OPERATIONS RESEARCH FOR
SMALL BUSINESS

by

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We accept this thesis as conforming to the
required standard

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July, 1968
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Date ____, 1968
ABSTRACT

This study is concerned with the practicability of using operations research in a small business. For purposes of the study, operations research is regarded as a separate management function for applying scientific methods to the understanding of the operations of goal-directed organizations. A small business is defined with regard to the size of its operations as having a value added of less than five million dollars per year.

An examination of recent surveys demonstrates that operations research is a prevalent, growing and valuable management aid in large and medium sized companies. They also provide evidence that OR is not used extensively in small business. On the other hand, statistics on business failures and reports of research on the management of small companies provide evidence that small businesses have management problems which possibly could be solved by operations research.

A survey of local small business management was conducted principally to determine the extent to which operations research is used by small companies, the reasons for non-use of OR by most small businesses and the existence of operating problems which might be effectively solved by operations research.
This survey, as well as other evidence indicates that operations research is used to a very limited extent by small business.

The reasons for non-use are: 1) the non-analytical approach of small business management, 2) the managers' lack of familiarity with operations research, 3) the lack of trained personnel, 4) the unavailability of accurate, relevant data, 5) the high cost of leasing and operating electronic computers and 6) the opinion that OR is not economical for small business. This survey and other research has identified small business problems to which OR might effectively be applied.

Retaining consultants is a means of overcoming the lack of trained personnel especially if the small business maintains a continuing relationship with a consultant who has a small, flexible operation and the ability to assist in other management functions. Computer time-sharing and computer service bureaus are inexpensive means of obtaining the computer capability which is often necessary for operations research. Small computers may also be feasible for a small business if it has enough other data processing work.

A case study of a local small business identified sales forecasting, capital budgeting, production scheduling and inventory control as areas in which operations research could possibly contribute towards the Company's goals.
Formulation and testing of decision rules for inventory management and estimation of the costs of an inventory control system for the Company demonstrate that operations research is practical for this small business.
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ACKNOWLEDGEMENTS

A considerable amount of the information for this study was gained in conversations with small business managers, computer service personnel and consultants. The author is particularly indebted to the managers of companies that are represented in the survey who gave up to three hours of their valuable time. No names will be mentioned as many wished to remain anonymous. Mr. Morris Carley of Kates, Peat, Marwick Company, Messrs. W. Tennant and D. Bowman of Computech Consulting Canada Ltd. are consultants who provided valuable information. The personnel at EDP Data Centers, Ltd. and Westcoast Data Processing co-operated as did Messrs. J. Kinvig of Univac and D. MacDonald and J. Laak of IBM.

The author is also indebted to his advisors, Dr. J. Swirles, Professor H. Wilkinson and Professor D. Fields. Having acknowledged the assistance of others, my wife can not be ignored for typing many drafts and providing considerable encouragement.
CHAPTER I
INTRODUCTION

I. THESIS STATEMENT

The increasing interest in operations research by large companies has raised the question of its relevance to small businesses.\(^1,2\) In this regard it is the purpose of this study to examine the following propositions:

1) Small businesses do not generally use operations research as an aid to management.

2) The main reasons why operations research is not used more extensively in small businesses are a lack of knowledge among small business managers as to the scope, techniques and value of OR\(^3\) and the unavailability of competent, trained personnel for doing the operations analysis.

3) Operations research could be used for more effective management of small businesses in many instances.

Both 'operations research' and 'small business' are terms which have rather broad and varied meanings. Therefore they will be defined for purposes of this study.


\(^3\)OR will be used interchangeably with, and, as an abbreviation for operations research.
II. THE DEFINITION OF OPERATIONS RESEARCH

The very fact that so much is written concerning the meaning and scope of operations research suggests that there is considerable confusion as to its definition. Some businessmen and scientists regard it as the application of statistics and common sense to business problems. To many operations researchers, OR is a comprehensive function including many other management services such as systems analysis, market research and industrial engineering. To many staff groups, it is the development of new tools of analysis to be used in their particular area of management service. For instance, accountants claim OR techniques as part of their kit of tools as do industrial engineers and systems analysts. These views of operations research are widely different and hence it can not be said that there is a generally accepted definition of operations research.

Even in the definitions given by authorities in the field of OR there is a considerable divergence. For instance Starr and Miller regard OR as "applied decision theory" and there is much to commend this concept of OR. A simulation

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model is an example in that it tests alternatives to select the one which gives the highest expected reward in terms of organizational goals. However this concept tends to make OR rather broad, for it could then include many aspects of accounting, industrial engineering, etc. On the other hand Stafford Beer regards operational research as the application of science to the analysis of activity, which again is quite broad.

Our purpose here is to define OR as a particular management service in parallel relationship with accounting, systems analysis, finance, industrial engineering and market research, and to determine if, by definition, operations research is applicable to small businesses. The following definition, which probably is not generally accepted, is based on the definitions of Herrman and Magee and Ackoff, leading authorities in the field of OR, and provides a basis for defining the boundaries of operations research as a management service.

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Operations research is, as its name implies, research on the operations of organizations, involving a particular kind of research, a particular view of operations and a definite concept of organizations. Thus it is necessary to define these terms as used in this regard. The 'research' referred to above is the application of the 'scientific method' to discover an underlying mechanism in the system or organization which gives rise to the observed facts. In this context, research is not solely concerned with the formulation of new, generally applicable techniques and the algorisms for their solution, even though this particular aspect occupies by far the greatest proportion of the OR literature. Rather, because for practical purposes each business organization is unique, the research referred to here applies to the study of the interacting variables of a particular system or part of the operation. Specifically, the operations researcher builds a model of the system by the application of scientific techniques, including mathematical manipulation, which is useful for predicting

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9 Herrman, and Magee, op. cit., p. 23

its behaviour under different environments and decision alternatives - a means of clarifying the relationship between actions and their outcomes.\textsuperscript{11} Thus, as Herrman and Magee state; "The application of the scientific attitude and the associated techniques to the study of operations, ---, is what is implied by operations research."\textsuperscript{12}

From Ackoff we learn that, "An 'operation' is a set of acts required for the accomplishment of some desired outcome; that is, it is not a single act but a complex of acts (involving the possibility of choices) performed simultaneously or in sequence, which lead to the accomplishment of some desired outcome."\textsuperscript{13} But OR is not concerned with all types of operations. For instance, the operation of an individual who 'operates' a machine is the concern of industrial engineers, not of operations researchers. Ackoff states that operations research is concerned with


\textsuperscript{12}Herrman, and Magee, \textit{op. cit.}, p. 24.

\textsuperscript{13}Ackoff, \textit{op. cit.}, p. 8 (for a more formal definition of 'operation' see Ackoff, \textit{op. cit.}, pp. 9-10)
the operations of organizations where:

"an organization can be defined as a purposeful system with four essential characteristics:

1) Some of its components are human beings;
2) Responsibility for choices---(alternative) acts is divided among two or more individuals---.
3) The functionally distinct sub-groups are aware of each other's choices either through communication or observation.
4) A sub-group of individuals in the organization has a control function - normally an executive body." 14

This definition suggests that many small businesses would not be suitable subjects for operations research, in that responsibility for choices is not divided and often the same individual or group that exercises the control function also makes all the decisions. In deed, complexity of system or organization is often held as an essential feature of operations research.15,16 Many small businesses consist of an individual proprietor who manages the business by himself. Such a business apparently would not be a suitable subject for operations research. Thus we have

14 Ibid., pp. 11-12
16 Ferrero di Roccaferrera, loc. cit.
placed a lower bound on the 'size' of business to which operations research is applicable. This bound is defined by the existence of more than one functional sub-group which makes decisions affecting the achievement of organizational objectives, and the existence of a control sub-group which compares achieved outcomes with desired outcomes. Any business that does not have these organizational sub-groups we accept as being inappropriate for the application of operations research, based on the above definition of operations research.

III. THE DEFINITION OF SMALL BUSINESS

'Small business' is a term used in a wide variety of contexts and therefore it too has no generally accepted definition. Some authorities have suggested that small business can be generally described in terms of qualitative considerations. For instance:

a) the controlling owners are usually the managers;

b) few, if any specialized professional staff members are available to execute separate management functions;

c) research facilities are lacking;

d) the business is self-dependent (which is not entirely synonymous with independent);

are some of the suggested characteristics of small
businesses. Although these hold as general considerations of this study, a more quantitative definition is deemed necessary.

In the United States, the Small Business Administration (SBA) employs a variety of standards. For government purchasing incentives, a small business generally has less than 500 employees, but it varies depending on the industry. By example, a small business in the flat glass industry has less than 1000 employees. For SBA loan purposes a small business has less than 250 employees although again it varies among industries. For purposes of this study a business is small relative to the large companies employing full-time OR staffs and therefore a 'small business' by our definition may be somewhat larger than for other purposes. Also the measure should approximate the size of the operation and, for this reason, value added has been selected as a measure of size.

To obtain a maximum limit on the value added for a small business, the following calculation is made. If we accept as small a business employing 350 people, approximate the labour cost at $8,000 per man year and

assume that the sum of depreciation, interest, taxes and profit approximately equal labour costs, then a small business will have a value added of five million dollars per year or less.

In this study we are therefore concerned with those businesses which have a value added of less than five million dollars per year, but whose operating decisions are made by more than one person with the knowledge of each others actions and with overall control exercised by a sub-group of the business management.

IV. PURPOSE AND SCOPE OF THIS STUDY

The apparent success of operations research as an aid to planning and control in large organizations has created an interest in applying it to small business management. For instance, the United States Small Business Administration has sponsored research in this area and has also issued a "Technical Aid" on operations research for small business managers.\(^\text{18}\) As regards the local situation, there are many small manufacturers, distributors, and other small businesses in British Columbia

which could perhaps use operations research to increase their viability and growth prospects and therefore assist the development of local secondary industry. In this regard, a number of local consultants have expressed their interest from the point of view of the market for their services in operations research.

With this in mind, it is the purpose of this study to examine the validity of the three propositions stated at the beginning of this chapter. In general, to what extent is operations research feasible for small businesses? Obviously this question can only be answered for a specific situation and therefore much of the following discussion will be concerned with identifying the factors which tend to hinder the successful use of OR by small businesses, and with suggesting how these hindrances might be overcome.

