standards	1.00														
2. Priority determination	-.080 .377	1.00													
3. Delivery dates determination	.280 .130	-.383 .058	1.00												
4. Material requirements planning	.350 .078	-.113 .328	.318 .099	1.00											
5. Routing information	.456 .029	-.349 .078	.479 .022	.203 .209	1.00										
6. Capacity utilization	-.046 .429	.270 .139	-.473 .024	-.142 .287	-.046 .428	1.00									
7. Backlog measurement	-.020 .469	-.121 .317	.010 .485	-.290 .122	-.295 .117	-.229 .180	1.00								
8. Total intensity score	.732 .000	-.007 .488	.406 .047	.625 .003	.483 .021	.111 .331	.128 .306	1.00							
9. Delivery dates performance	.066 .397	-.263 .145	-.003 .496	.390 .055	-.160 .263	.281 .129	.343 .082	.420 .041	1.00						
10. Lead times	-.014 .478	.179 .238	.238 .171	.155 .269	.117 .322	.048 .425	-.084 .371	.204 .209	.052 .419	1.00					
11. Subcontract work	.040 .438	-.516 .014	.423 .040	.198 .216	.405 .048	-.101 .345	.011 .483	.206 .206	.136 .296	.222 .188	1.00				
12. Direct labor overtime	.014 .478	.025 .461	.473 .024	.334 .088	.124 .312	-.120 .318	.056 .413	.344 .081	.354 .075	.376 .062	.486 .020	1.00			
13. Direct labor efficiency	-.029 .454	.042 .434	.059 .408	-.073 .387	-.050 .422	.521 .013	.113 .328	.213 .198	.259 .150	.486 .021	-.048 .424	.039 .440	1.00		
14. Plant and equipment utilization	.351 .077	-.029 .455	.322 .096	.062 .404	.605 .004	.194 .221	-.123 .314	.450 .030	.011 .482	-.263 .146	-.011 .483	.104 .341	.005 .492	1.00	
15. Work in process inventory	-.695 .001	.042 .434	-.274 .136	.031 .452	-.293 .119	.017 .473	-.187 .229	-.470 .025	.058 .410	-.169 .251	.006 .491	.219 .191	-.247 .161	-.092 .359	1.00

Notes: (coefficient/significance.) Number of cases: 18.

TABLE 23

PEARSON CORRELATION COEFFICIENTS
SIC 36

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Production standards	1.00														
2. Priority determination	-.254 .147	1.00													
3. Delivery dates determination	.000 .500	.045 .427	1.00												
4. Material requirements planning	.342 .076	.068 .391	.262 .139	1.00											
5. Routing information	-.181 .229	.583 .004	-.224 .178	.157 .261	1.00										
6. Capacity utilization	.112 .324	-.087 .362	.448 .027	-.073 .383	-.180 .230	1.00									
7. Backlog measurement	.176 .236	-.122 .309	-.427 .034	-.042 .432	.354 .069	-.104 .335	1.00								
8. Total intensity score	.446 .028	.357 .067	.396 .047	.710 .000	.409 .041	.399 .045	.162 .253	1.00							
9. Delivery dates performance	.282 .121	.067 .393	-.146 .276	.432 .033	.298 .108	-.092 .354	.107 .331	.364 .063	1.00						
10. Lead times	-.185 .224	.118 .316	.219 .184	-.031 .450	-.045 .428	.019 .470	-.078 .375	-.011 .482	.021 .466	1.00					
11. Subcontract work	-.015 .475	.119 .314	-.181 .229	-.094 .351	.133 .293	-.074 .382	-.225 .177	-.108 .342	.018 .470	.045 .427	1.00				
12. Direct labor overtime	-.392 .048	-.087 .362	-.114 .321	-.295 .110	-.124 .307	-.312 .097	.111 .326	-.459 .024	-.250 .151	.291 .113	-.041 .434	1.00			
13. Direct labor efficiency	.357 .067	.021 .466	.113 .323	.014 .478	-.205 .200	-.048 .423	-.198 .208	.034 .445	.105 .334	-.250 .151	.421 .036	-.172 .240	1.00		
14. Plant and equipment utilization	.086 .363	.310 .098	.126 .304	.341 .077	.025 .460	-.170 .244	-.117 .316	.241 .161	-.174 .239	.170 .244	.092 .354	.254 .147	.021 .466	1.00	
15. Work in process inventory	.247 .154	.174 .238	.511 .013	.256 .145	.061 .402	.471 .021	-.002 .497	.575 .005	.053 .416	-.114 .321	-.128 .301	-.087 .361	.005 .493	.357 .067	1.00

Notes: (coefficient/significance.) Number of cases: 19.

TABLE 24

PEARSON CORRELATION COEFFICIENTS
SIC 39

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Production standards	1.00														
2. Priority determination	-.106 .333	1.00													
3. Delivery dates determination	-.132 .295	.381 .054	1.00												
4. Material requirements planning	.333 .081	.017 .472	.133 .293	1.00											
5. Routing information	.126 .304	-.089 .359	-.194 .214	.346 .074	1.00										
6. Capacity utilization	.299 .107	.209 .195	.385 .052	.099 .343	.030 .452	1.00									
7. Backlog measurement	.231 .171	.157 .261	-.120 .312	-.210 .194	.195 .212	.376 .056	1.00								
8. Total intensity score	.594 .004	.355 .068	.287 .117	.597 .004	.416 .038	.670 .001	.458 .024	1.00							
9. Delivery dates performance	.530 .010	-.138 .286	-.154 .265	.417 .038	.207 .197	.280 .123	.145 .277	.465 .022	1.00						
10. Lead times	.003 .496	.053 .415	.083 .368	.034 .445	-.195 .212	-.034 .445	-.473 .020	-.152 .267	.265 .136	1.00					
11. Subcontract work	-.337 .079	-.057 .408	.061 .401	.003 .496	-.525 .011	-.444 .028	-.614 .003	-.541 .008	-.093 .352	.351 .070	1.00				
12. Direct labor overtime	-.281 .122	-.138 .287	-.216 .187	.021 .466	.005 .492	-.304 .103	-.210 .194	-.296 .109	-.017 .473	.234 .167	.305 .102	1.00			
13. Direct labor efficiency	.310 .098	-.040 .435	-.357 .067	-.155 .263	-.062 .401	-.130 .298	-.006 .490	.047 .424	.243 .159	-.037 .440	.166 .248	-.351 .071	1.00		
14. Plant and equipment utilization	-.082 .370	.052 .416	-.218 .185	-.151 .268	.629 .002	.027 .456	.222 .181	.098 .344	.325 .087	.114 .321	-.390 .049	.285 .119	-.087 .361	1.00	
15. Work in process inventory	.085 .364	.010 .484	.008 .487	-.356 .067	.136 .289	.340 .077	.258 .143	.091 .356	.017 .473	.020 .468	-.256 .145	-.030 .452	.209 .195	.330 .084	1.00

Notes: (coefficient/significance.) Number of cases: 19.

Priority determination (an intensity variable) had a -0.516 correlation coefficient with subcontract work (an effectiveness variable). Delivery dates determination (an intensity variable) had a 0.423 correlation coefficient with subcontract work and a 0.473 correlation coefficient with direct labor overtime (both effectiveness variables). Routing information (an intensity variable) had a 0.405 correlation coefficient with subcontract work and a 0.605 correlation coefficient with plant and equipment utilization (both effectiveness variables). Capacity utilization (an intensity variable) had a 0.521 correlation coefficient with direct labor efficiency (an effectiveness variable). Backlog measurement (an intensity variable) had a 0.343 correlation coefficient with delivery dates performance (an effectiveness variable). Total intensity score had a 0.420 correlation coefficient with delivery dates performance, a 0.450 correlation coefficient with plant and equipment utilization, and a -0.470 correlation coefficient with work in process inventory (all effectiveness variables).

Table 23 relates to the nineteen respondents that are classified under electrical and electronic machinery, equipment, and supplies (SIC 36). For this group there were six significant correlations between intensity and effectiveness variables. Work in process inventory (an effectiveness variable) had a 0.511 correlation coefficient with delivery dates determination, a 0.471 correlation coefficient with capacity utilization, and a 0.575 correlation coefficient with total intensity score (all intensity variables). Table 24 relates to the nineteen respondents that are classified under miscellaneous manufacturing industries (SIC 39). For this group ther were nine significant correlations between intensity and effectiveness variables. Delivery dates performance (an effectiveness variable) had a 0.530 correlation coefficient with production standards, a 0.417 correlation coefficient with material requirements planning, and a 0.465 correlation coefficient with total intensity score (all intensity variables). Subcontract work (an effectiveness variable) had a -0.525 correlation coefficient with routing information, a -0.444 correlation coefficient with capacity utilization, a -0.614 correlation coefficient with backlog measurement, and a -0.541 correlation coefficient with total intensity score (all intensity variables).

<u>Multiple Linear Regression</u>

Multiple linear regression is used to analyze the relationship between a single dependent variable and several independent variables. In this study the seven intensity variables were regressed against each of the seven effectiveness variables. As a result, seven regressions were performed. Three of the regressions did not yield any significant findings at the 0.05 level. The other four regressions yielded very limited amounts of significant findings. The results are presented in tables 25 through 28.

TABLE 25

MULTIPLE LINEAR REGRESSION DEPENDENT VARIABLE:
DELIVERY DATES PERFORMANCE

Step	Variable Added	Multiple R	R Square	Degrees of Freedom		F	B Values in Final Equation
				Regression	Residual		
1	Material requirements planning	.358	.128	1	117	17.23**	1.17

* $p < .05$.
** $p < .01$.

TABLE 26

MULTIPLE LINEAR REGRESSION DEPENDENT VARIABLE:
DIRECT LABOR OVERTIME

Step	Variable Added	Multiple R	R Square	Degrees of Freedom		F	B Values in Final Equation
				Regression	Residual		
1	Capacity utilization	.183	.033	1	117	4.081*	-.40

* $p < .05$.
** $p < .01$.

TABLE 27

MULTIPLE LINEAR REGRESSION DEPENDENT VARIABLE:
DIRECT LABOR EFFICIENCY

Step	Variable Added	Multiple R	R Square	Degrees of Freedom		F	B Values in Final Equation
				Regression	Residual		
1	Production standards	.258	.066	1	117	8.38**	1.41

* $p < .05$.
** $p < .01$.

TABLE 28

MULTIPLE LINEAR REGRESSION DEPENDENT VARIABLE:
PLANT AND EQUIPMENT UTILIZATION

Step	Variable Added	Multiple R	R Square	Degrees of Freedom		F	B Values in Final Equation
				Regression	Residual		
1	Backlog measurement	.263	.069	1	117	8.73**	-.34
2	Routing information	.324	.105	2	116	6.83**	.58

* $p < .05$.
** $p < .01$.

Material requirements planning explained 12.8 percent of the delivery dates performance variance (table 25). Capacity utilization explained only 3.3 percent of the direct labor overtime variance (table 26). Production standards explained 6.6 percent of the direct labor efficiency variance (table 27). Backlog measurement explained 6.9 percent and routing information an additional 3.6 percent of the plant and equipment utilization variance (table 28).

Cross-Tabulation

In addition to using quantitative statistical tools a more qualitative descriptive analysis of the data is also useful. Figures 1 through 15 present the distribution of participants' scores on each of the seven intensity variables, the total intensity score and the seven effectiveness variables. Tables 29 and 30 contain a classification of the scores by two of the three demographic characteristics. Classification by the Standard Industrial Code (SIC) is not presented. Due to the large number of categories in this factor findings were meaningless. As far as size (number of employess) is concerned, the medium plants scored most effective in three out of seven categories. Those plants had the highest intensity scores in four out of seven categories and in the total intensity score (table 29). In the type of operation classification the manufacture to stock only plants scored most effective in four out of seven categories (table 30).

Each of tables 31, 32, and 33 present a classification of the respondents by a pair of demographic characteristics. These tables clearly demonstrate the fact that the number of observations in the cells is very disproportional. This had created some difficulty in interpretation of analysis of variance designs. A major cause of the difficulty originated from the fact that the SIC factor had twenty categories. A meaningful way for subgrouping categories could not be found. Helpful information about the questionnaire response frequencies is contained in appendix F.

As time frame is concerned, all measurements were related to current conditions. An attempt was made though to provide a limited dynamic dimension to the study. While all variables utilized questions to provide current measurement, two effectiveness variables were equipped with two questions each. The two questions were designed to provide measurement of the past as well as present conditions. The effectiveness variables involved are the subcontract work and the direct labor overtime. For the subcontract work variable, question VIII D related to the current year while question VIII C related to the year before. For the direct labor overtime variable the questions were VIII F and VIII E respectively. Two tests of significance for the scores means, one for each variable, resulted in the conclusion that there was no significant difference between the score means in the two time periods.

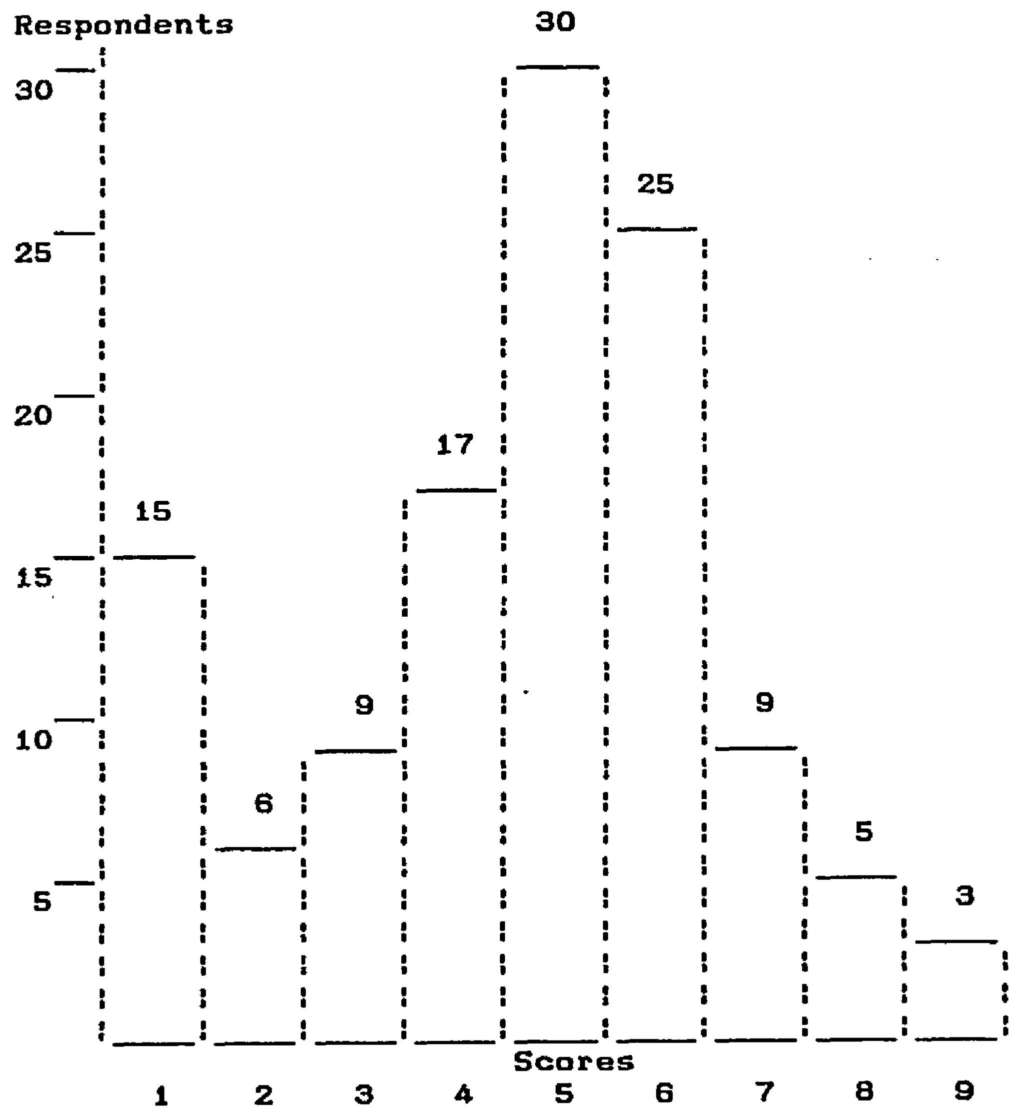

Fig. 1. Distribution of scores for the production standards variable (mean = 4.639; median = 5.000; skewness = -0.264).