Some evidence to support the suggestion that there is a need for OR in small businesses is provided in the following chapter. This includes statistics on business failures and their causes, and some results of surveys on the extent, growth and value of operations research in industry. Chapter III discusses the results of a survey of local small businesses conducted by the author. To a large extent it deals with the difficulties of using OR in small businesses. Two of these are the lack of trained
personnel, and the high cost of leasing electronic computers. In Chapter IV assessment will be made of the services of consultants and the various methods for obtaining electronic computer capability as means of reducing these difficulties. Finally, a case study of a small manufacturer will be the subject of Chapter V. In particular, the inventory problems of this company are studied from an OR standpoint as an example of the application of operations research to small businesses.
CHAPTER II

THE PREVALENCE OF OR IN INDUSTRY AND THE MANAGEMENT NEEDS OF SMALL BUSINESS

The purpose of this chapter is to determine the degree to which industry has engaged in operations research as an aid to management, and to assess if small businesses have a need for operations research. In other words, an attempt is made to indicate why small business should be interested in operations research. In this chapter we demonstrate by reviewing the results of various surveys that operations research is used by a significant proportion of large companies in Canada, Great Britain, and the United States of America. These surveys also show that operations research may be a useful aid to management and that its importance is growing.

As to whether or not small business requires operations research can only be answered in a particular case (see Chapter V.) However, it was considered that statistics on productivity and profitability as a function of company size and the reasons for the high failure rate of small firms might indicate that small businesses do require management aids such as operations research. The degree to which the readily available literature demonstrates this need will
be discussed in this chapter.

I. OPERATIONS RESEARCH IN INDUSTRY

The importance and growth of operations research in industry since the Second World War has been suggested by surveys of industrial management of which the ones by Hertz\(^1\), Vatter\(^2\), Schumacher and Smith\(^3\), Rivett\(^4\), Robinson\(^5\), and Gander\(^6\), were examined particularly with respect to size of company and the value of the results. Unfortunately, none of the results of the surveys can be assumed to be random samples so that no definite conclusions can be drawn as to the proportion of companies, even of a particular type or

\(^1\)D.B. Hertz, "Progress of Industrial Operations Research in the U.S.," (1957), pp. 455-468


size category, which are engaged in operations research because the mere fact of voluntary response represents a bias. Also, the characteristics of those surveyed were different in each case. However, the surveys do provide evidence that OR is an important and growing activity in industry.

**OR Activity in American Industry**

Table I summarizes the results of three surveys on the extent of OR activity in American companies. In all cases the questionnaires were sent to different populations and the response level was fairly low.

In the survey by Hertz, a questionnaire was sent to 5,325 individuals comprising the entire membership of OR oriented societies and of presidents of American companies with more than one thousand employees. The survey is thus biased by particularly including people who have an obvious interest in OR. Schumacher and Smith's survey included the 168 companies of Fortune's 'Top 500' industrials which were seeking to employ mathematicians and engineers as evidenced by their advertisements in the 1964 United States "College Placement Manual". Obviously
TABLE I
SURVEYS OF THE NUMBER OF AMERICAN

<table>
<thead>
<tr>
<th></th>
<th>Hertz (1957)(^7)</th>
<th>Schumacher and Smith (1964)(^8)</th>
<th>Vatter (1967)(^9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Companies to which questionnaires were sent</td>
<td>3,150</td>
<td>168</td>
<td>3,500</td>
</tr>
<tr>
<td>2. Respondents</td>
<td>631</td>
<td>65</td>
<td>360</td>
</tr>
<tr>
<td>3. Companies</td>
<td>324</td>
<td>49</td>
<td>237 (287)*</td>
</tr>
<tr>
<td>4. Companies planning to use OR</td>
<td>144</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>5. Percent Range of OR users</td>
<td>10-50</td>
<td>30-75</td>
<td>7-65</td>
</tr>
<tr>
<td>6. Subjective Estimate of Percent of OR users</td>
<td>20</td>
<td>60</td>
<td>35</td>
</tr>
<tr>
<td>7. Reported results</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>good</td>
<td>75</td>
<td>not in questionnaire</td>
<td>728**</td>
</tr>
<tr>
<td>fair</td>
<td>55</td>
<td></td>
<td>361**</td>
</tr>
<tr>
<td>poor</td>
<td>not included</td>
<td></td>
<td>52**</td>
</tr>
<tr>
<td>uncertain</td>
<td>167</td>
<td></td>
<td>167**</td>
</tr>
</tbody>
</table>

* includes 'informal' users.

** includes results for each technique used, see Page 17

\(^7\)Hertz, loc. cit.
\(^8\)Schumacher and Smith, loc. cit.
\(^9\)Vatter, loc. cit.
this survey is biased towards very large companies interested in doing quantitative analysis. The companies to which Vatter sent his questionnaire represent the most unbiased population, but unfortunately, he obtained a very poor response. The 3,500 companies surveyed were represented in the Financial Executives Institute by individual managers or as corporate members, the total of which made up the entire membership.

With reference to the contents of Table I, the "Percent Range of OR Users" was obtained on the low side by assuming that none of the non-respondents were engaged in OR and on the upper limit by assuming that the respondents were a random sample of companies included in the survey. The subjective estimate as to the percentage of OR users in the population that was surveyed is by the author based on his study of the results.

The growth of OR activity in The United States is barely discernible from the above surveys even though they cover a ten year period of obviously, rapidly growing interest in OR. Comparison of the Hertz and Vatter surveys does provide some evidence of growth especially considering that the 1957 survey was especially aimed at people obviously interested in OR whereas the 1967 survey was not. Additional evidence of growth is obtained from Vatter's survey which enquired into the length of time the company had been
engaged in OR activity. Of the 237 formal users, only 60 had recognized it as a specific function for more than five year, that is, a great majority of companies have only started using OR formally within the last five years!

The Effectiveness of OR in American Industry

The Hertz and Vatter surveys both enquired as to the respondent's evaluation of the OR work. For assessing results, Hertz suggested phrases such as "appreciable savings" and "too early to tell" so that some interpretation was necessary to make them correspond to Vatter's terms (Table I.) Also the Hertz evaluations apply to OR in general usage by the company whereas Vatter's applies to specific OR techniques, as used by each company. In other words, the numbers under Vatter in Table I represent the total of all techniques as used by all companies. The evaluations were most likely made by respondents to the questionnaire who would generally be in staff positions, rather than by operating managers and therefore they are no doubt biased. Even so, the surveys provide support for other evidence, such as the continuing interest in OR, that operations research is proving effective as an aid to management.

With this evidence of general effectiveness the reasons for non-use of OR is an interesting result of
Vatter's survey in that it approximately parallels evidence for non-use in small businesses as demonstrated in Chapter III. (see Table II). The results show the number of companies which gave each reason. The general area of lack of education is by far the main reason for not using OR.

**TABLE II**

**REASONS FOR NON-USE OF OR**

<table>
<thead>
<tr>
<th>Reason</th>
<th>Number of Companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. &quot;Inadequate access to appropriate equipment&quot;</td>
<td>31</td>
</tr>
<tr>
<td>2. &quot;Lack of sufficiently competent personnel&quot;</td>
<td>103</td>
</tr>
<tr>
<td>3. &quot;Lack of interest among operating managers&quot;</td>
<td>91</td>
</tr>
<tr>
<td>4. &quot;Not applicable to this business at all&quot;</td>
<td>8</td>
</tr>
</tbody>
</table>

The Use of OR by Size of Firm in the United States

In both the Hertz and Schumacher reports there is evidence that only large companies were surveyed. Only in Vatter's survey was there a breakdown of usage by size of company. Of the seventy-seven companies with sales of less than twenty-five million dollars, forty-two or approximately fifty-five per cent recognized OR as a spec-

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pecific function in the organization as compared to eighty per cent for all size groups.\textsuperscript{11} However, the relatively small number of replies from small business and the speculation that non-respondents are less likely to be OR users, suggests that a much smaller proportion of small companies use OR, unless of course the members of the Financial Executives Institute are by and large employees of large companies.

**Operations Research Activity in Canada**

In 1957, Robinson suggested that perhaps only twenty-five Canadian companies had or were building operations research activities.\textsuperscript{12} He reports on a University of Western Ontario survey which sent out questionnaires to sixty-seven organizations thought to be using operations research, or to be interested in the subject. Of the fifty-two responding companies, only eleven were using OR and another thirteen companies were considering using it. That this small number of companies has apparently increased is evidenced by the increasing length of the membership list of the Canadian Operational Research Society.

\begin{itemize}
  \item\textsuperscript{11}\textit{Ibid.}, p. 726
  \item\textsuperscript{12}\textit{Robinson, op. cit.}, pp. 469-480.
\end{itemize}
Operations Research Activity in Britain

The literature apparently contains no recent survey that is aimed at estimating the number of British firms engaged in operations research. However, Gander\textsuperscript{13} describes OR activity in a number of important industries such as power, transport, iron and steel, etc. It appears from his article that most of the large firms in these industries were using operational research by 1957 even if they did not have a specific OR department. Many of the formally established OR departments are large, having up to fifty qualified people. Gander also states that the membership of the Operational Research Society tripled in membership between 1953 and 1957.

II. THE NEED FOR GREATER EFFICIENCY IN SMALL BUSINESS

The above findings indicate that small firms do not use operations research as extensively as large companies. The question arises - Do they need operations research? In an attempt to answer this question the literature was surveyed for information on productivity, profitability and failure rate as a function of size of firm. Unfortunately

\textsuperscript{13}Gander, loc. cit.
no information on productivity was obtained. However, there exists some research on profitability, and articles on the need for improved management of small businesses.

As a substitute for productivity information, failure rates and the causes of failure are examined to assess those areas where small business management is weak and ascertain if OR has anything to offer. Again no statistics on failure rates by size of firm were obtained but numbers of failure by size of liability indicate (and it seems generally accepted) that small firms are very susceptible to failure.\textsuperscript{14,15} For instance, in 1966 approximately eighty per cent of the thirteen thousand failures in the United States had liabilities of less than $100,000.

More relevant to our study are the statistics on causes of failures. Dun and Bradstreet statistics for 1967, based on the opinion of creditors and information in credit reports are given in Table III.

\begin{footnotesize}
\begin{enumerate}
\item See monthly issues of \textit{Dun's Review}.
\item J.C. Worthy, "Who Fails and Why?" (1966) pp. 21-26
\end{enumerate}
\end{footnotesize}
TABLE III
CAUSES OF BUSINESS FAILURES IN THE UNITED STATES FOR 1967

<table>
<thead>
<tr>
<th>Cause</th>
<th>Percentage of Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neglect</td>
<td>3.1%</td>
</tr>
<tr>
<td>Fraud</td>
<td>1.4%</td>
</tr>
<tr>
<td>Inexperience, Incompetence</td>
<td>92.5%</td>
</tr>
<tr>
<td>Inadequate sales</td>
<td>39.9%</td>
</tr>
<tr>
<td>Heavy operating expenses</td>
<td>12.8%</td>
</tr>
<tr>
<td>Receivables difficulties</td>
<td>9.9%</td>
</tr>
<tr>
<td>Inventory difficulties</td>
<td>6.2%</td>
</tr>
<tr>
<td>Excessive fixed assets</td>
<td>4.7%</td>
</tr>
<tr>
<td>Poor location</td>
<td>3.2%</td>
</tr>
<tr>
<td>Competitive weakness</td>
<td>21.2%</td>
</tr>
<tr>
<td>Disaster</td>
<td>1.0%</td>
</tr>
<tr>
<td>Reason Unknown</td>
<td>1.1%</td>
</tr>
</tbody>
</table>

These statistics are corroborated by a survey of the causes of success and failure of ninety-five Michigan manufacturers that were established in the year ended 30 June, 1960. Of these firms, thirty-seven were clear successes and thirty-six firms failed. The difference between success

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and failure was mainly found in marketing and management practices. For example, over-extension of plant and equipment was a frequent cause of failure. Another study to determine the causes of failure of small manufacturing firms found that unsuccessful companies had poorly informed managements whose decision making was based on historical precedent or industry practice. The research by Fowler and Sandberg confirmed that relevant data is usually not collected and when it is collected the information is not properly used because the basic nature of decision making, that is, selecting alternatives with respect to goals and constraints, is not understood. A survey of small companies in Ohio with less than five hundred employees indicated that even some of the most basic tenents of management are not followed in small businesses. Organization structure and communications are not well established. Of more importance from the OR standpoint, objectives are ill-


defined and decisions are made without explicit attempts to obtain the relevant available information. All of these studies demonstrate that there is a need for improved management of small businesses especially with respect to analysis of information for decision making.

A recent statistical study shows that the profitability of small United States firms, especially those with assets of less than $50,000 is significantly lower than larger companies. The statistical analysis of company profits as a function of company size as measured by total assets is based in U.S. Department of Internal Revenue data for 1955 to 1957. As an example, the analysis shows that the average rate of return on assets for firms with assets between $50,000 and $100,000 is 5.3% as compared to the highest rate of return, 7.4% for the $10,000,000 to $25,000,000 size category, and to an approximate 6.8% average return for all size categories.

In contrast to this result are data from Canadian taxation statistics for the years of 1957 to 1960 which indicate that small firms in Canada are just as profitable as large firms. In particular the average pre-tax earnings of firms with assets of under $100,000 was 24% as compared to 19%

21 H.O. Stekler, "Profitability and Size of Firm", (1963)

for companies with assets of less than $1,000,000. These figures may be distorted by the lower salaries of owner managers of small firms but they indicate that small firms are profitable.

Having established that there is evidence that generally small businesses require improved management, it can not be stated that operations research is also required. OR is only one of a large number of management tools which may improve the operations of small businesses, others being, improved information systems possibly using EDP, industrial engineering, market research and others. Indeed, it may be that the costs of using operations research exceed the benefits which can be derived. However, there remains the possibility that in certain situations, especially for analysis of information for rational decision-making, operations research can provide substantial net benefits which will improve the viability and growth of small businesses. In particular, operations research can improve equipment allocation and usage, inventory control, location selection, all of which have been mentioned as causes of small business failures. The remainder of this paper is an attempt to generalize as to what extent this is true.
CHAPTER III

THE USE OF OPERATIONS RESEARCH IN SMALL BUSINESSES
INCLUDING A SURVEY OF LOCAL EXPERIENCE

This chapter aims at answering the following questions:

1) To what extent and with what success is operations research used in small businesses?

2) For what reasons is operations research not used more extensively in small businesses?

3) What are some of the common problems faced by small business managers that might be effectively solved by OR?

A section of this chapter is devoted to each of these questions in turn. The information was mainly gleaned from a survey of local small business managers; a description of this survey is the subject of the first section.

In addition to the local survey, information was obtained by interviewing local consultants, computer service bureaus and the Seattle office of the U.S. Small Business Administration. The literature was surveyed for reports of the use of OR in small businesses, to support the author's assessment of local experience. In this regard the U.S. Small Business Administration has published reports of research on the application of OR to small businesses but they do not report any actual usage, and discuss the problems of using OR in small businesses to a very limited extent.
Some of the results of these research studies will be mentioned but it is not the purpose of this study to assess their findings.

I. THE SURVEY OF LOCAL SMALL BUSINESSES

The constraints of time and resources limited the extent of this survey. Ideally a random sample of a population which could be specifically identified would be selected as a basis for determining the extent to which operations research is used. However, it was neither possible to identify from readily available data all local firms with a value added of less than five million nor would it have been possible to interview the managers of all companies in a significant random sample. The interview technique rather than a mailed questionnaire was deemed necessary because of the lack of knowledge of operations research among small business managers. Therefore a limited survey of subjectively selected companies was made using the interview technique.

Members of the management of twelve small businesses in B.C. were interviewed. Five companies were selected by their response to a letter sent to managers of small companies participating in a one day seminar on operations research. With the other companies, the author was familiar with their operations and considered them as representative of local small businesses. The relevant characteristics of each company and the position of the manager(s) interviewed is outlined in Table IV.

The managers were questioned according to the format given in Appendix I. The questions were formulated to obtain
an estimation of the size of the company and the educational level of the company's management. Subsequently, the extent of the managers' knowledge of operations research and a few common OR techniques was determined, followed by brief explanations by the author so as to facilitate the subsequent discussion. Any experience by the company in using OR was then discussed. On the other hand, if OR had not been used, the interviewer delved into the reasons for non-use. In either case, the problems of the small business were discussed to identify possible areas for OR application.

The remainder of this chapter deals with the results of this survey, which are summarized in Table V, plus information obtained from other sources as stated above.

II. THE EXTENT AND SUCCESS OF USE OF OPERATIONS RESEARCH

The survey of local small businesses provides evidence that operations research is used to a rather limited extent by small business. Four of the twelve companies in the survey have used operations research to solve one or two problems. However in none of the companies is operations research a general activity of the firm even though in every company there existed problems to which OR might well be applied. In two companies consultants used it in the area of inventory control. A foundry reported using a small linear programme for minimizing alloy input costs. Another firm reported using CPM successfully for contract maintenance projects.
<table>
<thead>
<tr>
<th>Company</th>
<th>Industry</th>
<th>Value Added* in Millions</th>
<th>No. of Employees</th>
<th>Formally Educated Employees</th>
<th>Position of Manager(s)</th>
<th>Familiarity with OR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Metal-working</td>
<td>$1 mill.</td>
<td>90</td>
<td>5</td>
<td>Sales Mgr. Generally</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Distribution</td>
<td>$0.75 mill.</td>
<td>40</td>
<td>1</td>
<td>Gen. Mgr. None</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Foundry</td>
<td>$4 mill.</td>
<td>265</td>
<td>12</td>
<td>Gen. Mgr. Some</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Metal-working</td>
<td>$2 mill.</td>
<td>140</td>
<td>4</td>
<td>Plant Supt. None Production Some Engineer</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Real Estate</td>
<td>$1.5 mill.</td>
<td>110</td>
<td>2</td>
<td>Sec.-Treas. None Cost Acct. Some</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Equipment Mfg.</td>
<td>$4 mill.</td>
<td>100</td>
<td>6</td>
<td>Mgg. Dir. None Chief Eng. Generally</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Woodworking</td>
<td>$2 mill.</td>
<td>150-470</td>
<td>6</td>
<td>Chief Eng. Some Purch. None Agent</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Metal-working</td>
<td>$0.50 mill.</td>
<td>40</td>
<td>3</td>
<td>President None</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Mfg. &amp; Distribution</td>
<td>$5 mill.</td>
<td>300-800</td>
<td>8</td>
<td>Gen. Mgr. None Warehouse Some Manager</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>Construction Mtls.</td>
<td>$2 mill.</td>
<td>200</td>
<td>8</td>
<td>Chief Eng. Some Accountant None</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Distribution</td>
<td>$1.5 mill.</td>
<td>130</td>
<td>4</td>
<td>Gen. Mgr. Some Sales Mgr. Some</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Paint Mfg.</td>
<td>0.75</td>
<td>45-65</td>
<td>2</td>
<td>Mgg. Dir. Generally</td>
<td></td>
</tr>
</tbody>
</table>

*approximate - estimated by author in some cases.
The surveys reported in Chapter II also provided evidence that operations research is used infrequently by small business. A recent report of a survey on the use of modern management techniques by small businesses in the Atlantic provinces of Canada found that many techniques, some of which can be grouped under operations research, are used to a very limited extent by the companies in their survey.¹ In addition conversations with local consultants, data center personnel, Dr. R. Johnson of the University of Washington and the personnel of the Seattle office of the Small Business Administration revealed only three other instances of operations research being used by small companies. Thus there is considerable evidence to indicate that operations research is used to only a limited extent by small business.

Most of the companies in the survey who had used operations research have found the results useful. One of the companies using inventory control models was very pleased with the resulting control system whereas in the other company some doubt was expressed concerning the usefulness of the results although it was admitted that it was too early to tell. In both cases consultants were retained for installing the systems. In the latter case, the inventory consisted of one raw material of different

grades and sizes in which the price and delivery fluctuated markedly. Also orders for the company's products were based on contract bidding so that demand was highly volatile. In such a situation it can be appreciated that controlling inventories is an extremely difficult problem and extensive use of judgement must be made even when using a well formulated model.

In the former case, company K purchases approximately 8,000 items from one manufacturer who maintains fairly constant delivery times of approximately one month. This inventory control system is run on a computer once a week for updating stocks and for ordering, and once a month for forecasting and changing reorder quantities. The system employs an exponential smoothing technique for forecasting sales for the succeeding three months. Ordering costs, carrying costs, stockout costs and lead times are utilized for calculating reorder points and reorder quantities. Much of the benefit of this system is derived from clerical efficiency through electronic data processing alone. However, considerable benefit has resulted from the reduction of inventory investment and improved customer service. The company's management states that the monthly cost of approximately $1,000 in running this on a computer is well justified and they plan to control more of their inventory by this method.
This company also uses a small scale simulation to assess the prospects of doing business in a certain area for a three to five year period. Single best estimates of operating parameters and business conditions are used, calculations are performed on a desk calculator and the result is a simple yes or no as to whether the company should undertake the project.

Company J has used critical path methods on a simple, non-computerized basis for scheduling contract maintenance projects. This technique is used to determine when and how many men and resources are required to complete a project in the specified time. No time-cost trade-offs are used as it is considered that time is generally far more important. The company is very pleased with the results of using this OR technique and stated that without CPM, some projects could not have been completed in time. Needless to say, they plan to continue its use.