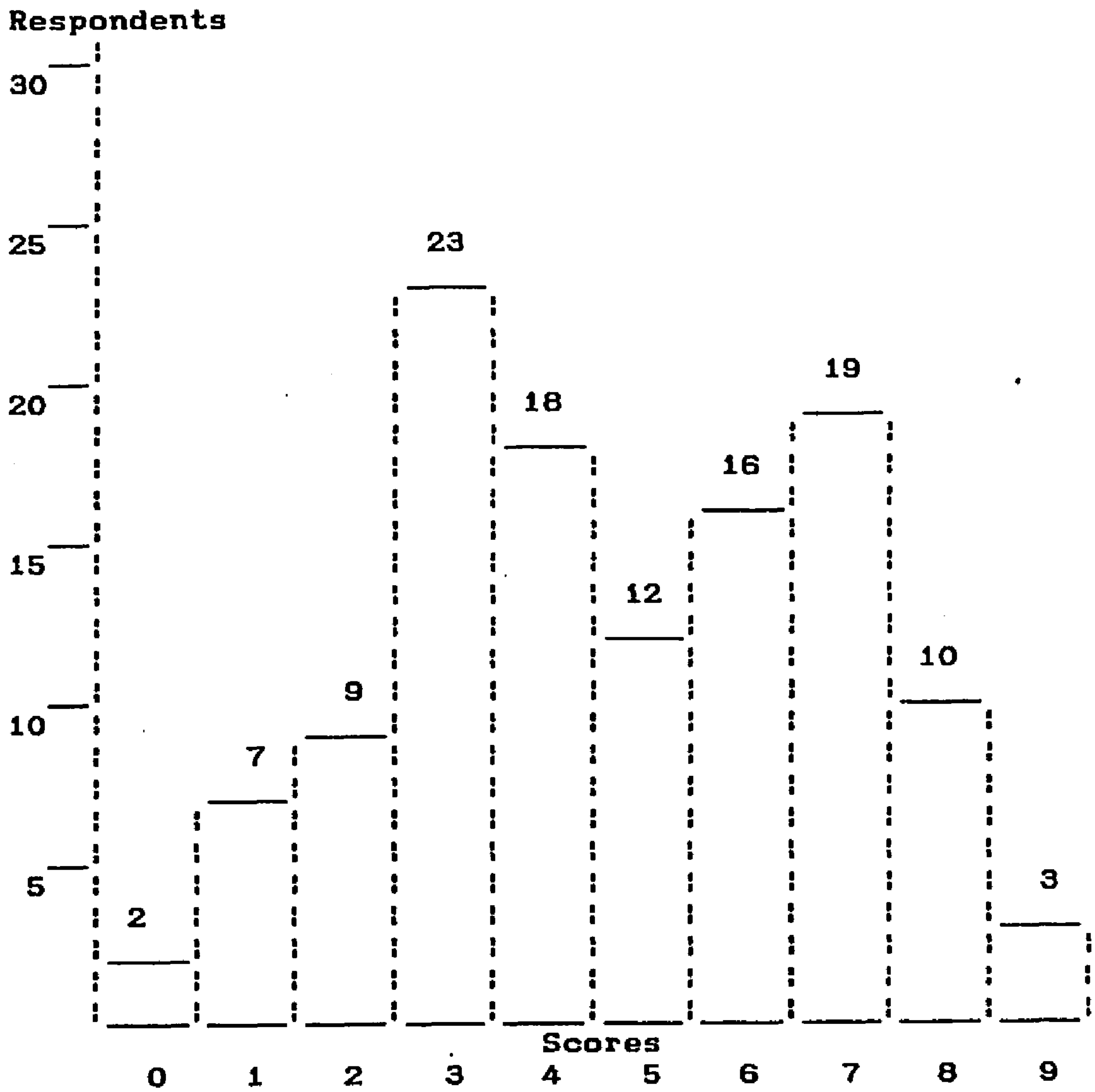

Fig. 2. Distribution of scores for the priority determination variable (mean = 4.723; median = 5.000; skew-ness = -0.027).

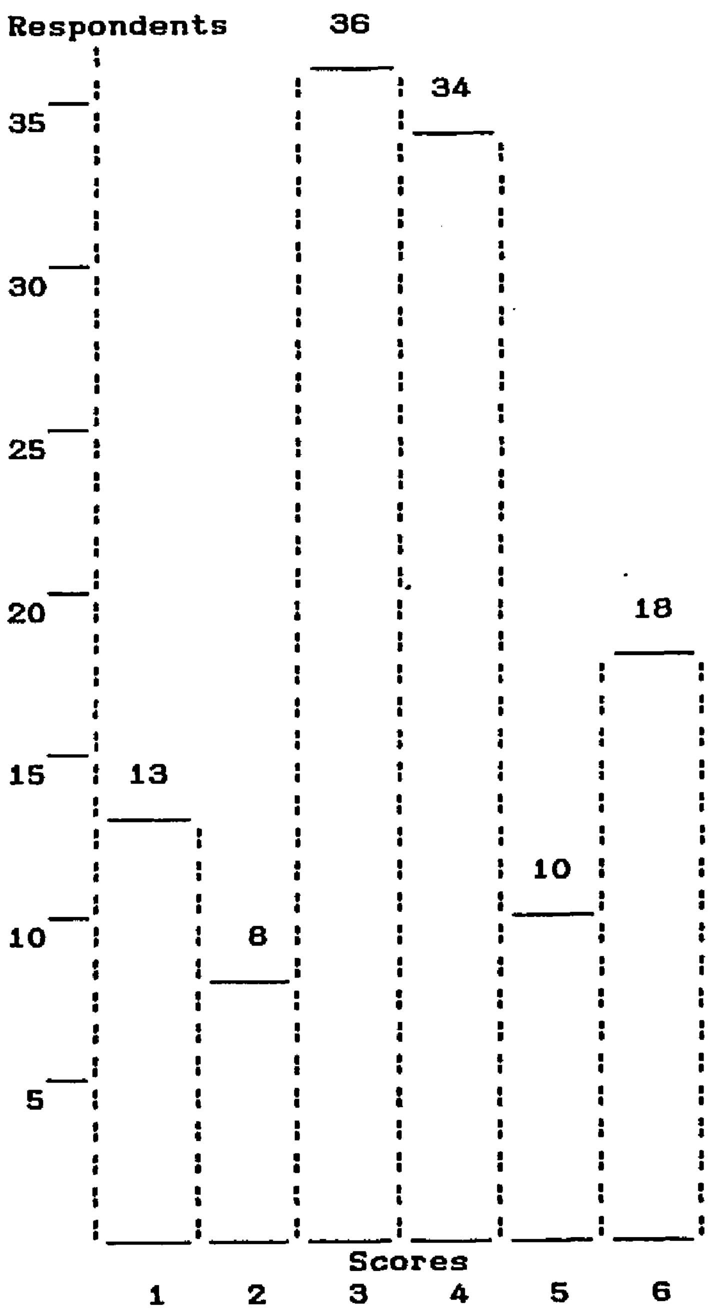

Fig. 3. Distribution of scores for the delivery dates determination variable (mean = 3.622; median = 4.000; skewness = -0.019).

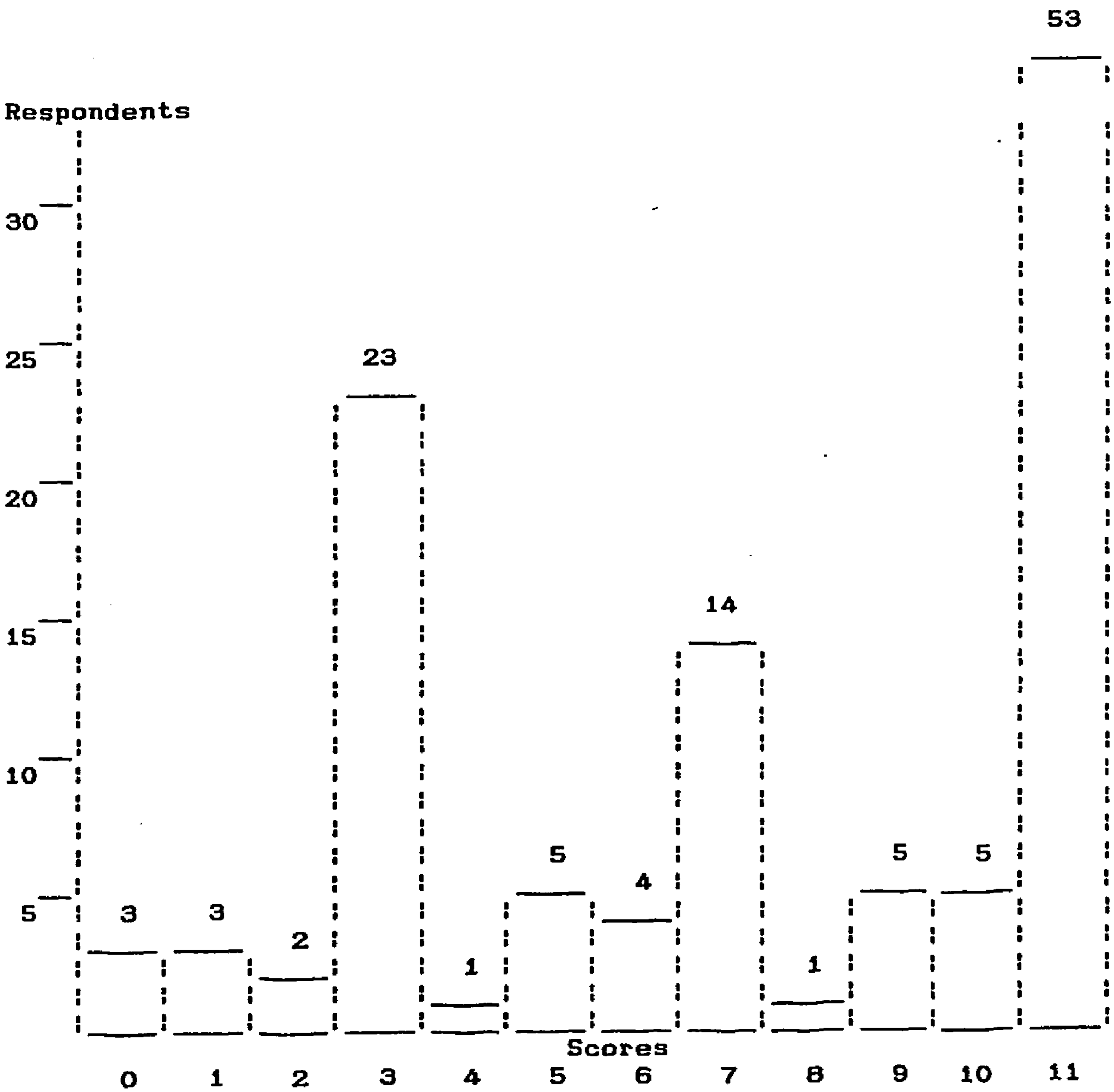

Fig. 4. Distribution of scores for the material requirements planning variable (mean = 7.672; median = 9.000; skewness = -0.552).

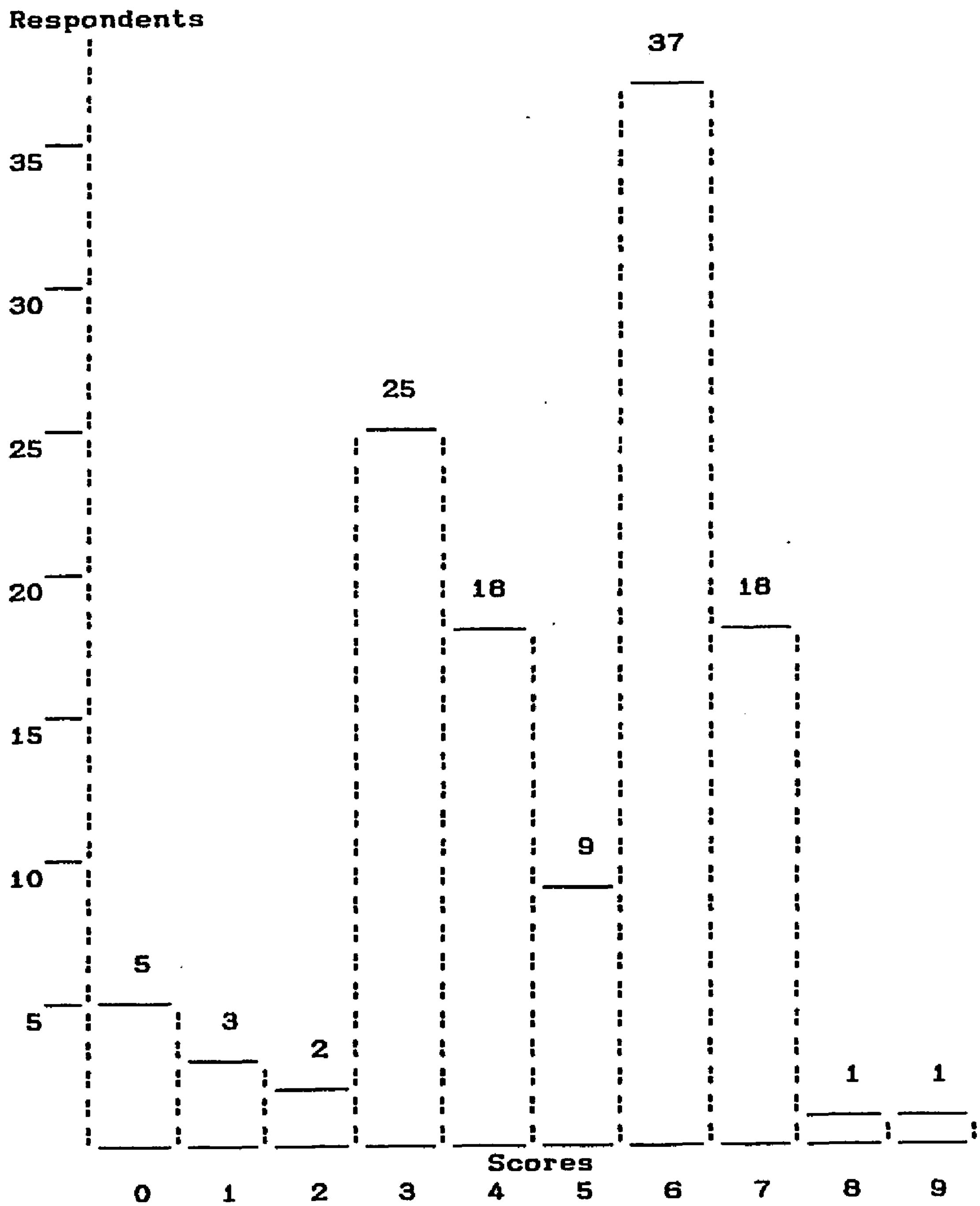

Fig. 5. Distribution of scores for the routing information variable (mean = 4.739; median = 5.000; skewness = -0.264).