A survey of the literature revealed only two reports on the use of OR in small business, but included a fairly detailed account of its use in one firm.\(^2\) This firm started using OR "by accident" when they obtained the services of a mathematician as an assistant bookkeeper and he became interested in applying a quantitative approach to the comprehension and control of the company's problems. This company reported using OR in (1) media selection and

budgeting for a three year advertising campaign; (2) sales forecasting by regression analysis and (3) production planning and inventory control. Top management appears very impressed by the benefits. Forecasts for five quarters are reported to have an error range of two to five percent where previously forecasts could be "off by as much as twenty or thirty percent."\(^3\) Finished goods inventory are kept at reasonable levels, the work force is more efficiently employed and storage and production space have been freed for new products. Other reported benefits of this more disciplined approach to business problems are increased customer goodwill and better overall planning. Unfortunately neither the size of the company nor the size of the OR group are reported but it is stated that the saving in manpower utilization through production planning was sufficient alone to cover the cost of the "small" OR activity.

The other report describes how an operations research study was formulated and implemented for determining the size and type of hog to buy each day at different price levels.\(^4\)

\(^3\)Ibid., p. 44

Analysis of meat values for each type and size of hog and operating costs made it possible to simulate one day's operations so as to calculate the breakeven prices for each size and type of hog. This data was displayed on a chart so that the hog buyers purchased hogs only if the market price was less than the breakeven price.

III. REASONS WHY OPERATIONS RESEARCH IS NOT USED EXTENSIVELY IN SMALL BUSINESS

The above summaries indicate that operations research can be used advantageously in small businesses. The results of the survey of local small businesses and the SBA sponsored research suggest some reasons why it is not used more extensively. The results of the survey in this regard are summarized in Table V. It is important to note the relationship of these considerations for each company. For instance, the executive in Company H knew nothing about operations research, was not interested in it and thus he did not know which factors would hinder his company from engaging in OR. On the other hand, the executives of Company F displayed a genuine interest but suggested a number of reasons as to why it would be difficult to engage in meaningful operations research. Although these reasons are not necessarily peculiar to small business, they tend to exist more generally than for large organizations. The following discussion also indicates why they are more difficult for the smaller firm
<table>
<thead>
<tr>
<th>Company</th>
<th>Had Exposure to OR</th>
<th>Top Management Familiarity a Constraint</th>
<th>Use OR and plan to increase its use</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Short Course</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>B</td>
<td>No</td>
<td>Difficult to answer</td>
<td>No</td>
</tr>
<tr>
<td>C</td>
<td>Not formally</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>D</td>
<td>Seminar</td>
<td>Yes</td>
<td>Use but do not plan to increase</td>
</tr>
<tr>
<td>E</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>F</td>
<td>Yes, but not formally</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>G</td>
<td>Yes, Seminar</td>
<td>Possibly</td>
<td>No</td>
</tr>
<tr>
<td>H</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>I</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>J</td>
<td>Yes, Seminar</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>K</td>
<td>Yes, Short Course</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>L</td>
<td>Yes, Short Course</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Is it possible OR could aid management of firm?</td>
<td>Believe it would not be economical</td>
<td>Lack of trained personnel is a constraint</td>
<td>Other constraints on use of OR</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>-----------------------------------</td>
<td>----------------------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Yes</td>
<td>Don't know and not prepared to find out</td>
<td>Yes</td>
<td>Fear of loss of control</td>
</tr>
<tr>
<td>Yes</td>
<td>Probably yes</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>It does</td>
<td>It is economic</td>
<td>Yes</td>
<td>- -</td>
</tr>
<tr>
<td>Yes</td>
<td>Sometimes it is economic</td>
<td>Yes</td>
<td>Forecasting</td>
</tr>
<tr>
<td>Yes</td>
<td>Not sure</td>
<td>Yes</td>
<td>- -</td>
</tr>
<tr>
<td>Yes</td>
<td>Don't know</td>
<td>Yes</td>
<td>Forecasting and insufficient data</td>
</tr>
<tr>
<td>Doubtful</td>
<td>Probably yes</td>
<td>- -</td>
<td>Difficulty in forecasting</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>- -</td>
<td>Work not sophisticated enough</td>
</tr>
<tr>
<td>It does</td>
<td>It is economic</td>
<td>Yes</td>
<td>- -</td>
</tr>
<tr>
<td>It does</td>
<td>It is economic</td>
<td>No, Use Consultants</td>
<td>Finances</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Insufficient Data</td>
</tr>
</tbody>
</table>
Non-analytical Approach to Management.

There was some evidence in this survey that managers do not have a formalized rational approach to decision making. When asked to give examples of problems to which OR might be usefully applied, the managers mentioned aspects of their operations which reduce company profits but often suggested that nothing could be done to improve the situation because their "business is different". Some managers suggested that if the environment was different then the problem would be easy to solve, implying that there is no way to solve the problem in the present situation. Thus fairly important problems were ignored without a thorough analysis of the situation to identify its importance and relationship to organizational objectives, the real constraints upon its solution, and the course of action that will yield the highest return in terms of the objectives. In other words, many decisions are made intuitively or by historical precedence.

These findings are confirmed in a study by Fowler and Sandberg for the U.S. Small Business Administration on the manner in which small businessmen in one industry make decisions relative to the goals of growth and
viability. The following points are made in their conclusions:

1) "The (typical small business) administrator (in their study) specifies goals after the fact as opposed to the general concept of administration which insists the goals be specified "ex ante"." 

2) "Where operating decisions are made in the absence of a set of explicit goals, alternatives are chosen either on the basis of historical precedent, tradition, or folklore; or by following the leader."

3) "Even where objectives are explicitly stated, it is evident that what information is available is used in ex post analysis of performance rather than in the ex ante evaluation of alternative courses of action."

4) "Failure to appreciate the importance of control information before the fact results in a situation where relevant data is neither generated nor processed for ex ante evaluation of alternatives."

5) "It is quite obvious that there is absent from among the firms in this industry, and probably generally among 'small' businesses, an appreciation of the basic nature of the administrative process: decision making relative to goals and alternatives. The irrational patterns of behaviour developed in the analysis undoubtedly result more from this deficiency than from any specific area of inexpertness of the individual manager."

In the present survey, the evidence of the above characteristics of decision making was not as extensive but the degree to which it exists is a constraint on the use of

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OR. Managers must appreciate the value of rational decision making before they will pay for the efforts of operations analysts to obtain information which is useful for specifying constraints and weighing alternatives. Inherent in all operations research is rational decision making. Indeed operations research can be regarded as applied decision theory. Conversely, the executive who understands the theory of rational decision making is more likely to appreciate the possible benefits that can be derived from operations research. The obvious solution has to do with educational programmes but it is beyond the scope of this paper to delve into that subject.

Management's Lack of Familiarity with OR

Most of the managers interviewed had some impressions concerning operations research, or one or more OR techniques, but any knowledge was expressed in rather vague terms. (see Table IV). Almost none of the managers interviewed had a working knowledge of any of the techniques except of course in the few instances where OR was used in the firm and the manager was directly involved. Even the people who had attended the one day seminar on operations research had very uncertain knowledge as to the aims, methods and results

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of OR.

There seems to be no relationship between the number of formally educated employees (and generally the managers interviewed were formally educated beyond high school) and the degree of familiarity with operations research. Operations research is a rather new approach to increasing business productivity and has been taught only for the last few years at most business schools. Business pressures usually keep the small business manager too preoccupied to spend much time investigating new aids to management. Therefore this lack of familiarity is not surprising and is likely to change very slowly even with the increasing interest in management science and business applications of computers. The obvious solution is to provide opportunities for exposure to the approach of operations research so that managers will be motivated to study the possibility of its use in their organizations. In this regard, it is interesting to note that most of the managers who had some knowledge of OR had obtained it at short courses and seminars and generally were quite interested in the possibility of using OR. Even they, however, felt a need to know more about it before initiating an OR approach to their business problems. (see Table V.).

The managers who were by and large ignorant of OR
frequently expressed the dicta, "our firm is different" or "our work is not sophisticated enough for the use of these techniques." This displays a general lack of appreciation for the aims and techniques of operations research in that OR attempts to deal with the situation as it exists in any organization, not with some theoretical model. Thus, although these managers did not feel that their lack of familiarity was a constraint on the use of OR in their firms, the author concluded that in fact it was a real constraint.

Lack of Trained Personnel

Managers in six of the companies interviewed stated that the absence in their organizations of people trained in operations research or related disciplines was a constraint on their use of OR. Certainly the staff who are to undertake an operations research approach must have some appreciation for the scientific method7 in general and preferably a working knowledge of the common OR techniques. Although some of the people interviewed had been to seminars or short courses on OR, it was obvious that this had not provided them with a working knowledge and generally it was these people who expressed the belief that the lack of

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7 See Chapter 1, p. 4
trained personnel is a constraint.

For the present there appears to be a scarcity of trained operations analysts. Even if they were available many small companies feel that they could not provide enough challenge or afford to retain them on staff. One alternative is for the small company to have their own people trained as is the case with one of the companies now using OR. Short courses are offered by consultants, computer manufacturers and universities, but other than for specific applications a working knowledge of operations research is not obtained, especially if the employee does not already have an education in mathematics, engineering or science. Of course there is the possibility of using consultants as a substitute for full-time OR analysts and this will be discussed in the following chapter.

Forecasting Problems

The managers of three firms discussed the very real problem of forecasting for the small business. These managers had a fairly good understanding of OR and fully realized the importance of forecasting for inventory control, scheduling, etc. For many small firms, especially in the capital equipment industries, sales fluctuate markedly and no doubt such fluctuations are difficult to predict. However, a careful study of the factors which control sales
and in some cases careful trend analysis may increase forecasting accuracy as witnessed by the experience of Company K in our survey and the Noreen Corporation, two small companies which use exponential smoothing and regression analysis respectively for sales forecasting. If inventories are carried and if manufacturing schedules are based on expected sales as well as orders on hand, then by implication some forecasting is done. Therefore attempts to put forecasting on an explicit, rational basis will provide a basis for better planning.

However, as compared to larger companies who exercise some control over the market, sales forecasting is generally a more difficult problem for small businesses to solve. Concurrently the net benefits from scientifically based forecasts are generally not as large, in that for a given relative improvement absolute benefits will be less for the small company whereas research costs may be the same. Thus the difficulty of sales forecasting as required for operations research represents a very real problem which cannot be answered except in the context of the economic assessment of using OR in a particular situation.

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8Baum, op. cit., pp. 43-45
Data Availability

Only two managers expressed the opinion that sufficient, accurate data was probably not available for meaningful analysis, although this is probably prevalent among small businesses. This opinion is confirmed by Fowler and Sandberg,\(^9\) and Holdren et al\(^10\) based on their research. Most small businesses do not have well established information systems which is not surprising if their management does not use an analytical approach to decision making.

Accurate, meaningful data is a necessity for any operations research.\(^11\) How else can the operations be observed and represented by a model which is useful for description and prediction? Even if the company does collect and record data it is often not useful for operations research as is noted in the case study in Chapter V. Of course, for any company it is difficult to foretell what data is going to be required for a particular OR study. This suggests that OR should be a continuing activity cooperating with

\(^9\) Fowler and Sandberg, _op. cit._, pp. 67-68.