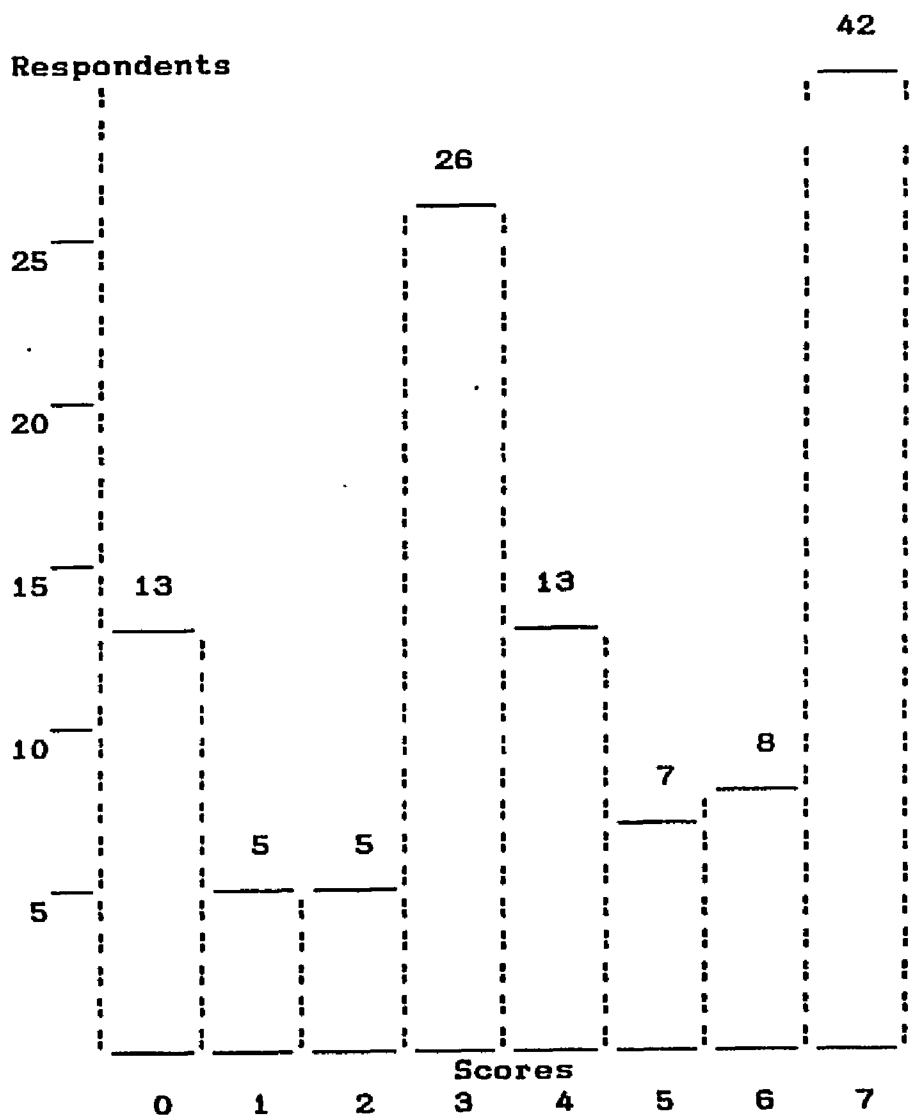

Fig. 6. Distribution of scores for the capacity utilization variable (mean = 4.387; median = 4.000; skewness = -0.386).

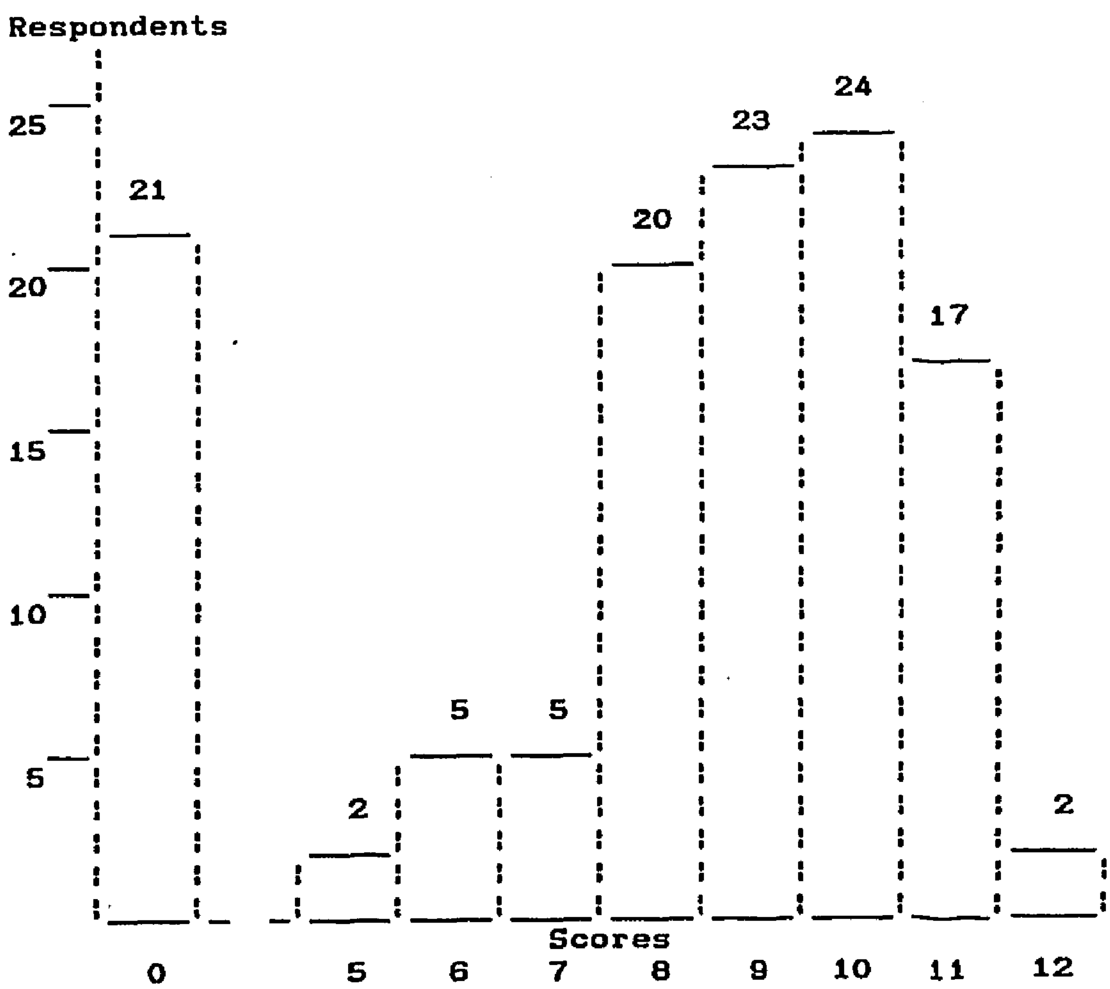

Fig. 7. Distribution of scores for the backlog measurement variable (mean = 7.504; median = 9.000; skewness = -1.233).

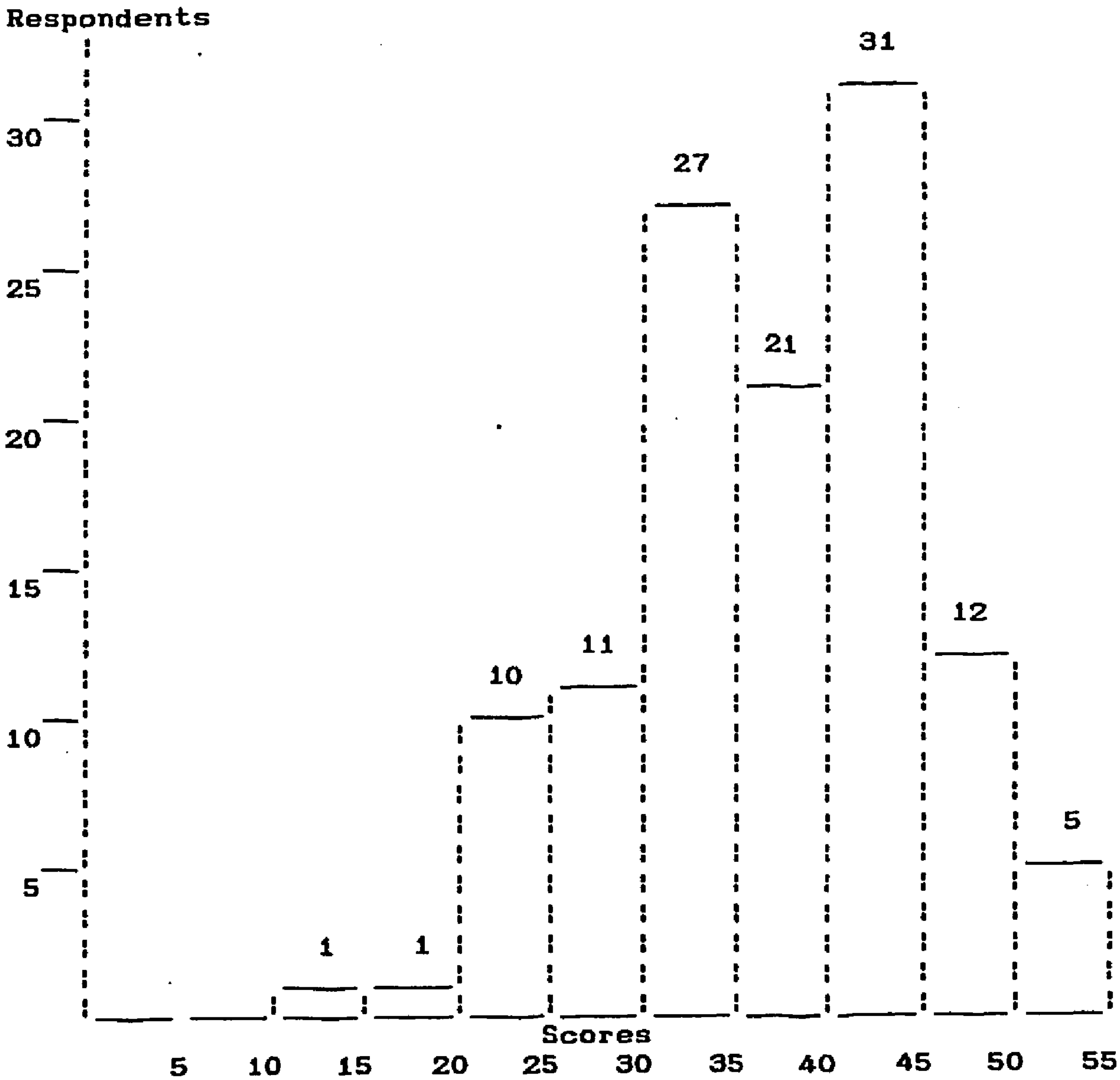

Fig. 8. Distribution of scores for the summation of the seven capacity management intensity variables (mean = 37.286; median = 38.000; skewness = -0.371).

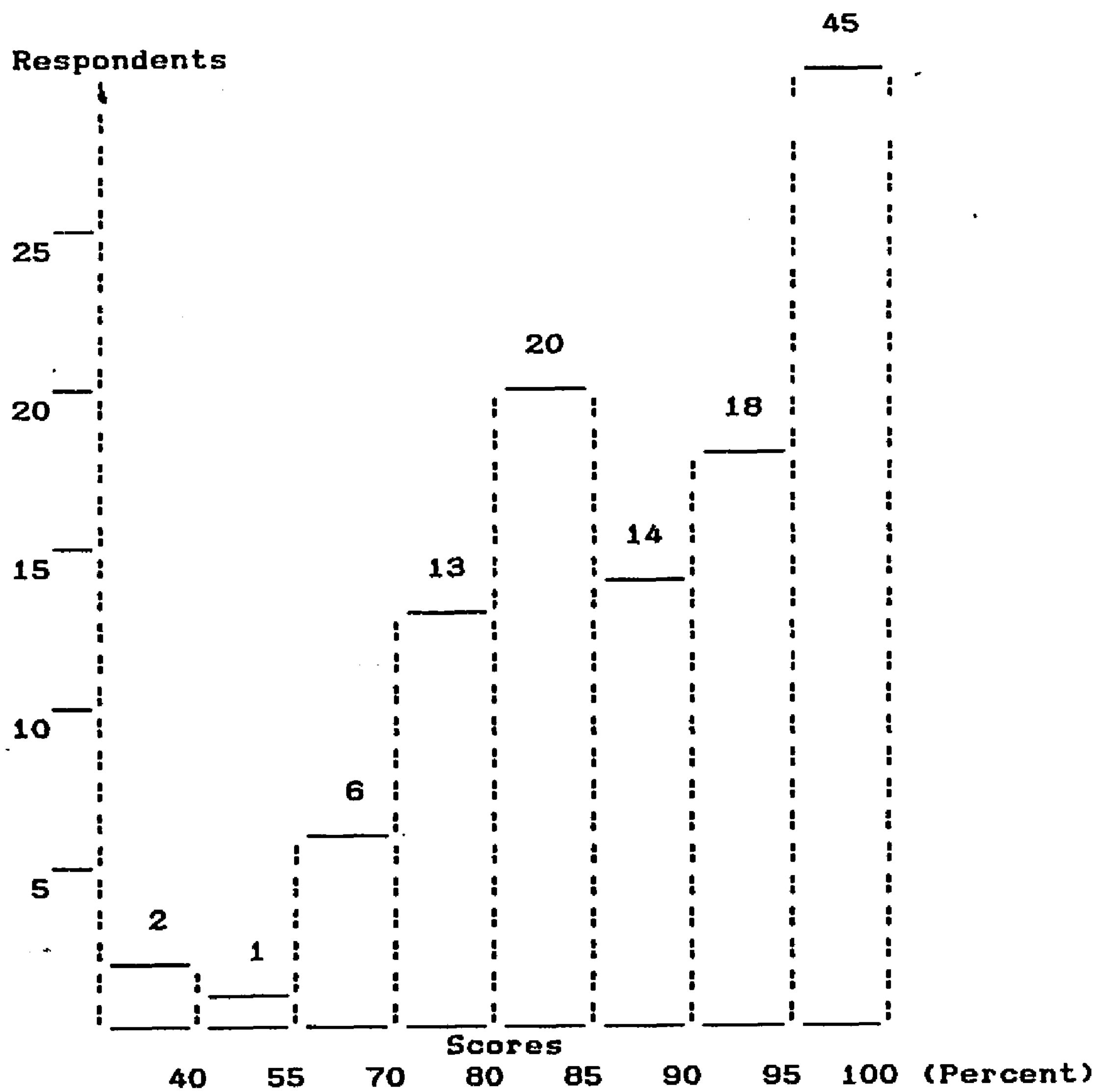

Fig. 9. Distribution of scores for the delivery dates performance variable (mean = 87.487; median = 93.000; skewness = -1.796).