\(^11\) Axelson, _op. cit._, p. 78.
the systems analysis function to generate the necessary
data and to improve and update OR models. Whether or not
this ideal situation can be justified in a small company
can only be answered in a particular case. In general
however, the application of OR in small businesses will be
seriously hampered by the lack of accurate, meaningful data.

**Electronic Computing Availability**

None of the managers that were interviewed suggested
that the cost or availability of computers was a reason for
not using OR inspite of the fact that the leasing of
computers can be quite expensive for the small company.
A recent study of Canadian computer users shows that for
businesses with sales of up to ten million dollars the mean
cost is over one per cent of sales and the upper quartile is
over two per cent of sales.\(^1\)\(^2\) Thus for a firm with ten
million dollars in sales, the cost of leasing and operating
a computer will likely be at least $100,000 per year and
could conceivably be more than $200,000 per year. Even so,
two firms stated their intentions to eventually purchase or
lease their own computers.

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Not all OR models need electronic computers to process the data inputs and solve for the optimum or satisfactory solution; as for instance with the linear program being used by Company C and the CPM used by Company J. However for control of large inventories, solution of large linear programmes, etc., there is no doubt that access to an electronic computer is highly desirable if not essential. The various means by which access to an electronic computer and related services can be obtained are detailed in Chapter IV.

Operations Research is Not Economical for the Small Firm

In that most of the above problems can be resolved by education or the application of money, the real criteria is whether or not the benefits from using OR are greater than the costs. The managers of five companies suggested that, based on their understanding of OR, they doubted that it would be economical for their business. Unfortunately, three of these managers had very vague ideas as to what OR is. Of the other companies in the survey, three were using OR with generally satisfactory results, two expressed no opinion on its economic feasibility and two others thought that it probably was economic but there are other constraints on its use in their companies. (see Table III). Basically these remarks represent management attitudes rather than careful analysis. The opinion that OR is feasible for small
business in some situations has been expressed by researchers who have studied the problem for the U.S. Small Business Administration.¹³,¹⁴

There are factors in addition to the problems outlined above which tend to make the use of operations research in a small business less profitable than for large organizations. Frequently problems of small businesses are just as complex to solve as the large company's problems if carried to the same degree of refinement. For instance, the problem of managing inventories of ten thousand items is not more complex for the company whose dollar volume turnover is ten times that of the other company's, and yet the potential dollar savings would generally be much greater for the first company. In other cases, the complexity of problem is much less for the small company. By example, the problem of scheduling in a company performing just one or two operations on similar parts is easier to deal with than scheduling in a company which builds complex machines by performing many sequential operations on a wide variety of parts, and most likely the second firm is larger than the first. In any case, whether the cost of formulating and implementing decision rules based on operations research is the same or less for the small company, the potential benefits are almost certainly less

¹³Holdren et al, loc. cit.
¹⁴W.J. Gavett and J.M. Allderidge, Operations Analysis in Small Manufacturing Firms, (1963)
for similar types of problems. Other factors operating against the economic application of OR in small businesses are higher incremental cost of OR expertise and electronic computing capacity. However, these will be discussed in the ensuing chapter.

IV. SMALL BUSINESS PROBLEMS FOR OR

The range of problems experienced by small businesses in attempting to remain viable and profitable and hopefully to expand are no doubt considerable; but not all such problems are suitable for operations research. The formulation of the questionnaire was an attempt to acquire some insight into possible areas in which OR might usefully be applied. The results in this regard were disappointing. No doubt the questions could have been formulated for more effect. Also the expression of the managers was constrained by their limited knowledge of OR. A third reason for the survey's failure to portray a wide variety of possibly interesting subjects for operations research was that a certain state of affairs is only regarded as a problem if it is brought to the attention of the manager as such. For instance, the head melter in a foundry is responsible for specifying the source materials for each alloy and usually this will be based on historical precedence or a salesman's influence. Determining the appropriate mix is not a problem
for the melter or top management because no one has drawn their attention to potential savings in operating at the optimum.

In spite of these considerations, production scheduling and inventory control were frequently mentioned as possible problem areas to which OR might be applied. Also some managers expressed a desire to formulate a more comprehensive method for making capital expenditure decisions. These managers felt that too many factors were being overlooked in deciding between a multitude of alternatives.

The studies conducted under the auspices of the U.S. Small Business Administration have pointed out other problem areas to which OR might be advantageously applied in small businesses. The entire field of marketing strategy is suggested; equipment replacement, equipment allocation and job shop estimating models have also been formulated for use by small companies.

As to whether the application of OR to these problems results in a net benefit for small businesses can only be

\[16\] Ibid., pp. 27-52.
\[17\] Gavett and Allderidge, op. cit. p. 5.
determined in a particular case. Nor is it the purpose of this paper to assess in general terms the merits and deficiencies of applying OR in each of the above areas. Rather, in the two succeeding chapters a more detailed examination will be made of the reasons given above as to why OR is not used in small business. In particular, Chapter IV will attempt to answer the questions: Can the use of consultants resolve the small company's deficiency in operations analysts? What computer facilities are economically available for implementing OR in small businesses? Chapter V is the report of a case study on the prospects of applying operations research in a particular company, including an assessment of data deficiencies, sales forecasting difficulty, and the economic feasibility of applying OR in the area of inventory management.
CHAPTER IV

CONSULTANTS AND COMPUTERS

The preceding discussion has identified the lack of trained personnel and the cost of electronic computers as two reasons why OR is not being used in small businesses. The first part of the present chapter is an assessment of the extent to which small businesses can rely on outside consultants as substitutes for staff OR analysts. An examination of the benefits of using consultants and the factors giving rise to the relatively high cost of their services will lead to some recommendations for their effective retention by small businesses. This section is mainly based on discussions with local consultants and small business managers, especially those who had used consultants.

The subsequent part of this chapter will examine the advantages and costs of computer service bureaus, computer time-sharing and small computers as means by which small businesses can obtain the electronic computing capacity that is often necessary for formulating and implementing OR solutions to small business problems. In this regard, the author had discussions with data centre managers, representatives of computer manufacturers, and computer consultants.
I. OR CONSULTANTS FOR SMALL BUSINESSES

Most management consultants have operations researchers on their staff. Some computer service centres also have qualified operations analysts who are readily available. For the small business there are some rather obvious advantages in retaining the services of an OR consultant for an operations study. Most consultants have a wide practical experience backed by a knowledge of the theoretical aspects. This, with their analytical approach to business problems, permits consultants to come quickly to the essence of the problem and to a practical approach to its solution. Additionally, the consultant can identify other aspects of the operation which can be more effectively controlled by implementing OR formulated decision rules. Consultants can also train company personnel for implementing the results of an OR study and possibly to a degree sufficient for doing their own analysis in specific areas. For instance, the consultant might train the production manager in the use of linear decision rules for production scheduling. These advantages are in addition to the fact that retaining an OR consultant enables the small business to engage in effective operations research without having to employ a full-time specialist which may be fairly costly, especially if there is insufficient OR work and the person
is not effective in other areas of the organization.

On the other hand, the services of a consultant are relatively expensive for the small business. For instance, it has been suggested by consultants that the formulation and implementation by a consultant of an operations research technique in a major business function, such as inventory control or scheduling, would cost at least $20,000 and for most small businesses this corresponds to a major capital expenditure. The basic reasons for the high cost are (1) the relatively high fees of consultants as compared to salaried employees, (2) the time it takes the consultant to understand the organization and operation of the particular company and (3) the time required to assess available data and estimate operating parameters from it.

Consultants obtain fairly high salaries as a result of their qualifications but a greater contributing factor to high fees is the relatively high overhead of consulting firms mainly due to the need to have sufficient personnel to handle assignments whenever they may develop. In other words, the firm has to bear the expense of inactive consultants so as to be able to service clients immediately upon request. A Harvard University study has found, in surveying small businesses as to their use of consultants, that eighty-seven per cent of the non-users regarded consultants' fees as a significant concern to them while
only twenty-four per cent of the users stated that cost was an important consideration. Consequently the Harvard study recommends that consultants to small businesses keep their overhead low, their operations small and flexible, and spread their charges over a relatively long period. Obviously, one means to create flexibility and reduce overhead is for the consulting firm to employ qualified personnel in periods of peak activity, that is, on a part-time basis.

Every business is different in the detailed aspects of its operations and the consultant must completely understand not only the particular phase of the operation which presents the problem but also its interaction with other aspects of the operation. Therefore, a considerable amount of the consultant's time in each assignment is spent learning about the operation. For instance, he must understand the objectives and operating environment of the organization, the functional areas of authority and the constraints on decision alternatives. Furthermore, this task is greatly complicated if the consultant has no previous experience in the particular industry. One means by which this

\footnote{H.C. Krentzman, and J.N. Samaris, "Can Small Businesses Use Consultants?" (1960) p. 130.}
situation can be relieved is for the small firm to maintain a continuing relationship with one consultant who therefore must be able to give assistance in many other functions of the organization. That is, the consultant should have not only a good working knowledge of OR but also of organization theory, marketing, finance, etc. in order to facilitate this continuing relationship.

Unfortunately, most small businesses do not have readily available the data which is necessary to formulate models of decision situations. Of course, this is also a problem in large companies but it apparently exists to a greater extent in small firms. For this reason the consultant spends considerable time determining the accuracy and relevance of available data, and estimating operating parameters which are not explicitly available from the firms information system. In this regard the small business can facilitate operations analysis by upgrading its information system, perhaps with the advice of the OR consultant who is better qualified to predict the information requirements.

In addition to the high cost of retaining consultants, the small business must expend a considerable amount of employee and executive time in working with the consultant,

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especially in giving him a complete understanding of the firm's business and operations. This can be a relatively large expense in that the small company relies on fewer key personnel to control its operations, and consequently they are very busy. The total time that the managers are required can be reduced by the company maintaining a continuing relationship with the consultant and by the consultant's willingness to go into 'the shop' to see for himself how the business is run.

Another cost of employing consultants, which may or may not be real, but is often mentioned by small business executives, is the exposure of 'company secrets' to outside people. Generally, most small businesses don't have as many secrets as they may think. Also the consultant cannot ethically inform others of special aspects of a client's operations. Still he may gain 'experience' from the company's operation and see where a certain procedure might be useful in another client's operation. On the whole, this cost is probably greatly overemphasized and on the other hand, if a firm is so far ahead in its field, it probably doesn't need consultants.

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3 Krentzman and Samaris, op. cit., pp. 135,136
In the balance then, although a consultant's services are expensive, their employment is often the only means of applying OR and thus the application of operations research is relatively expensive for the small business. This can be reduced by a continuing relationship with the consultant particularly if he can assist in other areas; by the development of meaningful information systems; and by having the consultant train the firm's personnel in the relevant aspects of operations research.