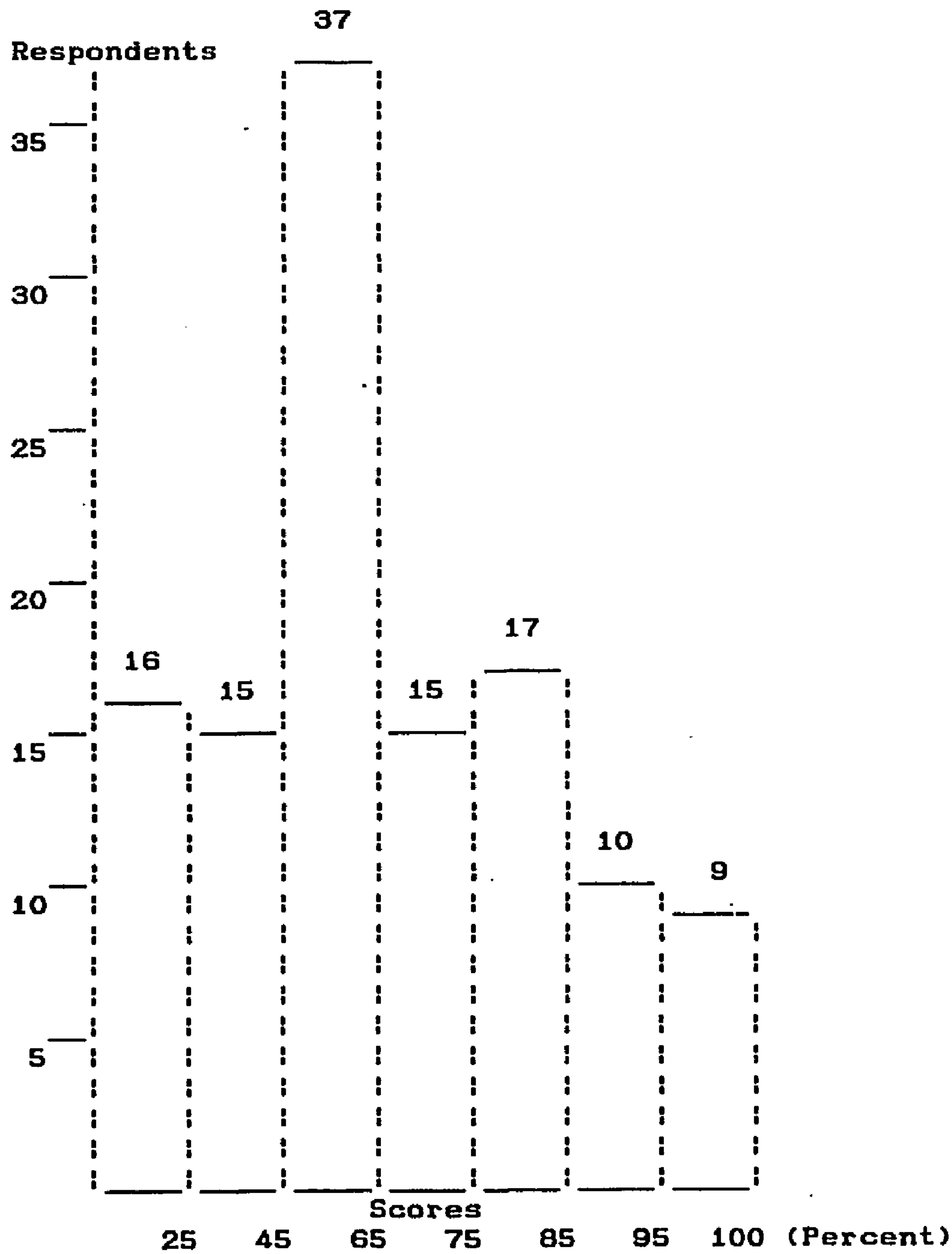

Fig. 10. Distribution of scores for the lead times variable (mean = 60.025; median = 55.000; skewness = -0.040).

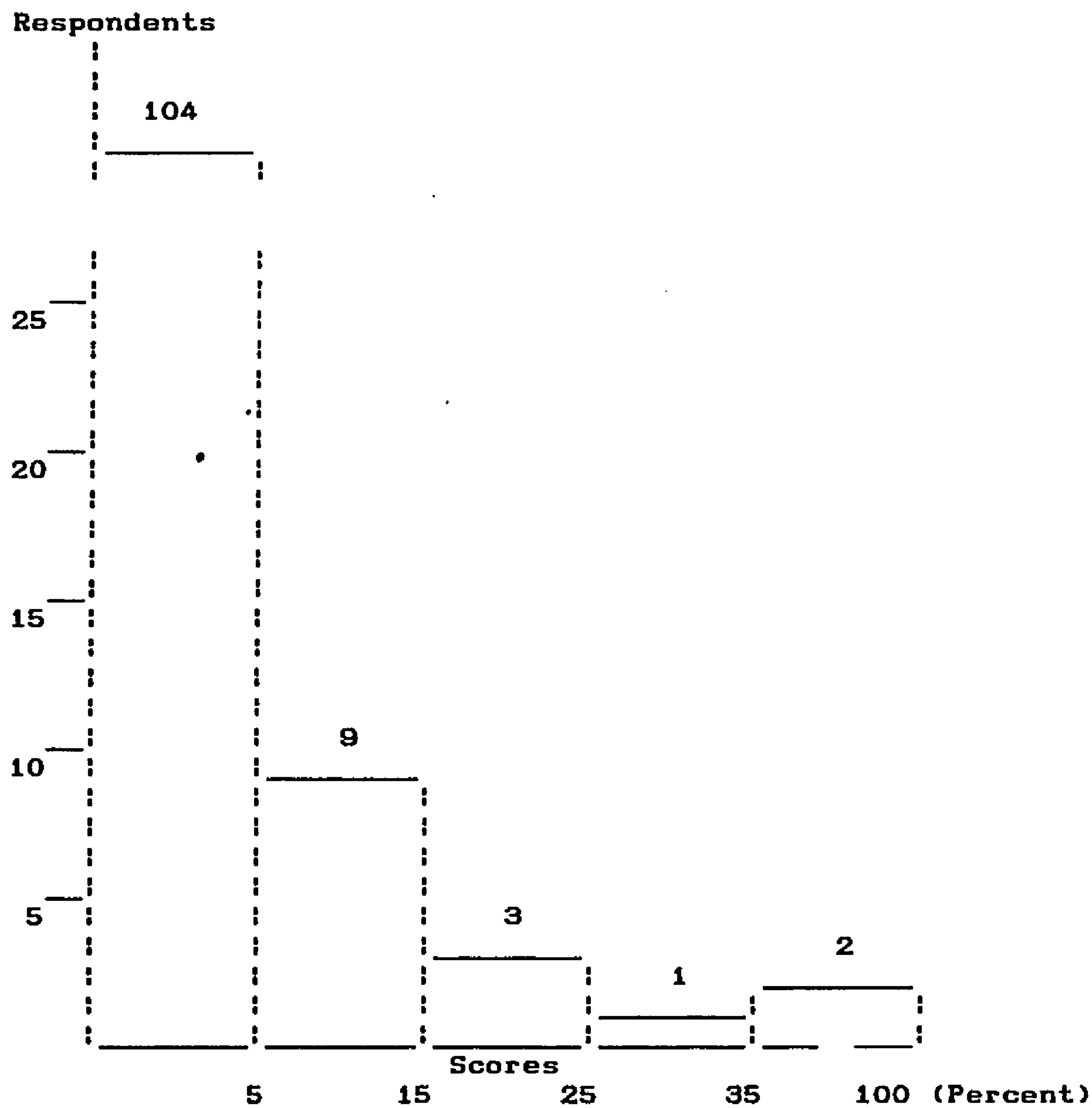

Fig. 11. Distribution of scores for the subcontract work variable (mean = 7.008; median = 5.000; skewness = 6.091).

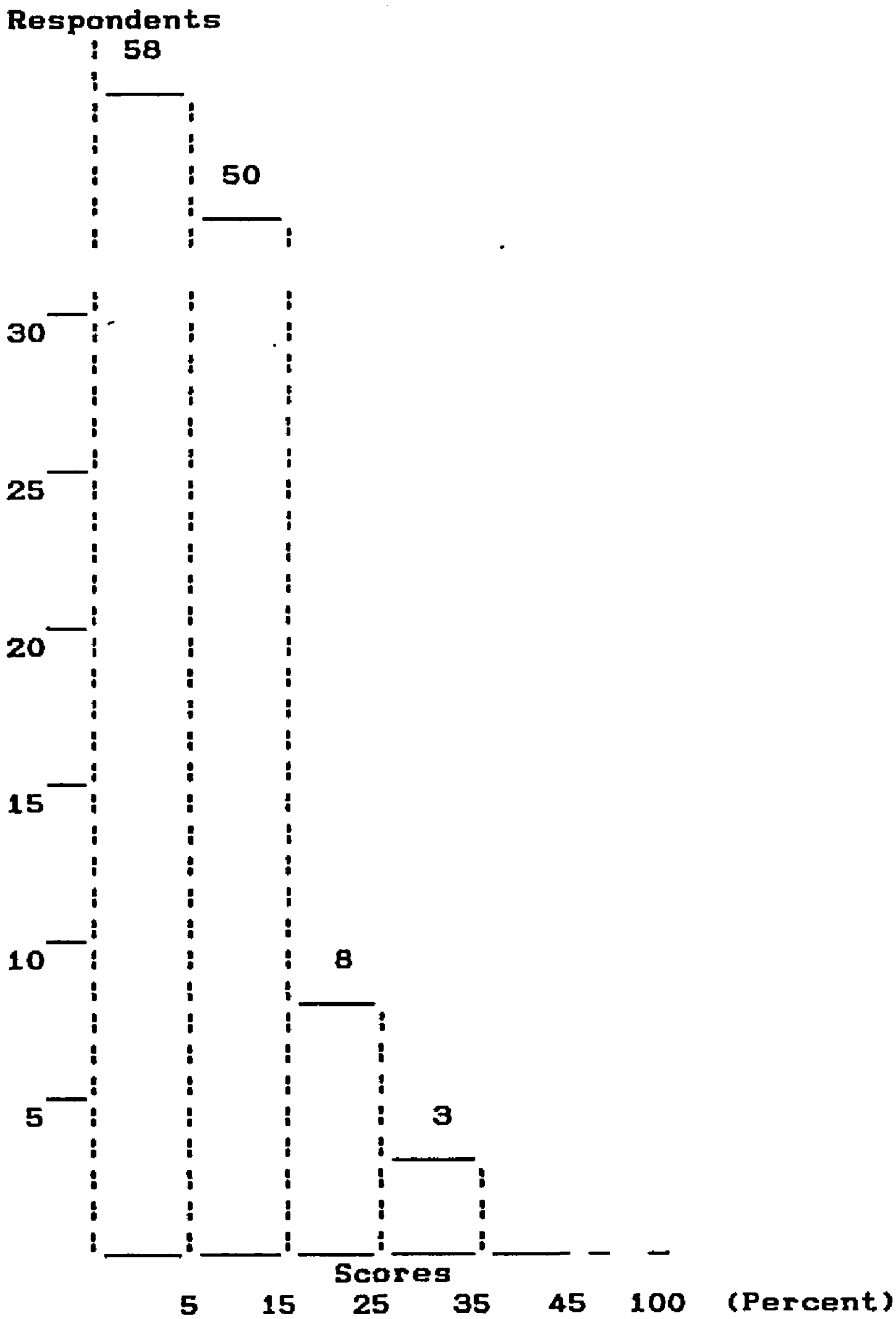

Fig. 12. Distribution of scores for the direct labor overtime variable (mean = 8.739; median = 10.000; skewness = 2.214).

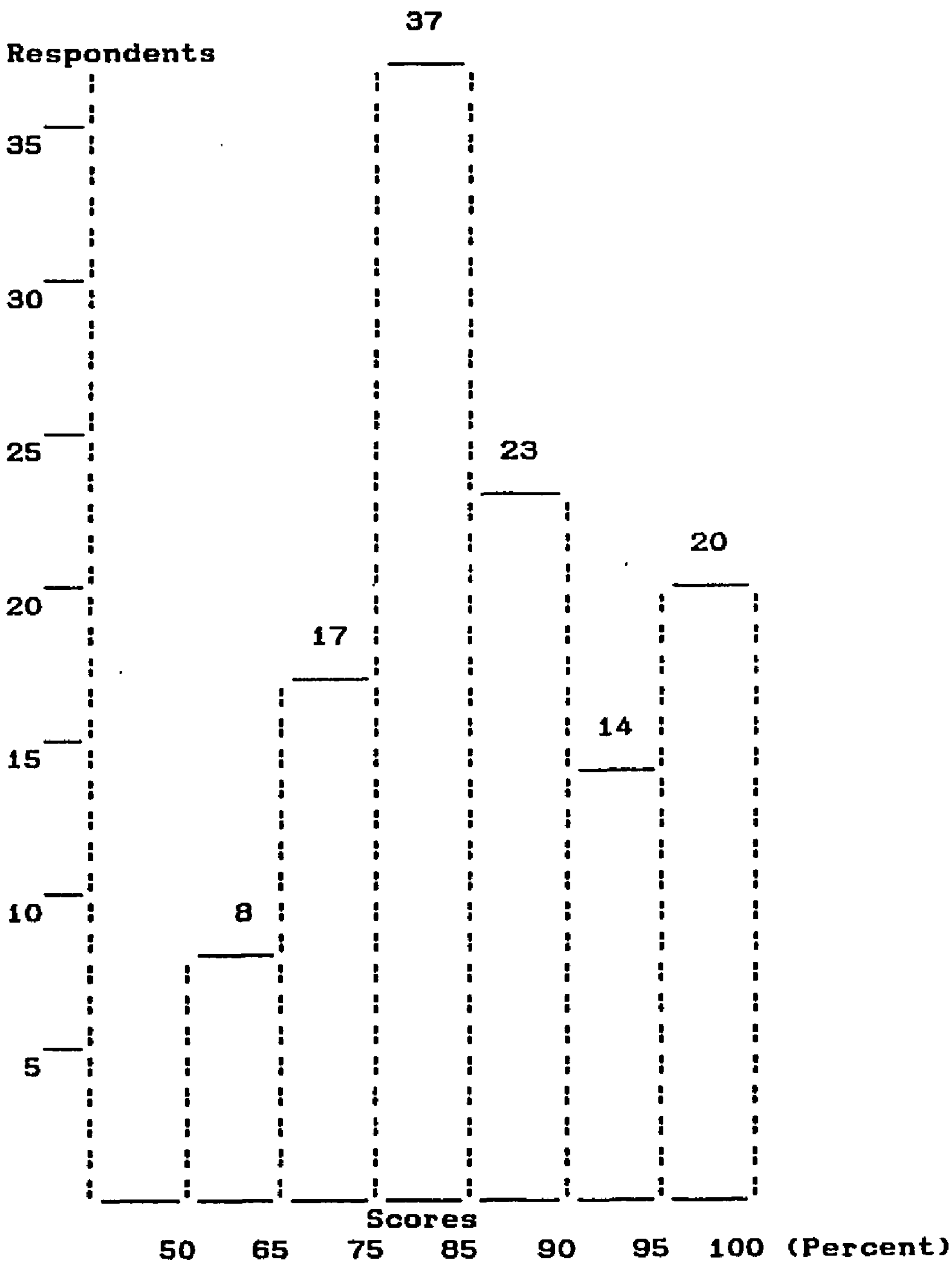

Fig. 13. Distribution of scores for the direct labor efficiency variable (mean = 82.958; median = 80.000; skewness = -0.666).

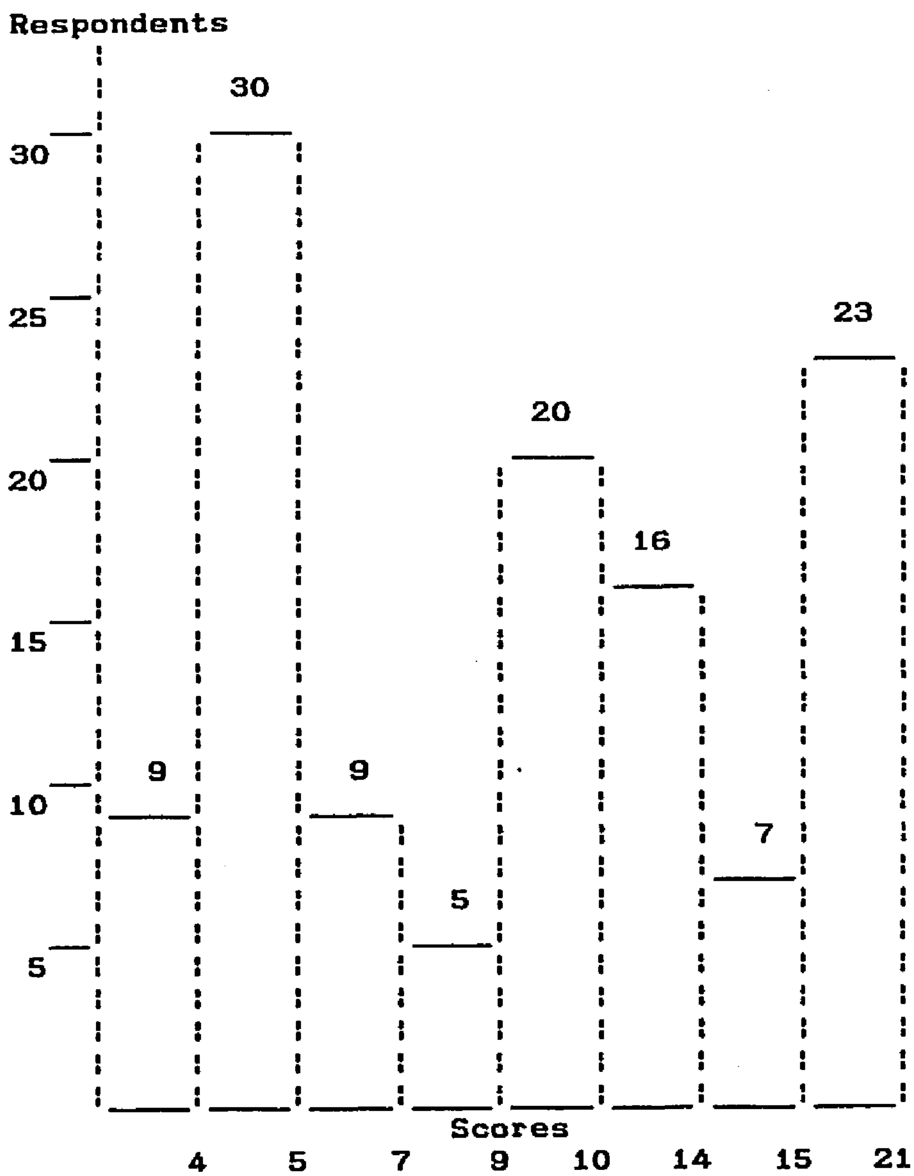

Fig. 14. Distribution of scores for the plant and equipment utilization variable (mean = 9.933; median = 10.000; skewness = 0.387).

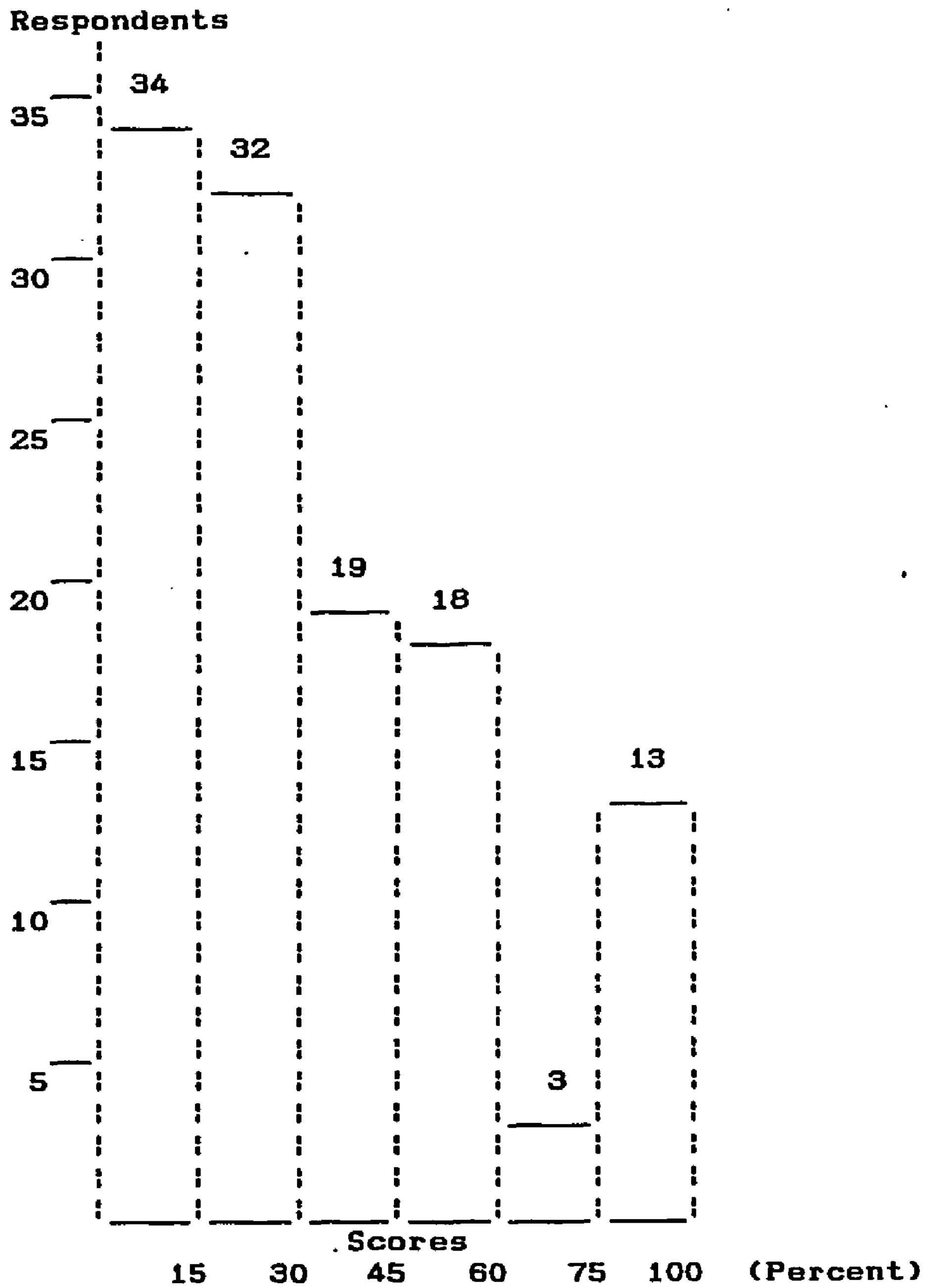

Fig. 15. Distribution of scores for the work in process inventory variable (mean = 35.504; median = 22.000; skewness = 1.109).

TABLE 29

SCORES CLASSIFIED BY NUMBER OF EMPLOYEES

Variable	500 to 1000	1001 to 1500	1501 to 2000	2001 to 2500	Over 2500
Production standards	4.63 1-9	3.20 1-5	5.00 4-6	7.25 6-9	4.00 2-7
Priority determination	4.75 0-9	3.20 1-7	7.00 6-8	5.00 2-9	4.17 2-8
Delivery dates determination	3.55 1-6	4.20 1-6	5.00 4-6	3.75 2-6	3.50 1-6
Material requirements planning	7.49 0-11	7.80 0-11	9.67 7-11	9.50 7-11	8.50 7-11
Routing information	4.74 0-8	3.80 3-6	5.33 3-9	4.25 3-7	5.50 3-7
Capacity utilization	4.36 0-7	5.00 2-7	7.00 7-7	3.25 0-7	3.83 1-7
Backlog measurement	7.21 0-11	6.60 0-10	10.00 8-12	10.00 8-11	10.33 8-12
Total intensity score	36.73 12-53	33.80 28-42	49.00 45-51	43.00 32-49	39.83 32-47
Delivery dates performance	89.90 40-97	87.40 75-97	94.00 88-97	90.25 83-97	92.33 83-97
Lead times	58.46 25-97	78.40 55.97	65.00 35-80	71.75 55-97	60.83 25-80
Subcontract work	6.55 5-67	17.40 5-67	5.00 5-5	5.00 5-5	8.33 5-20
Direct labor overtime	8.42 5-30	14.00 5-30	8.33 5-10	11.25 5-20	8.33 5-10
Direct labor efficiency	83.19 57-97	76.80 57-97	85.33 80-88	90.50 88-93	78.00 70-88
Plant and equipment utilization	9.81 3-18	10.80 5-18	6.67 5-10	10.50 5-15	12.50 5-18
Work in process inventory	35.20 15-87	34.60 22-53	48.00 38-53	26.25 15-53	41.33 15-87
Number of cases	101	5	3	4	6

Note: (Mean/Minimum-Maximum)

TABLE 30

SCORES CLASSIFIED BY TYPE OF OPERATION

Variable	Mfg. to Stock Only	Mfg. to Order Only	Mfg. to Stock and to Order
Production standards	3.83 1-7	4.18 1-7	4.89 1-9
Priority determination	3.50 0-7	4.82 1-9	4.78 0-9
Delivery dates determination	2.83 1-6	3.73 1-6	3.64 1-6
Material requirements planning	10.33 7-11	8.09 0-11	7.30 0-11
Routing information	5.00 3-6	4.79 0-9	4.70 0-8
Capacity utilization	4.33 3-7	4.94 0-7	4.16 0-7
Backlog measurement	5.33 0-10	8.09 0-11	7.43 0-12
Total intensity score	35.17 22-45	38.64 25-53	36.89 12-51
Delivery dates performance	94.67 83-97	88.15 40-97	86.68 40-97
Lead times	53.33 25-80	60.12 25-97	60.49 25-97
Subcontract work	17.00 5-67	7.18 5-67	6.19 5-30
Direct labor overtime	6.67 5-10	9.70 5-30	8.50 5-30
Direct labor efficiency	87.67 80-97	81.27 57-97	83.30 57-97
Plant and equipment utilization	7.17 5-15	10.21 3-18	10.03 3-18
Work in process inventory	29.33 15-87	41.94 15-87	33.31 15-87
Number of cases	6	33	80

Note: (Mean/Minimum-Maximum)

TABLE 31

RESPONDENTS CLASSIFIED BY A TWO-DIGIT STANDARD INDUSTRIAL CODE AND NUMBER OF EMPLOYEES

Two-digit Standard Industrial Code	Number of Employees				
	500 to 1000	1001 to 1500	1501 to 2000	2001 to 2500	Over 2500
20	8	2	1		
21					
22	3				
23	9				
24	1				
25	2				
26	1				
27	1		1		
28	4				
29	1				
30	3				
31	1				
32	2				
33	8	1			
34	17			1	
35	3			1	
36	11	2	1	2	3
37	7				2
38	1				
39	18				1

TABLE 32

RESPONDENTS CLASSIFIED BY A TWO-DIGIT STANDARD INDUSTRIAL CODE AND TYPE OF OPERATION

Two-digit Standard Industrial Code	TYPE OF OPERATION MANUFACTURE		
	To Stock Only	To Order Only	To Stock and to Order
20	1	2	8
21			
22		1	2
23	3		6
24			1
25			2
26		1	
27		2	
28	1	1	2
29			1
30			3
31			1
32			2
33		3	6
34		7	11
35			4
36	1	8	10
37		4	5
38			1
39		4	15

TABLE 33

RESPONDENTS CLASSIFIED BY NUMBER OF EMPLOYEES AND TYPE OF OPERATION

Number of Employees	TYPE OF OPERATION MANUFACTURE		
	To Stock Only	To Order Only	To Stock and to Order
500-1000	4	24	73
1001-1500	1	3	1
1501-2000		2	1
2001-2500		1	3
Over 2500	1	3	2

In addition to the questions corresponding to the study, personal background information about the participants was gathered. This information is contained in questions IX D through IX G of the questionnaire response frequencies (appendix F). In question IX D, the category "other" was chosen by fifteen respondents. Of those, nine had a formal education in science, while only one had no formal education. In question IX E, thirty-one chose the category "other" that indicated a wide variety of professional associations, a majority of which were represented only once. Those with higher frequency were: ASQC (4), ASPE (3), ASME (2), and The American Foundrymen Society (2). Only nine of the participants indicated in question IX G that they have gained a professional certificate. Six out of the nine certificates were identified as the CPIM, awarded by the American Production and Inventory Control Society. The title was identified by 116 of the 119 respondents. The largest group included sixty-nine individuals who were manufacturing managers at different levels. The remainder included: top management (9), engineering management (8), production control (7), material management (3), quality control (2), and sales (2).

Cross-tabulation of the personal background information versus effectiveness mean scores are presented in Appendix H (tables 44-46).