II. COMPUTER SERVICES FOR SMALL BUSINESSES

Electronic computing capacity is frequently a prerequisite to the formulation and implementation of operations research as indicated in Chapter III. To own or lease electronic computers has in the past been prohibitive for small businesses. Even with the marked reduction of computer costs, medium and large size computers are beyond the means of the typical small company. However, computer service bureaus, computer time-sharing and small computers with limited capacity are alternative means of economically obtaining computer services. This section deals with the advantages and disadvantages of each from the point of view of obtaining the electronic computing capacity which often is necessary for operations research.
Computer Service Bureaus

Computer service bureaus are independent companies or regional offices of computer manufacturers who sell time, usually for batch processing, on medium to large size computers. In that large computers can process data more cheaply than small computers, the capability of doing fairly large linear programmes, inventory control routines, simulations, and other OR techniques is provided at reasonable cost. For instance, a linear programme which was run for about forty hours on a small computer and never completed, was run and completed in seven minutes on a large computer.

The computer centres generally sell two types of services. One is the "block time" rental of their computers in which the client brings his own programmes and data in machine language, and operates the computer. Naturally the service bureau takes no responsibility for errors in programmes or data. Charges for this service vary from $100 per hour to $1,200 per hour or more depending on the size of the computer.

The other type of service is an undertaking by the bureau to do the complete job from analysis of the requirements and programming, to putting the data in machine language and processing it, usually on a periodic basis.\(^4\) The cost of

maintaining key punch machines and ancillary devices, programmers and computer operators in addition to the high cost of installation and leasing of the computer is thus shared by many users, the clients of the service bureau. The author was not able to discover any examples of an operations research type problem being processed on a periodic basis using this service of computer centres. However, an inventory information programme which gives item usage, stock receipts, stock level, cost of items, etc., for 12,000 items is processed weekly for approximately $2,500 per year. This charge does not include the preparation of the data for computer input as the data is received as punched paper tape from the telex terminal. Also the programming costs are not included. It does however indicate that the services of a computer centre are quite reasonable for the small business which requires the batch processing of one or two jobs on a periodic basis.

With batch processing there is some inefficiency in having to feed the programme and a certain proportion of fixed and old data into the computer with each run as compared to keeping the data base and programme on-line.5

Generally, retaining the data base and programmes on-line is possible only with captive computers or large independent computers, and is feasible from a benefit-cost point of view, only if it can be accessed randomly and directly by the people who require the information. This service which is not provided by most computer centres is called time-sharing and will be discussed subsequently.

Although computer service centres make available the talents of programmers and systems analysts, they generally do not have competent operations analysts for formulating OR solutions to business problems. Nor is the availability of canned programmes of OR techniques an alternative in that they must be tailored to the particular situation and the interpretation of the computer print-out requires a degree of familiarity with the technique. Also the service centre is not usually willing to get involved with the implementation of the results. For these reasons, computer service bureaus do not undertake operations research projects although they will rent 'block time' on their computers and provide programming and key punch services.

Computer Time-Sharing

Time-sharing is the ability of several users to gain access to a computer's memory and logic capability at more or less the same time. The prospect of simultaneous access of remote on-line customers to a central computer has elicited the concept of a computer utility. This service is of considerable interest to the small businessman because it makes some of the capabilities of large electronic computers available to his organization at any time of the day (or at least at any time when the time-sharing system is on-line) and at reasonable cost.

The essential components of a time-sharing system are: a large central computer with secondary on-line memory devices such as disc, drum or data cell units, software packages, terminal equipment and communication lines between the terminal equipment and the central processor. Two such systems are available locally, the RAX system provided by IBM and the Canadian General Electric time-sharing system. Comparative user rates are listed in Table VI. Typical charges for other systems are $350 per month providing 50

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hours of terminal time. These costs will however, vary substantially with the distance between the terminal and the computer. The managers of a time-sharing service in Boston, U.S.A. state that their market is limited to a radius of sixty to seventy miles by the cost of communication lines. In fact, with the continuing reduction of data processing costs, communication costs will become the limiting factor of the time-sharing potential especially in remote areas. However, there is some indication that improved technology for transmitting data will significantly reduce communications costs also.

Another user advantage is the relative ease of using the system. The subscriber need not have extensive programming ability and input can be through a normal teletype console. For instance many of the Canadian General Electric system's programmes are in the Basic language which can be learned in one day and the terminal is a standard telex teletypewriter. Also, the subscriber has access to on-line programmes which cover a wide variety of applications and include small linear programmes, inventory control routines using economic order quantities, capital investment analysis

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8 Ibid. p. 23.
9 Ibid. p. 24.
using Monte Carlo simulations, as well as other OR techniques. These programmes are excellent for solving small problems but they are limited in the size of problem that can be handled. For instance, the C.G.E. linear programme is limited to a 18 by 30 matrix in Basic language and a 30 by 60 matrix in Fortran. Presumably programmes for larger problems could be made available but the normal terminal devices, for which the above costs were quoted, operate at slow speeds so that the costs of data input and solution print-out could become excessive. Therefore, time shared-computers with low speed terminals have limited applicability for processing OR-type problems.

There are two alternatives with which to overcome the problem of getting large quantities of data to the remote computer and the detailed analysis back to the user. High speed terminals are available using punched paper tape or card readers and high speed printers. For the present their costs are almost as high as a small computer, especially when it is considered that they require multiple high-grade communication lines. A more suitable alternative is for the user to maintain the programmes and data base on-line in the computer. New data and the essential results of a run could be communicated through the slow speed terminal at any time. For instance, in an inventory control system receipts and sales could be entered daily through the terminal and each
day groups of items could be processed to obtain stock levels and reorder quantities. Alternatively, the programme to obtain reorder quantities could be run periodically and printed at the computer center for physical delivery to the user. The approximate costs of storing such a system on line would be $50.00 per month for an 8,000 item inventory using IBM's RAX system rates.

Two problems arise with on-line storage in a time-shared computer: privacy and failure. To access the user's proprietary programmes and data base, a code is required. Visitors or unfaithful employees might obtain the code and make it available to competitors using the same time-sharing service. Also, as with any on-line system there is the possibility of a computer failure, and even more catastrophic, the accidental elimination of the data base. In an inventory system, for instance, this would require a physical inventory count plus a search for quantities on order; unless of course, duplicate records were incorporated in the system. In spite of these difficulties, the possibility of keeping proprietary OR formulated programmes and the requisite data on-line at a remote computer exists and will become increasingly attractive as computers with even larger memory capacities and lower processing costs become available. For the small company which can process data for its conventional information systems more economically on an electronic computer, the
### TABLE VI

**TIME-SHARING COSTS**

<table>
<thead>
<tr>
<th></th>
<th>IBM</th>
<th>RAX</th>
<th>CGE Time-Sharing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Terminal Rental</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic Terminal</td>
<td>$145.00/month</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Set</td>
<td>30.00</td>
<td></td>
<td>$130.00/month</td>
</tr>
<tr>
<td>Telephone Line</td>
<td>17.00</td>
<td></td>
<td>(all inclusive)</td>
</tr>
<tr>
<td>Card-read capability</td>
<td>166.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper-tape and card-read</td>
<td>219.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Usage Charges</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terminal Time</td>
<td>$12.00/hr.</td>
<td>$12.00/hr.</td>
<td></td>
</tr>
<tr>
<td>CPU Time</td>
<td>First 60 minutes $3.00/min. free, thereafter $4.50/min.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disc Storage</td>
<td>First 100,000 bytes free, additional $.045/month/disc track* for 1536 characters</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 1 disc track = 2880 bytes.
alternative means of obtaining computer services is to lease a small computer. This possibility will be examined in the following section.

**Leasing Small Computers**

In keeping with the general reduction in data processing costs, the costs of leasing small computers has fallen markedly. Nearly all computer manufacturers have models which lease for less than $3,000 per month. One major manufacturer stated that 40% of its business in 1965 was with companies with less than 500 employees.\(^{10}\) Even so, this is an expensive tool for most small companies.

Before assessing the detailed costs of small computers for the small business engaging in operations research, the rather obvious advantages and limitations will be examined.

The availability of an on-site computer as a tool for operations analysis is very attractive. Mathematical models can be solved, and solutions tested, in addition to the periodic running of OR formulated programmes for operations planning and control. There are no problems of privacy and scheduling is accomplished internally. However, small computers have limited memory capacity so that batch

processing is a prerequisite. Also, they have slower computing speeds and therefore they are less efficient especially in processing some OR techniques such as large linear programmes.

In order to justify having its own computer, the small business must have a considerable number of other tasks which it can more effectively process on an electronic computer than by mechanical means. In having its own computer the small business will no doubt find many applications for its capabilities. However, in this lies a frequent source of trouble. Not always can the vast quantities of information obtained be utilized by the few managers that most small businesses have and the mere collecting and processing of the data requires considerable labour. In spite of this possibility, good systems design with electronic computing capability will no doubt improve management's control and planning functions.

However, the costs are relatively high for the small business. A recent survey of Canadian computer users, shows that for businesses with up to ten million dollar annual sales, the mean cost of electronic data processing as a percentage of revenue, was one percent whereas for companies of over five hundred million dollars in annual sales, the mean cost was about one tenth of one percent.¹¹ These

results include all direct computer costs such as materials and staff as well as equipment. In this regard another result of the survey showed that mean staff costs represented forty-nine per cent of direct electronic data processing costs, whereas mean equipment costs were about forty-three per cent.\textsuperscript{12} With this in mind and accepting the results of the survey on number of staff for lowest cost computer equipment, the direct costs of leasing and operating a small computer would be approximately seventy-five thousand dollars per year, assuming common experience is a guide. This would not include the cost of maintaining staff programmers which we have tried to keep separate in our assessment of computer services. Thus, in spite of the many advantages for both operations research and conventional data processing, the high costs of leasing and operating even small computers limit their applicability to small business.

\textbf{Computer Services for Various Requirements}

The foregoing discussion has indicated that the effectiveness of computer service bureaus, computer time-sharing and small leased computers as vehicles for electronic data processing depend on the particular company's total requirements. Besides the few programmes required for

\textsuperscript{12}Ibid., Exhibit 2
implementing operations research, the small business must have many other applications for a small computer if it is to consider leasing. Also, care should be taken to insure that none of the programmes are too large to be run on a small computer.

Time-sharing is an attractive service if the company has need of quick calculating power on a regular basis. In this regard it is interesting to note the consulting firms, for both engineering and management are the most prevalent users of the local time-sharing services. Indeed, the capability of solving or manipulating small mathematical models is a useful tool for the operations analyst but it is only applicable where the small business is doing operations research or some other quantitative analysis such as engineering on a regular basis. The time-sharing system may also be feasible if the small company desires to keep some of its proprietary programmes and data on-line for random access. In either case the time-sharing service is limited by the distance between the central computer and the potential user.