TABLE 34

ONE-WAY ANALYSIS OF VARIANCE BY DEMOGRAPHIC CHARACTERISTICS

Variable	Number of Employees	Two-Digit (SIC)	Type of Operation
Production standards	--	--	--
Priority determination	--	--	--
Delivery dates determination	--	--	--
Material requirements planning	--	--	--
Routing information	--	--	--
Capacity utilization	--	--	--
Backlog measurement	--	*	--
Delivery dates performance	--	--	--
Lead times	--	--	--
Subcontract work	--	--	--
Direct labor overtime	--	--	--
Direct labor efficiency	--	--	--
Plant and equipment utilization	*	*	--
Work in Process Inv.	--	--	--

* $p < .05$

TABLE 35

TWO-WAY ANALYSIS OF VARIANCE BY DEMOGRAPHIC CHARACTERISTICS

Variable	Source of Variation: By Number of Employees and a Two-Digit Standard Industrial Code			
	Main Effects			Two-Way Interaction
	Joint	Number of Employees	Two-Digit SIC	
Production standards	--	--	--	--
Priority determination	--	--	--	--
Delivery dates (1)	--	--	--	--
Material requirements planning	--	--	--	--
Routing information	--	--	--	--
Capacity utilization	--	--	--	--
Backlog measurement	*	--	--	--
Delivery dates (2)	--	--	--	--
Lead times	--	--	--	--
Subcontract work	--	--	*	*
Direct labor overtime	--	--	--	--
Direct labor efficiency	--	--	--	--
Plant and equipment utilization	*	--	*	--
Work in process inv.	--	--	--	--

* $p < .05$.
Note: (1) = Determination, (2) = Performance

TABLE 36

TWO-WAY ANALYSIS OF VARIANCE BY
DEMOGRAPHIC CHARACTERISTICS

Variable	Source of Variation: By Number of Employees and Type of Operation			
	Main Effects			Two-Way Interaction
	Joint	Number of Employees	Type of Oper.	
Production standards	--	--	--	--
Priority determination	--	--	--	--
Delivery dates (1)	--	--	--	--
Material requirements planning	--	--	--	--
Routing information	--	--	--	--
Capacity utilization	--	--	--	--
Backlog measurement	*	--	--	--
Delivery dates (2)	--	--	--	--
Lead times	--	--	--	--
Subcontract work	*	--	--	*
Direct labor overtime	--	--	*	--
Direct labor efficiency	--	--	--	--
Plant and equipment utilization	--	--	--	--
Work in process inv.	--	--	--	--

* $p < .05$.
Note: (1) = Determination, (2) = Performance

TABLE 37

TWO-WAY ANALYSIS OF VARIANCE BY DEMOGRAPHIC CHARACTERISTICS

Variable	Source of Variation			
	By Type of Operation and a Two-Digit Standard Industrial Code			
	Main Effects			Two-Way Interaction
	Joint	Type of Operation	Two-Digit SIC	
Production standards	--	--	--	--
Priority determination	--	--	--	--
Delivery dates (1)	--	--	*	*
Material requirements planning	--	--	--	--
Routing information	--	--	*	--
Capacity utilization	--	--	--	--
Backlog measurement	*	--	*	--
Delivery dates (2)	--	--	--	--
Lead times	--	--	--	--
Subcontract work	--	--	*	*
Direct labor overtime	--	--	--	--
Direct labor efficiency	--	--	--	--
Plant and equipment utilization	*	--	*	--
Work in process inv.	--	--	--	--

* $p < .05$.
Note: (1) = Determination, (2) = Performance

TABLE 38

THREE-WAY ANALYSIS OF VARIANCE BY DEMOGRAPHIC CHARACTERISTICS

Variable	Source of Variation							
	Main Effects				Two-Way Interactions			Three-Way Interaction
	Joint	Number of Employees	Type of Operation	Two-Digit SIC	No. of Employees by Type of Operation	No. of Employees by a Two-Digit SIC	Type of Operation by a Two-Digit SIC	
Production standards	—	—	—	—	—	—	—	—
Priority determination	—	—	—	—	—	—	—	—
Delivery dates (1)	—	—	*	—	—	—	*	*
Material requirements planning	—	—	—	—	—	—	—	—
Routing information	—	—	—	—	—	—	—	—
Capacity utilization	—	—	—	—	—	—	—	—
Backlog measurement	*	—	—	—	—	—	—	*
Delivery dates (2)	—	—	—	—	—	—	—	—
Lead times	—	—	—	—	—	—	—	—
Subcontract work	—	—	—	*	—	*	—	*
Direct labor overtime	—	—	—	—	*	—	*	—
Direct labor efficiency	—	—	—	—	—	—	—	—
Plant and equipment utilization	*	—	—	*	—	—	*	*
Work in process inventory	—	—	—	—	—	—	—	—

* $p < .05$.
Note: (1) = Determination, (2) = Performance

Analysis of Variance

The material presented in the cross-tabulation section is descriptive and does not lend itself to statistical significance testing. In this section analysis of variance (ANOVA) techniques are utilized to test the cross-tabulation results.

A one-way ANOVA was performed for the fourteen variables (seven intensity variables and seven effectiveness variables) against each of the three demographic characteristics. The results are shown in table 34. The plant and equipment utilization (effectiveness variable) varied significantly by plant size and the two-digit SIC. For the backlog measurement (intensity variable), a significant difference existed only for the two-digit SIC.

In effort to further partition the effects of different demographic characteristics, several multiple factor ANOVA designs were performed. These designs included two-way analyses (tables 35 through 37) and three way analysis (table 38). In these analyses the variables that showed significant variances most frequently were plant and equipment utilization, subcontract work, backlog measurement and delivery dates determination. Except for subcontract work those variables loaded heavy on some of the factors that were extracted in the factor analyses.

As indicated in the cross-tabulation section, the disproportional number of observations in each cell created difficulty in interpretation. The limited findings should be used cautiously.

Synthesis: Capacity Management Intensity

Production Standards

This variable measured the percent of plant operations that were covered by time standards and the techniques utilized to set them.

Distribution

Scores were distributed almost normally with 46 percent of the participants scoring five or six. Skewness was -0.264. Scores were influenced by the type of operation, with manufacture to order scoring the highest.

Association

The variable loaded highest on the capacity planning factor. It had a 0.240 correlation coefficient with material requirements planning (intensity), and a 0.259 correlation coefficient with direct labor effciency (effectiveness). In regression analysis the variable provided a significant explanation for 6.6 percent of the direct labor efficiency variance. In the canonical correlation it had the second highest correlation coefficient of all intensity variables.

Priority Determination

This variable measured the percent of orders to which priority codes are assigned and their frequency of change, identified the priority system/s utilized and the authority assigning them.

Distribution

Scores distribution was rather level in the two to seven range. Skewness was minimal (-0.027). Plant size influenced the scores, with the medium size plants scoring higher than smaller or larger plants.

Association

The variable had a 0.260 correlation coefficient with capacity utilization (intensity). It loaded moderately on both the capacity planning and capacity control factors.

Delivery Dates Determination

This variable measured the percentage of cases in which a customer forecast was sought and identified the method of delivery date determination.

Distribution

Scores distribution was almost normal with 59 percent of the participants scoring three or four. Skewness was negligible (-0.019). Plant size influenced the scores, with a medium size plant scoring highest.

Association

The variable loaded highest on the capacity control factor. It had a 0.195 correlation coefficient with the material requirements planning variable (intensity).

Material Requirements Planning

This variable identified the existence of an MRP system and measured it accuracy.

Distribution

The distribution of scores was trimodel with 76 percent of the participants scoring three, seven, or eleven. Scores were influenced by the plant size with the medium size plants scoring highest and the extreme sizes scoring lowest.

Association

The variable loaded fourth heaviest on the capacity planning factor and third heaviest on the capacity control variable. It had a 0.358 correlation coefficient with delivery dates performance (effectiveness). In the regression analysis it explained 12.8 percent of the delivery dates performance variance. In the canonical correlation it had the highest correlation of all the intensity variables.

Routing Information

This variable measured the availability of routing information and the factors dictating the selection of alternative routings.

Distribution

While the posssible scoring range was zero to nine, 90 percent of the paticipants scored between three and seven. Skewness was -0.264.

Association

The variable loaded second highest on the capacity control factor. It had a 0.211 correlation coefficiant with the plant and equipment utilization variable (effectiveness). In the regression analysis it explained 3.5 percent of the plant and equipment utilization variance.

Capacity Utilization

This variable measured the availability of load information and its use in changing delivery dates.

Distribution

Bunching occured at the extremes and the middle of the scores distribution. Skewness was -0.386. The medium size plant scored higher than the extreme sizes.

Association

The variable loaded third highest on the capacity planning factor. It had a 0.184 correlation coefficient with the direct labor overtime variable (effectiveness). In the regression analysis it explained 3.3 percent of the direct labor overtime variance. The relationship was negative.

Backlog Measurement

This variable measured the use of a backlog as a planning and control tool.

Distribution

The distribution was almost normal, between five and twelve. In addition 18 percent of the participants scored zero. Skewness was negative (-1.223). The scores were influenced by the plant size, with the largest plants scoring highest.

Association

The variable had a 0.264 correlation coeffcient with plant and equipment utilization (effectiveness). In the regression analysis it provided an explanation for 6.9 percent of the plant and equipment utilization variance. The relationship was identified as negative.

Total Intensity Score

This variable was produced by summing all the individual intensity scores and provided an overall measure of intensity.

Distribution

Scoring was almost normally distributed with a minimum score of twelve and a maximum score of fifty-three. Possible minimum was zero while the possible maximum was sixty-eight. The distribution was skewed by -0.371. The medium size plants' total score was higher than those of the smaller or larger plants.

Association

As might be expected, this variable was consistently, significantly correlated with the seven intensity variables.

Synthesis: Manufacturing Effectiveness

Delivery Dates Performance

This variable measured the percent of the time in which promised delivery dates were met.

Distribution

The distribution was skewed (-1.796) so that the frequencies increased as the scores increased. The medium size plants scored higher than the smaller or larger plants.

Association

The variable loaded highest on the manufacturing effectiveness factor. In the canonical correlation it had the highest correlation coefficient of all effectiveness variables. In regression analysis 12.8 percent of its variance was explained by the material requirements planning variable. It had a 0.358 correlation coefficient with the material requirements planning and a 0.159 correlation coeffcient with production standards.

Lead Times

This variable measured the percent of the time in which the respondent's lead times were shorter than those of his competitors.

Distribution

The distribution was rather level except for 31 percent of the paticipants scoring fifty-five. Skewness was at a minimum. The type of operation influenced the scores with the manufacture to stock and to order scoring highest.

Association

The variable loaded third heaviest on the manufacturing effectiveness factor. It had a 0.166 correlation coefficient with delivery dates performance (effectiveness).

Subcontract Work

This variable measured the percentage of output (in dollars) that was subcontracted due to lack of capacity.

Distribution

The distribution was highly concentrated at the lower side of the range with 87 percent of the participants scoring five. Skewness was 6.091. The type of operation influenced the score, with the manufacture to stock and to order scoring most effective.

Association

The variable had a 0.165 correlation coefficient with work in process inventory (effectiveness).

Direct Labor Overtime

This variable measured what percent of total direct labor hours were overtime hours.

Distribution

The distribution was positively skewed (2.214). While no participants scored forty or seventy-two, 49 percent scored five. The medium size plants scored more effective than the larger or smaller plants.

Association

In regression analysis 3.3 percent of the variance in this variable was explained by the capacity utilization variable (intensity). It had a -0.184 correlation coefficient with capacity utilization (intensity), and a 0.165 correlation coefficient with lead times (effectiveness).

Direct Labor Efficiency

This variable measured the overall direct labor efficiency as a ratio between output at standard and actual hours.

Distribution

The distribution was negatively skewed (-0.666) with no participants scoring fifty. The manufacturing to stock only plants scored most effective.

Association

In regression analysis 6.6 percent of the variance in this variable was explained by production standards. This variable had a 0.259 correlation coefficient with production standards (intensity), and a 0.188 correlation coefficient with the delivery dates performance (effectiveness).

Plant and Equipment Utilization

This variable measured the number of weekly shifts of operation.

Distribution

The distribution was positively skewed (0.387). Plant size influenced the scores with the largest plants scoring highest.

Association

The variable loaded second highest on the manufacturing effectiveness factor. In the canonical correlation it had the second highest correlation coefficient of all the effectiveness variables. In regression analysis 6.9 percent of its variance was explained by backlog measurement while an additional 3.5 percent was explained by routing information. This variable had a -0.264 correlation coefficient with backlog measurement (intensity) and a 0.211 correlation coefficient with routing information (intensity).

Work in Process Inventory

This variable measured the percent of total inventory value dedicated to work in process inventory.

Distribution

The distribution was highly concentrated on the lower side of the range with 55 percent of the participants scoring fifteen or twenty-two. Plants manufacturing to stock only scored most effective.

Association

The variable had a 0.165 correlation coefficient with subcontract work (effectiveness).

CHAPTER VI

SUMMARY AND CONTRIBUTIONS

This chapter contains an explanation of the rejection of the null hypothesis. It also presents the conclusions from the survey results and suggestions for additional research.

Hypothesis

The main objective of this study was to examine the relationship between the intensity of short-range and medium-range capacity management and the effectiveness of manufacturing operations. Data were collected to test the null hypothesis:

H_o The intensity of short-range and medium-range capacity management does not influence manufacturing effectiveness.

The results of this research did not adequately support the rejection of the null hypothesis. However, they did definitely identify a distinct group of capacity management intensity variables that influence manufacturing effectiveness in specific cases. A summary of the findings with a managerial orientation are presented below.

Intensity Variables

The intensity variables were placed in three groups that identified how influential they were over the effectiveness measures.

Most Influential

The variables in this group were: production standards and material requirements planning. They were identified as such by all the different statistical analyses that were performed. The indication for the manufacturing manager is to concentrate on improvements in these areas.

Moderately Influential

Members of this group were: the routing information and the capacity utilization variables.

Least Influential

The intensity variables placed in this group were: priority determination, delivery dates determination, and backlog measurment.

Effectiveness Variables

The effectiveness variables were divided into three groups. The groups identify the level at which the variables were influenced by the intensity variables. A higher level of influence should indicate to the manufacturing manager that he can exercise a better level of contol.

Highly Influenced

The variables identified in this group were the plant and equipment utilization and delivery date performance.

Plant and Equipment Utilization

Plants with a higher plant and equipment utilization rate had significantly better routing information, a finding that is intuitively clear. Those plants were also found to use backlog as a capacity planning tool less extensively, a finding that is not intuitively clear. It is possible that a higher rate of plant and equipment utilization represents two different things: a greater absorption of overhead but a less efficient operation. The factor analysis, canonical correlation, and Pearson correlation supported the placing of the variable in this group.

Delivery Dates Performance

For participating plants, those having a better delivery date performance were significantly advanced in their production standards and material requirements planning system. The factor analysis, canonical correlation, and Pearson correlation supported the placing of the variable in this group.

Moderately Influenced

The variables that were placed in this group were direct labor efficiency and direct labor overtime. The factor analysis and canonical correlation supported the placing of the variables in this group. For plants that are not labor intensive this should not create a problem.

Least Influenced

This group was comprised of the following variables: subcontract work, lead times, and work in process inventory. It is possible that these variables were subject to control not only by manufacturing management but by forces from other corporate functions.

Demographic Characteristics

In regard to the type of operation and plant size, findings were not only significant but could also be implemented, subject to mainly external but also some internal constraints.

Type of Operation

Participating plants that manufacture to stock only, were identified as the most effective in four out of the seven categories. The other two types of operation were less effective probably due to the fact that they react to the market more than they act.