For periodic batch-processing of OR formulated programmes, the computer service bureau in close proximity is almost certainly the most economic source of electronic data processing.
CHAPTER V

A CASE STUDY:

OPERATIONS RESEARCH FOR A SMALL COMPANY

As stated in the foregoing chapters, the question as to whether operations research can be effectively used by small business can only be definitely answered in a particular case. This chapter describes a detailed study of one company's operations, which was made to assess the prospective effectiveness of OR in a small company. Company F of the survey was selected for this study because of its interesting operating problems and the willingness of its management to cooperate.

In particular, the Company's business, organization and operations are described to identify organizational goals and operating problems. Subsequently, the effectiveness of operations research as an aid to inventory control is analysed. Ordering decision rules for seven important items are formulated and their use is simulated using past production schedules and actual demand. The simulated results are compared to past records as to inventory levels, number of orders placed and number of stockouts. Some indication of prospective savings are thus obtained. Recommendations are

1A stockout occurs when an item, that is not presently in stock, is required.
made for implementing an inventory control system based on the OR formulated decision rules. In addition, consideration is given to using operations research to improve sales forecasting, production scheduling, and equipment procurement and replacement.

In this study, the author was undergoing a learning process and so the study cannot be recommended as a typical, good approach to applying OR in a small business. However it does display some of the previously mentioned problems and it should give the reader a closer insight into the practicality of using OR in a small business.

I. A DESCRIPTION OF THE COMPANY'S BUSINESS

Product and Market Environment

Company F produces relatively complex, heavy equipment for a particular phase of one industry. The few dominant companies in the Canadian industry have, on occasion, tended to emphasize capital expenditures in different phases of their operations at different times. Also the Canadian segment of this industry exports a high proportion of its product and therefore is subject to the vagaries of world markets and, as in many other industries, when business is poor they rarely make capital expenditures. Consequently, this Company experiences rather marked
fluctuations in the demand for its products and does not experience a significant replacement parts business, which would tend to relatively reduce fluctuations in sales. In addition to the resulting cyclical and random variation, demand tends to be seasonal.

Recently, the Company has been successful in marketing its products in other countries so that it is not as dependent on the Canadian market. There is a good possibility that these sales will tend to dampen the fluctuations in total sales, but increase the problems of forecasting, which will be discussed later.

Currently the main product line consists of a few models of two large, complex and related machines, which are produced at rates of less than one hundred per year. The Company produces another line of equipment of far less importance and in slack periods undertakes custom manufacturing.

Design changes are often introduced by the relatively large engineering staff to take effect of technological advances and introduce product improvements. In addition, the Company has undertaken a programme to design and build new types of equipment for the particular phase of the industry that it supplies, in order to maintain its position as a leading supplier of efficient and reliable equipment. These development programmes, coupled with marked variations
in demand for its standard products, give rise to considerable instability in the operations of this Company.

Company Objectives

The main objective of this Company is to grow at a rapid pace while maintaining an adequate rate of return, by introducing new types of equipment and by aggressive marketing while confining itself to the phase of the industry it now serves. In particular the Company is attempting to achieve a one hundred per cent increase in sales within the next four years while maintaining a five percent profit on sales. Also, the Company management feels a strong responsibility towards the welfare and satisfaction of its employees and this manifests itself in the organization and methods of operation.

II. A DESCRIPTION OF THE COMPANY

Organizational Structure

The organization structure of this company is not well defined and is congruous with the rather informal mode of operation. Overall direction of the Company is provided by the chief executive officer, who also manages the financial aspects of the Company and plays the leading role in production scheduling. The Company also has an active
board of directors which, for instance, makes all major capital expenditure decisions.

The sales manager and the chief engineer also play leading roles in the management of the company. The chief engineer has considerable authority in the area of production planning and control, besides supervising the engineering department. He also initiates most proposals for capital equipment purchases with special recognition for the manufacturing requirements of design changes. The engineering department maintains close contact with customers and the sales division so as to assess the industry's equipment needs and initiate design improvements.

The Company has supervisors who operate in the areas of accounting, office management, purchasing and production. One superintendent and two foremen supervise the production workers with direction from the chief executive officer and the chief engineer. There is a remarkably high worker to supervisor ratio of about twenty-five to one and therefore an unusual amount of responsibility is vested in the individual worker. The assemblers work in groups of two or three on one type of sub-assembly, whereas the machinists work individually at one machine. The complexity involved requires that the workers have fairly general skills and a high degree of familiarity with their tasks.
Current Operating Practice

The production process thus retains a fair degree of specialization. Some parts are machined and fabricated from wrought metal and castings. Other components and parts are purchased ready for assembly, but usually only if the Company does not have the capability of producing them. Generally the Company prefers to manufacture all components for the equipment that they produce. Sub-assemblies are built at separate work stations and transferred to the final assembly area where also heavy components are fabricated.

The company has a fairly high investment in production equipment which up to the present has been mainly standard machines. Currently, the Company is considering purchasing rather expensive specialized equipment so that it can produce some of the components that it now procures and in order to increase its capability for the production of different types of equipment.

The complexity of the main line products requires a large investment in raw materials and purchased components. Each machine requires many thousands of parts and these must be kept on hand to maintain the production process. Inventories for standard items are controlled so as to practically eliminate stockouts which would hold up pro-
duction. Many items are stocked by local suppliers, sometimes especially for the Company on a blanket order basis for release as required, with delivery in one or two days. Other items are manufactured upon receipt of an order, with varying lead times of up to about ninety days. Besides insuring the availability of items for standard production, the purchasing department must also procure the material requirements for prototype and custom machines.

The Company's inventory control cards do not provide a perpetual record of stock levels because items are not charged out of stock until the particular machine in which the item was used has been completed and sometimes even later. The cards do, however, provide the total stock in inventory plus work-in-process. As a substitute for actual records, the purchasing agent is made aware of low stock levels by the warehousemen or, in the case of raw steel, by the cut-off saw operator. The five men involved make unsystematic checks and base their appraisal on normal practice as very few items have assigned minimum levels. Also, no formal system exists for informing the purchasing department of the exact item requirements of scheduled and forecast production. The schedules are

2This system was designed mainly for purposes of cost accounting. The Company uses a job costing system in which
broken down into sub-assembly requirements and the purchasing agent can determine the material requirements from the bills of material for each sub-assembly but in fact this is very rarely done. Consequently, purchasing decisions are based on informal stock level information and approximated material requirements, which sometimes give rise to stockouts but more frequently are manifested in unreasonably high stock levels.

Production is scheduled for orders on hand, once a month for the succeeding two months, by the chief executive officer. The schedule for the immediately following month is in sufficient detail to inform each group of assemblers or each machinist as to their work load for the month and is based on past records as to the time taken to perform each activity. Many parts must be produced at least one month ahead of the machine completion date and so in general, machinists' work is scheduled one month for the succeeding month's final assembly. However, schedules are often changed during the month due to extenuating circumstances such as customer demands or production problems. Therefore, monthly requirements for inventory items and machinery

all labour costs are accumulated from time cards and all materials are charged out after completion of the machine, using bills of material. Thus in terms of the chart of accounts, material is transferred directly from 'inventory' to 'finished goods' or 'cost-of-goods sold' and the inventory record cards are essentially the inventory accounts for each item.
capacity do not always correspond to original plans.

III. OPERATING PROBLEMS

The above description of Company F has provided a back-ground for discussing the related problems of sales forecasting, production scheduling and inventory control. Some remarks will also be made concerning capital equipment expenditures. Besides considering the difficulties in solving these problems, the discussion will demonstrate how improvements in these areas would significantly contribute to the organization's goals of rapid growth with adequate profits, and a high degree of employee satisfaction.

Sales Forecasting

To a considerable extent, the problems in production scheduling and inventory control stem from the difficulty of making accurate sales forecasts. The description of the environment indicated some of the causes of demand instability. The fluctuations have been extremely difficult to predict. The sales division has a leading role in sales forecasting but its main source of information is the clients' operating executives and they are rarely able to advise as to upcoming purchase orders. There is a possibility that certain economic factors may give some indication of future demand
and this approach will be discussed later.

If the volume of sales is difficult to predict, the sales by each type and model would seem virtually impossible to forecast. Fortunately, the bulk of the orders in any one year are for one or two standard models. Technological trends in the Company's market give some indication as to what these models will be in each succeeding year. Even so, customers may demand variations in the standard models and these can not be predicted.

The ability to predict sales accurately would to a large extent eliminate the other problems. Accurate production schedules for minimum cost operations are then more easily attained. Purchasing plans could be adhered to with little chance of stockouts occurring. The safety stocks that are carried for unknown demand could be greatly reduced and investment in inventory more closely controlled. Cash requirements would be known and so cash balances could be reduced. The objective of employee welfare is more readily attained as lay-offs are less likely to occur. These, and other benefits suggest that substantial efforts should be applied to sales forecasting.

Production Scheduling

The inability to forecast sales accurately creates serious problems in production scheduling. In the past,
products have, on occasion, been produced for forecasted sales so as to utilize excess productive capacity during periods of slow demand. However, the last time this occurred, the company found itself with a quarter of a year's production in finished goods inventory and consequently had to close the plant for some time. Therefore, at present, production is scheduled to orders in hand so that the production rate, to a large extent, fluctuates with demand. However, according to stated company policy, workers are generally not laid-off during slack periods; nor has the company found it desirable to have work done by independent machine shops during periods of peak activity. Instead the Company maintains a relatively constant labour force even if the production rate varies considerably.

The policy of maintaining full employment during times of decreased rates of production does have the advantages of reducing employee turnover, maintaining employee loyalty and thus decreasing the need for extensive supervision. However, it has the drawback of creating a higher labour content in the cost of machines produced in slow periods and it can eliminate the economies achieved by longer run production of parts. Another cost of the current production scheduling policy is the inordinate amount of expediting required of the shop workers and the engineering staff in particular. This
is primarily caused by the necessity of changing production schedules in mid stream, as it were, to meet rush orders.

As a means of overcoming the diseconomies of production consequent on the inability to forecast sales, the engineering department is initiating a programme to design equipment for modular construction. Thus, each model will be a different combination of a limited number of sub-assemblies or modules. As a result, the scheduling of part and sub-assembly production can be based more easily on forecast demand because investment in inventories and the risk of obsolescence will be relatively less as compared to producing completed machines for inventory. Rush orders can also be completed more quickly.

Even so, the problem of determining the lowest cost schedule for fluctuating sales would remain. For instance, if production rate is held relatively constant, investment in sub-assembly inventory could become excessive in periods of slack demand, or back-order delays could be damaging in periods of peak demand. Alternatively, variations in production rates without employee lay-offs will result in lower average labour productivity but frequent lay-offs would create morale and training problems. Each one of these alternatives results in additional expense, but no doubt some combination of all of them is the least expensive. The problem is to determine what that combination is for
each particular situation.