Number of Employees

The optimum plant size, as far as effectiveness, was the medium size. The larger and smaller plants were less effective. This finding supports the concept of diseconomy of scale beyond an optimum range, not only in regard to the production function but the management function as well.

Two-Digit Standard Industrial Code (SIC)

Due to the large number of categories, no significant findings could be presented.

Future Research

The geographic expansion of this research to a national survey may prove beneficial. At the same time, the number of SIC's should be substantially reduced. Certain variable scales should be altered in order to achieve better proportionality of observations per cells. As a result seveal surveys could be put into action--one for each group of SIC's that exhibit similarity in their operation.

Additional research could also include monetary measures. It will facilitate a cost/benefit analysis. This will ultimately enable a construction of a quantitative model for the purpose of finding the point of optimal capacity management costs and manufacturing effectiveness benefits could be identified.

APPENDIX A

NORTH TEXAS STATE UNIVERSITY
P.O. BOX 13677
DENTON, TEXAS 76203-3677

DEPARTMENT OF MANAGEMENT
COLLEGE OF BUSINESS ADMINISTRATION

March 26, 1986

Dear Manufacturing Manager:

We are conducting a study of the capacity management function and its influence on manufacturing effectiveness. The American economy will stand or fall on the strength of its manufacturing sector.

Please take fifteen minutes to complete the enclosed questionnaire. You will find the survey interesting, I believe, and of value to you and your company. By completing and returning the questionnaire you will be making a significant contribution to this study and to management literature in an area of key importance. A stamped addressed reply envelope is enclosed for your convenience.

All replies will be held in strict confidence. Only summary information will be reported and no individual or firm will be identified. A summary of the results of this study will be mailed to all the participants at no cost.

Only a limited number of companies have been asked to participate in this study, therefore your response is highly important. I appreciate your time and effort in support of this study and would like to thank you in advance.

Sincerely,

Joseph Yehudai

JY:oy

Encls: Questionnaire
Reply Envelope

AC 817-565-3140 • DALLAS-FT. WORTH METRO 267-2832

APPENDIX B

NORTH TEXAS STATE UNIVERSITY
P.O. BOX 13677
DENTON, TEXAS 76203-3677

DEPARTMENT OF MANAGEMENT
COLLEGE OF BUSINESS ADMINISTRATION

May 5, 1986

Dear Manufacturing Manager:

We are conducting a study of the capacity management function and its influence on manufacturing effectiveness. The American economy will stand or fall on the strength of its manufacturing sector. This research is underway now and you may have a copy of the results without cost just by providing some information about your own operation. Only a limited number of companies have been asked to participate in this study, therefore your response is highly important.

Please take fifteen minutes to complete the enclosed questionnaire. You will find the survey interesting, I believe, and of value to you and to your company. By completing and returning the questionnaire you will be making a significant contribution to this study and to management literature in an area of key importance. If you've already participated, thank you. If you have not yet had a chance to respond, I would be most grateful if you would do so now.

All replies will be held in strict confidence. Only summary information will be reported and no individual or firm will be identified.

I appreciate your time and effort in support of this study and would like to thank you in advance. A stamped addressed reply envelope is enclosed for your convenience.

Sincerely,

Joseph Yehudai

JY:oy

Encls: Questionnaire
Reply Envelope

AC 817-565-3140 • DALLAS-FT. WORTH METRO 267-2832

APPENDIX C

NORTH TEXAS STATE UNIVERSITY
P.O. BOX 13677
DENTON, TEXAS 76203-3677

DEPARTMENT OF MANAGEMENT
COLLEGE OF BUSINESS ADMINISTRATION

June 24, 1986

We are conducting a study of the capacity management function and its influence on manufacturing effectiveness. The American economy will stand or fall on the strength of its manufacturing sector. This research is underway now and you may have a copy of the results without cost just by providing some information about your own operation. Only a limited number of companies have been asked to participate in this study, therefore your response is highly important.

Please take fifteen minutes to complete the enclosed questionnaire. You will find the survey interesting, I believe, and of value to you and to your company. By completing and returning the questionnaire you will be making a significant contribution to this study and to management literature in an area of key importance. If you've already participated, thank you. If you have not yet had a chance to respond, I would be most grateful if you would do so now.

All replies will be held in strict confidence. Only summary information will be reported and no individual or firm will be identified.

I appreciate your time and effort in support of this study and would like to thank you in advance. A stamped addressed reply envelope is enclosed for your convenience.

Sincerely,

Joseph Yehudai

JY:oy

Encls: Questionnaire
Reply Envelope

AC 817-565-3140 • DALLAS-FT. WORTH METRO 267-2832

APPENDIX D

QUESTIONNAIRE RESPONSE VALUES

SURVEY OF CAPACITY MANAGEMENT PRACTICE

I. PRODUCTION STANDARDS

A. What percent of your plant operations are covered by production time standards? (check one)

0 Less than 25%
1 Between 25 and 50%
2 Between 51 and 75%
3 Over 75%

B. Which of the following techniques are used in your company to set production standards? (check all that apply)

1 Time study
1 Standard data
1 Predetermined motion times
1 Historical records
1 Work sampling
1 Other:______________

II. PRIORITY DETERMINATION

A. What percent of customer orders are assigned a priority level/code? (check one)

0 Less than 25%
1 Between 25 and 50%
2 Between 51 and 75%
3 Over 75%

B. What type of priority system is utilized in your company? (check all that apply)

1 Dynamic-critical ratios
1 Dynamic-order size
1 Static-customer size
1 Other:______________
1 Other:______________

C. Do you regularly change a priority level/code as market conditions dictate, after an order has been released to the shop?

2 Yes
0 No

D. Who has the final authority in assigning a priority level/code? (check one)

1 Sales Dept.
3 Manufacturing Dept.
2 Jointly by Sales Dept. and Mfg. Dept
1 Top management
1 Other:______________

III. DELIVERY DATES

A. In most cases, delivery dates are promised based on: (check one)

1 Customer request
2 Available capacity
3 Customer request subject to available capacity
1 Other:______________

B. What percent of the time do you seek and obtain from your customers, a forecast or an early warning of their requirements to help you better meet their needs? (check one)

_0_ Less than 25%
_2_ Between 51 and 75%
_1_ Between 25 and 50%
_3_ Over 75%

IV. MATERIAL REQUIREMENTS PLANNING

A. Does your company use a material requirements planning system, (MRP)? (check one)

_4_ Yes
_2_ Currently implementing
_0_ No

B. Does your company's capacity planning system directly interface with its material requirements planning system, (MRP)? (check all that apply)

_4_ Yes
_0_ Do not have an MRP system
_0_ No
_0_ Do not have a capacity planning system

C. For what percent of your plant's products (as measured in dollars) do you have an accurate bill of materials? (check one)

_0_ Less than 25%
_2_ Between 51 and 75%
_1_ Between 25 and 50%
_3_ Over 75%

V. ROUTING INFORMATION

A. For what percent of your plant's products/components, (as measured in dollars) do you have routing information or operations sequence? (check one)

_0_ Less than 25%
_2_ Between 51 and 75%
_1_ Between 25 and 50%
_3_ Over 75%

B. Are alternate sequences or alternate routing an integral part of your planning system?

_2_ Yes
_0_ No

C. Which of the following factors dictates a selection of alternate sequences? (check all that apply)

_1_ Order size
_1_ Other:________________
_1_ Capacity availability
_1_ Other:________________

VI. CAPACITY UTILIZATION

A. For what percent of your plant's work centers do you generate a load profile or load information? (check one)

_0_ Less than 25%
_2_ Between 51 and 75%
_1_ Between 25 and 50%
_3_ Over 75%

B. Do you sometimes change customers' delivery dates in order to improve capacity utilization?

4 Yes 0 No

VII. BACKLOG

A. Do you use a measure of your plant's back log as a capacity planning tool?

4 Yes 0 No

B. If your answer to A was yes, what decisions are made based on your backlog? (check all that apply)

1 Capacity expansion decisions
1 Authorizing overtime
1 Authorizing subcontract work
1 Reduction of workforce
1 Transfer employees between departments
1 Increase in workforce
1 Planning vacations
1 Other:________
1 Other:________

VIII. MANUFACTURING EFFECTIVENESS

A. What percent of the time does your company meet promised delivery dates? (check one)

40 Less than 40% of the time
47 Between 40 and 55%
63 Between 56 and 70%
75 Between 71 and 80%
83 Between 81 and 85%
88 Between 86 and 90%
93 Between 91 and 95%
97 Over 95%

B. What percent of the time are your company's actual lead times shorter than those of your competitors? (check one)

25 Less than 25% of the time
35 Between 25 and 45%
55 Between 46 and 65%
70 Between 66 and 75%
80 Between 76 and 85%
90 Between 86 and 95%
97 Over 95%

C. What percent of the total output, (in dollars) that you could normally produce internally has been subcontracted last year due to lack of capacity? (check one)

5 Less than 5%
10 Between 5 and 15%
20 Between 16 and 25%
30 Between 26 and 35%
62 Over 35%

D. What percent of total output, (in dollars) that you could normally produce internally is currently subcontracted due to lack of capacity? (check one)

5 Less than 5%
10 Between 5 and 15%
20 Between 16 and 25%
30 Between 26 and 35%
62 Over 35%

E. What percent of total direct labor hours were overtime hours last year? (check one)

5 Less than 5% of total direct hours
10 Between 5 and 15%
20 Between 16 and 25%
30 Between 26 and 35%
40 Between 36 and 45%
72 Over 45%

F. What percent of total direct labor hours currently, are overtime hours? (check one)

5 Less than 5% of total direct hours
10 Between 5 and 15%
20 Between 16 and 25%
30 Between 26 and 35%
40 Between 36 and 45%
72 Over 45%

G. Please estimate your company's overall direct labor productivity or efficiency. (Direct labor productivity is defined as: $\frac{\text{TOTAL STANDARD TIME}}{\text{TOTAL ACTUAL TIME}}$ or $\frac{\text{OUTPUT(at STANDARD)}}{\text{ACTUAL HOURS}}$

If information of this kind is not readily available from routine reports, work sampling or other sources, please use your judgment.)(check one)

50 Less than 50% productivity
57 Between 50 and 65%
70 Between 66 and 75%
80 Between 76 and 85%
88 Between 86 and 90%
93 Between 91 and 95%
97 Over 95%

H. On the average, how many 8 hour shifts per week does your plant operate? (round to the nearest whole number)

3 Less than 5 shifts
5 5 shifts
6 Between 6 and 7 shifts
8 Between 8 and 9 shifts
10 10 shifts
12 Between 11 and 14 shifts
15 15 shifts
18 More than 15 shifts

I. What percent of the total inventory value is dedicated to work in process inventory? (Total Inventory=Raw material inventory + Work in process inventory + Finished goods inventory.) (check one)

15 Less than 15% of total inventory
22 Between 15 and 30%
38 Between 31 and 45%
53 Between 46 and 60%
68 Between 61 and 75%
82 Over 75%

IX. CLASSIFICATION DATA

A. Please indicate the number of employees at your location.

1 500-1000
2 1001-1500
3 1501-2000
4 2001-2500
5 Over 2500

B. Please choose from the list below a two-digit SIC (Standard Industrial Code) that will best describe your company's major product/s. (choose only one code)

_ _

List of two-digit Standard Industrial Codes (SIC)

20 FOOD AND KINDRED PRODUCTS
21 TOBACCO MANUFACTURERS
22 TEXTILE MILL PRODUCTS
23 APPAREL AND OTHER FINISHED PRODUCTS MADE FROM FABRICS AND SIMILAR MATERIALS
24 LUMBER AND WOOD PRODUCTS, EXCEPT FURNITURE
25 FURNITURE AND FIXTURES
26 PAPER AND ALLIED PRODUCTS
27 PRINTING, PUBLISHING, AND ALLIED INDUSTRIES
28 CHEMICALS AND ALLIED PRODUCTS
29 PETROLEUM REFINING, AND RELATED INDUSTRIES
30 RUBBER AND MISCELLANEOUS PLASTICS PRODUCTS
31 LEATHER AND LEATHER PRODUCTS
32 STONE, CLAY, GLASS, AND CONCRETE PRODUCTS
33 PRIMARY METAL INDUSTRIES
34 FABRICATED METAL PRODUCTS, EXCEPT MACHINERY AND TRANSPORTATION EQUIPMENT
35 MACHINERY, EXCEPT ELECTRICAL
36 ELECTRICAL AND ELECTRONIC MACHINERY, EQUIPMENT, AND SUPPLIES
37 TRANSPORTATION EQUIPMENT
38 MEASURING, ANALYZING AND CONTROLLING INSTRUMENTS; PHOTOGRAPHIC, MEDICAL AND OPTICAL GOODS; WATCHES AND CLOCKS
39 MISCELLANEOUS MANUFACTURING INDUSTRIES

C. Please indicate your type of operation. (check one)

1 Manufacture to stock only
2 Manufacture to order only
3 Manufacture to stock and to order

D. Please indicate your area of formal education. (check all that apply)

__ Business Administration (management, accounting, etc.).
__ Engineering
__ Other: ____________________

E. Please indicate your membership with professional associations. (check all that apply)

__ American Production and Inventory Control Society
__ Institute of Industrial Engineers
__ National Association of Purchasing Management
__ American Management Association
__ Society of Manufacturing Engineers
__ Other:______________________________
__ Other:______________________________

F. Are you aware of a certification program offered by your professional association?

__ Yes __ No

G. If your answer to F was yes, have you gained a certificate such as CPIM awarded by APICS?

__ No
__ Yes; if so specify the certificate and association:

____

H. Please indicate your title.

____

****

Thank you. All information will be held in confidence. A stamped addressed envelope is attached.

To receive the results of this survey, just print the address information below:

Name ____________________ Title ____________________
Company Name ______________________________
Address ______________________________
City ____________,Texas Zip Code ________

(Please make any comments below and return with questionnaire.)

****

APPENDIX E

VARIABLES AND THEIR CORRESPONDING QUESTIONS

Variable	Questions	
Intensity		
1. Production standards	I	A,B
2. Priority determination	II	A,B,C,D
3. Delivery dates determination	III	A,B
4. Material requirements planning	IV	A,B,C
5. Routing information	V	A,B
6. Capacity utilization	VI	A,B
7. Backlog measurement	VII	A,B
Effectiveness		
1. Delivery dates performance	VIII	A
2. Lead times	VIII	B
3. Subcontract work	VIII	D
4. Direct labor overtime	VIII	F
5. Direct labor efficiency	VIII	G
6. Plant and equipment utilization	VIII	H
7. Work in process inventory	VIII	I

APPENDIX F

QUESTIONNAIRE RESPONSE FREQUENCIES

SURVEY OF CAPACITY MANAGEMENT PRACTICE

I. PRODUCTION STANDARDS

A. What percent of your plant operations are covered by production time standards? (check one)

20 Less than 25%
7 Between 25 and 50%
20 Between 51 and 75%
72 Over 75%

B. Which of the following techniques are used in your company to set production standards? (check all that apply)

73 Time study
59 Standard data
37 Predetermined motion times
73 Historical records
40 Work sampling
10 Other:__________

II. PRIORITY DETERMINATION

A. What percent of customer orders are assigned a priority level/code? (check one)

68 Less than 25%
7 Between 25 and 50%
13 Between 51 and 75%
31 Over 75%

B. What type of priority system is utilized in your company? (check all that apply)

29 Dynamic-critical ratios
26 Dynamic-order size
29 Static-customer size
58 Other:__________
3 Other:__________

C. Do you regularly change a priority level/code as market conditions dictate, after an order has been released to the shop?

57 Yes
62 No

D. Who has the final authority in assigning a priority level/code? (check one)

17 Sales Dept.
13 Manufacturing Dept.
52 Jointly by Sales Dept. and Mfg. Dept
21 Top management
16 Other:__________

III. DELIVERY DATES

A. In most cases, delivery dates are promised based on: (check one)

33 Customer request
5 Available capacity
76 Customer request subject to available capacity
5 Other:__________

B. What percent of the time do you seek and obtain from your customers, a forecast or an early warning of their requirements to help you better meet their needs? (check one)

45 Less than 25%
14 Between 51 and 75%
26 Between 25 and 50%
34 Over 75%

IV. MATERIAL REQUIREMENTS PLANNING

A. Does your company use a material requirements planning system, (MRP)? (check one)

74 Yes
11 Currently implementing
34 No

B. Does your company's capacity planning system directly interface with its material requirements planning system, (MRP)? (check all that apply)

65 Yes
23 Do not have an MRP system
30 No
11 Do not have a capacity planning system

C. For what percent of your plant's products (as measured in dollars) do you have an accurate bill of materials? (check one)

4 Less than 25%
12 Between 51 and 75%
5 Between 25 and 50%
98 Over 75%

V. ROUTING INFORMATION

A. For what percent of your plant's products/components, (as measured in dollars) do you have routing information or operations sequence? (check one)

9 Less than 25%
8 Between 51 and 75%
3 Between 25 and 50%
99 Over 75%

B. Are alternate sequences or alternate routing an integral part of your planning system?

63 Yes
56 No

C. Which of the following factors dictates a selection of alternate sequences? (check all that apply)

23 Order size
55 Other:________________
68 Capacity availability
4 Other:________________

VI. CAPACITY UTILIZATION

A. For what percent of your plant's work centers do you generate a load profile or load information? (check one)

26 Less than 25%
13 Between 51 and 75%
12 Between 25 and 50%
68 Over 75%

B. Do you sometimes change customers' delivery dates in order to improve capacity utilization?

20 Yes   49 No

VII. BACKLOG

A. Do you use a measure of your plant's back log as a capacity planning tool?

97 Yes   22 No

B. If your answer to A was yes, what decisions are made based on your backlog? (check all that apply)

63 Capacity expansion decisions
95 Authorizing overtime
46 Authorizing subcontract work
77 Reduction of workforce
82 Transfer employees between departments
86 Increase in workforce
43 Planning vacations
28 Other:________________
3 Other:________________

VIII. MANUFACTURING EFFECTIVENESS

A. What percent of the time does your company meet promised delivery dates? (check one)

2 Less than 40% of the time
1 Between 40 and 55%
6 Between 56 and 70%
13 Between 71 and 80%
20 Between 81 and 85%
14 Between 86 and 90%
18 Between 91 and 95%
45 Over 95%

B. What percent of the time are your company's actual lead times shorter than those of your competitors? (check one)

16 Less than 25% of the time
15 Between 25 and 45%
37 Between 46 and 65%
15 Between 66 and 75%
17 Between 76 and 85%
10 Between 86 and 95%
9 Over 95%

C. What percent of the total output, (in dollars) that you could normally produce internally has been subcontracted last year due to lack of capacity? (check one)

94 Less than 5%
16 Between 5 and 15%
5 Between 16 and 25%
1 Between 26 and 35%
3 Over 35%

D. What percent of total output, (in dollars) that you could normally produce internally is currently subcontracted due to lack of capacity? (check one)

104 Less than 5%
9 Between 5 and 15%
3 Between 16 and 25%
1 Between 26 and 35%
2 Over 35%

E. What percent of total direct labor hours were overtime hours last year? (check one)

33 Less than 5% of total direct hours
66 Between 5 and 15%
19 Between 16 and 25%
1 Between 26 and 35%
0 Between 36 and 45%
0 Over 45%

F. What percent of total direct labor hours currently, are overtime hours? (check one)

58 Less than 5% of total direct hours
50 Between 5 and 15%
8 Between 16 and 25%
3 Between 26 and 35%
0 Between 36 and 45%
0 Over 45%

G. Please estimate your company's overall direct labor productivity or efficiency. (Direct labor productivity is defined as: $\frac{\text{TOTAL STANDARD TIME}}{\text{TOTAL ACTUAL TIME}}$ or $\frac{\text{OUTPUT(at STANDARD)}}{\text{ACTUAL HOURS}}$

If information of this kind is not readily available from routine reports, work sampling or other sources, please use your judgment.)(check one)

0 Less than 50% productivity
8 Between 50 and 65%
17 Between 66 and 75%
37 Between 76 and 85%
23 Between 86 and 90%
14 Between 91 and 95%
20 Over 95%

H. On the average, how many 8 hour shifts per week does your plant operate? (round to the nearest whole number)

9 Less than 5 shifts
30 5 shifts
9 Between 6 and 7 shifts
5 Between 8 and 9 shifts
20 10 shifts
16 Between 11 and 14 shifts
7 15 shifts
23 More than 15 shifts

I. What percent of the total inventory value is dedicated to work in process inventory? (Total Inventory=Raw material inventory + Work in process inventory + Finished goods inventory.) (check one)

34 Less than 15% of total inventory
32 Between 15 and 30%
19 Between 31 and 45%
18 Between 46 and 60%
3 Between 61 and 75%
13 Over 75%

IX. CLASSIFICATION DATA

A. Please indicate the number of employees at your location.

101 500-1000
5 1001-1500
3 1501-2000
4 2001-2500
6 Over 2500

B. Please choose from the list below a two-digit SIC (Standard Industrial Code) that will best describe your company's major product/s. (chooce only one code)

_ _

List of two-digit Standard Industrial Codes (SIC)

20 FOOD AND KINDRED PRODUCTS
21 TOBACCO MANUFACTURERS
22 TEXTILE MILL PRODUCTS
23 APPAREL AND OTHER FINISHED PRODUCTS MADE FROM FABRICS AND SIMILAR MATERIALS
24 LUMBER AND WOOD PRODUCTS, EXCEPT FURNITURE
25 FURNITURE AND FIXTURES
26 PAPER AND ALLIED PRODUCTS
27 PRINTING, PUBLISHING, AND ALLIED INDUSTRIES
28 CHEMICALS AND ALLIED PRODUCTS
29 PETROLEUM REFINING, AND RELATED INDUSTRIES
30 RUBBER AND MISCELLANEOUS PLASTICS PRODUCTS
31 LEATHER AND LEATHER PRODUCTS
32 STONE, CLAY, GLASS, AND CONCRETE PRODUCTS
33 PRIMARY METAL INDUSTRIES
34 FABRICATED METAL PRODUCTS, EXCEPT MACHINERY AND TRANSPORTATION EQUIPMENT
35 MACHINERY, EXCEPT ELECTRICAL
36 ELECTRICAL AND ELECTRONIC MACHINERY, EQUIPMENT, AND SUPPLIES
37 TRANSPORTATION EQUIPMENT
38 MEASURING, ANALYZING AND CONTROLLING INSTRUMENTS; PHOTOGRAPHIC, MEDICAL AND OPTICAL GOODS; WATCHES AND CLOCKS
39 MISCELLANEOUS MANUFACTURING INDUSTRIES

C. Please indicate your type of operation. (check one)

6 Manufacture to stock only
33 Manufacture to order only
80 Manufacture to stock and to order

D. Please indicate your area of formal education. (check all that apply)

78 Business Administration (management, accounting, etc.).
63 Engineering
15 Other: ______________________

E. Please indicate your membership with professional associations. (check all that apply)

23 American Production and Inventory Control Society
21 Institute of Industrial Engineers
4 National Association of Purchasing Management
29 American Management Association
31 Society of Manufacturing Engineers
18 Other: ______
13 Other: ______

F. Are you aware of a certification program offered by your professional association?

65 Yes   35 No

G. If your answer to F was yes, have you gained a certificate such as CPIM awarded by APICS?

54 No
9 Yes; if so specify the certificate and association:

______

H. Please indicate your title.

______

****

Thank you. All information will be held in confidence. A stamped addressed envelope is attached.

To receive the results of this survey, just print the address information below:

Name ______ Title ______
Company Name ______
Address ______
City ______, Texas   Zip Code ______

(Please make any comments below and return with questionnaire.)

****

APPENDIX G

TABLE 39

INTERMEDIARY STATISTICS FROM FACTOR ANALYSIS DETERMINANT AND INVERSE OF FOURTEEN-VARIABLE CORRELATION MATRIX

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Production standards	1.23													
2. Priority determination	-.03	1.19												
3. Delivery dates determination	-.03	.00	1.14											
4. Material requirements planning	-.22	.08	-.24	1.35										
5. Routing information	-.11	-.21	-.08	-.23	1.20									
6. Capacity utilization	-.11	-.29	-.14	-.00	.00	1.22								
7. Backlog measurement	-.18	-.20	-.06	.17	.05	-.04	1.22							
8. Delivery dates performance	-.09	.10	.15	-.53	.11	-.09	-.05	1.42						
9. Lead times	-.06	-.08	-.02	.02	.13	-.06	.17	-.16	1.12					
10. Subcontract work	-.02	.09	-.14	-.05	-.05	.14	.01	.01	.02	1.14				
11. Direct labor overtime	.12	-.02	-.03	-.06	.15	.19	-.21	.05	-.24	-.17	1.21			
12. Direct labor efficiency	-.24	.08	-.07	.10	.05	-.14	.07	-.20	-.11	-.20	.16	1.22		
13. Plant and equipment utilization	.10	.09	-.19	.20	-.33	-.02	.32	-.48	.04	.14	-.25	.10	1.40	
14. Work in process inventory	.07	.10	-.08	-.05	.11	-.15	-.08	.10	.07	-.23	.03	.13	-.14	1.13

Note: Determinant of correlation matrix = .2452015.

TABLE 40

INTERMEDIARY STATISTICS FROM FACTOR ANALYSIS DETERMINANT AND INVERSE OF SEVEN INTENSITY VARIABLES CORRELATION MATRIX

Variable	1	2	3	4	5	6	7
1. Production standards	1.12						
2. Priority determination	-.00	1.15					
3. Delivery dates determination	-.01	.01	1.07				
4. Material requirements planning	-.26	.03	-.10	1.14			
5. Routing information	-.07	-.18	-.11	-.16	1.09		
6. Capacity utilization	-.16	-.29	-.12	-.02	.08	1.12	
7. Backlog measurement	-.15	-.23	-.04	.12	.12	.01	1.09

Note: determinant of correlation matrix = .6911965.

TABLE 41

INTERMEDIARY STATISTICS FROM FACTOR ANALYSIS DETERMINANT AND INVERSE OF SEVEN EFFECTIVENESS VARIABLES CORRELATION MATRIX

Variable	1	2	3	4	5	6	7
1. Delivery dates performance	1.17						
2. Lead times	-.16	1.08					
3. Subcontract work	.00	.04	1.09				
4. Direct labor overtime	.06	-.21	-.18	1.11			
5. Direct labor efficiency	-.21	-.14	-.19	.21	1.14		
6. Plant and equipment utilization	-.34	.03	.10	-.17	.10	1.13	
7. Work in process inventory	.09	.05	-.20	.02	.12	-.09	1.06

Note: Determinant of correlation matrix = .6967155.

TABLE 42

TRANSFORMATION OF MATRICES

Fourteen-Variable Analysis

	1	2	3
Factor 1	.71	.50	.49
Factor 2	.58	-.81	-.03
Factor 3	-.38	-.31	.87

Intensity Variables Analysis

	1	2
Factor 1	.78	.63
Factor 2	-.63	.78

Effectiveness Variables Analysis

	1	2
Factor 1	.88	-.47
Factor 2	.47	.88

Note: The transformation matrix was used to transfer the initial factor matrix to the terminal solution.

TABLE 43

FACTOR SCORE COEFFICIENTS

Variable	Fourteen-Variable Analysis			Intensity Variables Analysis	
	F_1	F_2	F_3	F_1	F_2
Production standards	.38	.02	.03	.30	.21
Priority determination	.14	-.32	.17	-.00	.50
Delivery dates determination	.02	-.07	.40	.35	.04
Material requirements planning	.16	.15	.28	.51	-.12
Routing information	-.03	.01	.36	.39	-.07
Capacity utilization	.28	-.14	.13	.09	.42
Backlog measurement	.13	-.34	-.04	-.20	.47
				Effectiveness Variables Analysis	
				F_1	F_2
Delivery dates performance	.13	.35	.12	.47	-.25
Lead times	.08	.21	-.09	.38	-.12
Subcontract work	-.02	-.04	.15	.00	.11
Direct labor overtime	-.26	.02	.08	.34	.43
Direct labor efficiency	.34	.17	-.12	.06	-.53
Plant and equipment utilization	-.26	.23	.31	.48	.21
Work in process inv.	-.11	-.26	.29	-.06	.39

APPENDIX H

TABLE 44

EFFECTIVENESS MEAN SCORES CLASSIFIED BY AREA OF FORMAL EDUCATION

Variable	Business Administration	Engineering
Delivery dates performance	88.80	86.67
Lead times	61.80	61.16
Subcontract work	6.69	6.19
Direct labor overtime	8.08	9.21
Direct labor efficiency	83.78	82.70
Plant and equipment utilization	9.65	9.52
Work in process inventory	36.73	33.89
Number of cases	78	63

TABLE 45

EFFECTIVENESS MEAN SCORES CLASSIFIED BY MEMBERSHIP WITH PROFESSIONAL ASSOCIATIONS

Variable	SME	AMA	APICS	IIE
Delivery dates performance	88.68	89.52	87.26	87.19
Lead times	59.39	60.79	58.04	61.86
Subcontract work	5.00	8.17	9.65	9.14
Direct labor overtime	9.68	8.10	8.91	10.00
Direct labor efficiency	82.19	84.14	84.09	78.71
Plant and equipment utilization	9.16	10.86	8.83	9.43
Work in process inventory	27.61	38.24	36.30	34.71
Number of cases	31	29	23	21

Note: SME - Society of Manufacturing Engineers, AMA - American Management Association, APICS - American Production and Inventory Control Society, IIE - Institute of Industrial Engineers.

TABLE 46

EFFECTIVENESS MEAN SCORES OF APICS MEMBERS CLASSIFIED BY THOSE WHO HOLD A CERTIFICATE AND THOSE WHO DO NOT

Variable	Members With A Certificate	Members Without A Certificate
Delivery dates performance	87.33	87.24
Lead times	51.67	60.29
Subcontract work	16.17	7.35
Direct labor overtime	10.00	8.53
Direct labor efficiency	90.50	81.82
Plant and equipment utilization	9.67	8.53
Work in process inventory	43.33	33.80
Number of cases	6	17

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