Identifying the minimum cost production schedules for varying demand could obviously lead to higher profits. For instance, under current policy, a fifty percent reduction in production rate results in a one hundred per cent increase in the labour cost of machines produced during this period, whereas a different policy might result in lower overall costs. Another benefit could be increased employee satisfaction. Good workers don't like being idle and by and large this Company's production workers are hard working, loyal and conscientious. A more rationalized production system would allow the engineering department to concentrate on its prime function of designing new equipment, the successful marketing of which, contributes to company growth.

Capital Expenditures

Determining the feasibility of investments in new production machines is a large problem because it is difficult to predict the future requirements of productive capacity. For standard machines such as lathes, the solution to the problem is closely related to scheduling policies in that if production rate was held fairly constant, the required machine shop capacity could be uniquely determined, whereas if production rate fluctuates widely there is a tradeoff between overtime production in periods of peak
demand and the fixed cost of idle machines during slow periods.

For more specialized equipment, matters of general policy come to the fore. Should the Company buy machines to perform complicated and unusual tasks or sub-contract the work? Large outlays for specialized machines tend to reduce production flexibility in that the Company will attempt to design components to their own production capability. That is, the ownership of certain types of equipment often determines the type of manufacturing that a company will undertake. On the other hand, sub-contracting can be expensive in terms of time and money. These considerations together with careful analysis of future production requirements must be examined if invested capital is to yield a high rate of return and contribute to rapid growth.

Replacement of present machinery is also an important consideration from an economic and technical standpoint. Present policy dictates the replacement of many standard machines every three years, but as to whether this is an optimum policy has never been analytically determined.

**Inventory Control**

Efficient inventory control is another victim of fluctuating sales and changed schedules. Design changes,
prototype construction and informal and inaccurate information on stock levels and material requirements are also factors which interfere with obtaining the objectives of minimum cost inventory operation. A manifestation of this situation is the rather high investment in inventory which ranges between about thirty and forty per cent of yearly material requirements. Another result is the rather high cost of operating the current system which involves the services of eight people. In addition, considerable time is spent by staff and production personnel in questioning the purchasing agent as to expected deliveries or in attempting to ascertain the stock level of a certain item. In short, because there is no well established system for controlling inventory, a time-consuming, informal communication network has become established and results in considerable labour inefficiency, conflict and frustration.

Inventory management has two aspects; data processing and decision making. The description of inventory control in the preceding section clearly demonstrates that improvements in the inventory control information system will reduce the cost of the inventory operation. For this reason, the engineering department is developing a material requirements system. For the present, the data will be manually processed but eventually it will be processed once a month
on a computer. The system will state the material requirements of scheduled production for the following two months using cross indexing forms which give the number of times each part is used in each sub-assembly. Machine completions will thus have to be scheduled once a month for the succeeding three months. This will permit the purchasing department to place orders for most items to scheduled demand. Actual requirements may be different from those scheduled, but certainly the variance will be small, especially when the Company has changed to modular production. However, the items with longer lead times must still be purchased to forecast demand.

In either case, the problem of determining when and how many of each item to buy would remain. Although the decisions can now be based on better information as to production requirements, the quality of these decisions will still suffer from the lack of readily available, accurate information on stock levels.

In making these decisions, proper cognizance must be taken of the variable costs involved. The cost in carrying a high level stock must be weighed against the cost of placing a large number of orders and the cost of running out of stock. Data on these costs is not readily available and considerable effort is required to obtain approx-
imations. In addition, the decisions must take effect of supplier policies regarding discounts, minimum quantities, et cetera, and plant production practice.

These factors will be closely examined in the study of a few inventory items for which an OR approach is used to formulate ordering decision rules. The decision rules are then used in a simulation of past experience to determine their effect on ordering costs and inventory levels.

In this regard the importance of investment is raw material inventory should be noted. For instance, if it were possible to reduce inventory investment by, say, ten per cent, the resulting release of funds would be sufficient to purchase two major pieces of production machinery. Additionally improved control over raw material inventory could conceivably reduce the personnel requirements in the purchasing department and decrease the efforts of engineering and production personnel in expediting urgently required items.

IV. INVENTORY STUDY

This section describes an attempt to determine the potential value of an operations research approach to solving a particular small business problem. The problems encountered in obtaining a meaningful estimate of the value
are prominent in the discussion. Another purpose is to illustrate the problems of applying OR in a small business. In this section we are concerned with company F's inventory control problems. In a later section some recommendations will be made for using OR to solve the company's other problems, namely, sales forecasting, production scheduling and capital budgeting.

Ideally a random sample of the company's inventory items should be selected for detailed study. An operations research approach would then be used to formulate optimum ordering rules for the items in the sample. These rules would then be tested by: 1) using them in actual practice for perhaps a year, 2) using them in a Monte Carlo simulation, which would require known probability distributions, 3) simulating their use on past data. In each case, average stock levels, number of stockouts and number of orders and shipments can be determined and compared to past performance to obtain an estimate of the reduction in variable costs resulting from the use of the decision rules for these items. The total benefits to be derived from using similarly formulated decision rules for all items can then be estimated from the benefits of the random sample and compared to the total cost of formulating, implementing and operating the new control system. In this regard, consideration must also be given to
design of an information system for generating the data to be used in the decision rules. Some of the costs can be estimated from the experience gained in the study of the sample items and others from the preliminary design of the data processing aspect. The difference between the benefits and the costs would give a good estimate of the value of the total system.

Of course much of the value would be attributed to the improved information system alone. The amount could be estimated by simulating the system without the ordering rules, and having the purchasing agent make 'off-the-cuff' decisions for ordering. These results could then be compared to the results using the system with OR formulated decision rules. This might indicate that an improved information system is all that is necessary to attain efficient inventory management. Therefore, allocating the value of the new system between OR formulated ordering policies and improved data processing is necessary to determine, in a strict sense, the value of operations research for inventory control in a small business.

However the two aspects are so closely interwoven that dividing the benefits and costs between them is both difficult and inconsequential. Often, the operations analysis is necessary to design a good information system;
that is, determining the interaction of the operating variables specifies the information that is required for improved operating control. Thus, improved information systems can be a major benefit of operations research. Also if the data processing aspect is to be run on a computer, the output should, for clerical efficiency, specify order quantities for each item. This implies that the computer programme will contain ordering decision rules. Thus, the data processing and operations research aspects are considered together.

Sample Selection

Unfortunately the 'ideal' approach of random sampling to obtain an estimate of the value of OR was not found to be practical for purposes of this study. Closer examination of the ordering characteristics of a wide variety of items showed considerable variation so that for sampling purposes the inventory would have to be segregated into sub-populations or the sample size increased to an unmanageable size for our brief study. Rather a few items with representative characteristics were selected for detailed study. All of these are items used in either or both of the two machines of the main product line (see Table VII).
Data Availability and Cost Factor Estimates

The ensuing discussion is an assessment of the available data for determining demand characteristics, and inventory costs. For this purpose the author spent considerable time discussing the data, the present ordering procedures and supplier policies with purchasing department personnel. As previously stated, the company maintains stock control cards for each item but the withdrawals are not recorded until the machine in which the item was used is completed, and sometimes even later. Therefore, the exact time at which an item was removed from raw material inventory is not known. For instance, in one month no items were charged out whereas in the succeeding month many more items than could possibly be used in one month were charged out. Obviously the withdrawals were spread in some manner over two months.

There is however, a means of approximating historical monthly demand. Accurate records are available on the number of machines completed in each month. Also bills of materials and inventory records state whether the machine used one or more of the items under consideration. By estimating the approximate time before completion that each item is used, the month in which it was removed from stock can be surmised. It must be emphasized that this is very approximate in that completions can be delayed for some time due to an unusual
## TABLE VII
### ITEMS FOR DETAILED STUDY

<table>
<thead>
<tr>
<th>Item</th>
<th>Price/unit</th>
<th>Yearly Demand</th>
<th>Leadtime</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item A</td>
<td>$132.50</td>
<td>120</td>
<td>1 day</td>
<td>This is used in fractions of a unit</td>
</tr>
<tr>
<td>Item B</td>
<td>$350.00</td>
<td>60</td>
<td>1 day</td>
<td>Generally requested five at a time by machine shop.</td>
</tr>
<tr>
<td>Item C</td>
<td>$680.00</td>
<td>60</td>
<td>3 weeks</td>
<td>Manufactured to order by local supplier.</td>
</tr>
<tr>
<td>Item D</td>
<td>$8,260.00</td>
<td>50</td>
<td>2 days</td>
<td>Stocked locally for Company on blanket order.</td>
</tr>
<tr>
<td>Item E</td>
<td>$150.00</td>
<td>50</td>
<td>2 weeks</td>
<td>Imported from U.S.A. Long Distance 'phone charges = $1.00.</td>
</tr>
<tr>
<td>Item F</td>
<td>$560.00</td>
<td>85</td>
<td>2 weeks</td>
<td>Imported from U.S.A. Long Distance = $2.50.</td>
</tr>
<tr>
<td>Item G</td>
<td>$1,740.00</td>
<td>60</td>
<td>3 months</td>
<td>Imported from U.S.A. Long Distance = $2.50.</td>
</tr>
</tbody>
</table>
situation so that an item might have been removed from stock considerably before the estimated time. Also it does not give the number of items sold as replacement parts or the number scrapped. It does however provide some evidence of the demand characteristics of each item for formulating decision rules and the actual demands which are used in the simulations.

The Company's records provide data on shipment arrivals but the quantities do not always correspond to the amount in any one order. For instance, two orders may be received in one shipment or one order may be delivered in two shipments. By and large, the number of shipments received does correspond to the number of orders placed. More accurate information on the number and size of orders is available from the original copies of orders but the effort required in digging them out was judged not to be worth the increased accuracy obtainable.

The costs which are dependent on purchasing practice are not recorded except for the price of each item. A considerable amount of investigation was required to produce working estimates.

The cost to the Company of carrying inventory is principally the opportunity cost of money invested in inventory. This does to some extent vary with the interest
rate on bank loans but for our general purposes we assume it to be constant at twelve per cent, a rate used by the Company in other investment decisions. For items stocked in the plant, there is a storage cost based on the size of the item and type of storage required. In our judgement, considering the obvious inaccuracy of other data, the increased accuracy of specifying this cost for each item was not worth the effort. Therefore an additional 3% was added to the carrying cost of all items stored in the plant. This estimate is based on an approximate total value of these items and the annual cost of the space required.\(^3\) Thus the total carrying cost is 15 per cent per annum of the value of the item.

The cost of placing orders depends on the item but a general estimate can be used for all but a few items. This cost was calculated by two methods and takes account only of the employee time involved. In one case the cost was calculated by dividing the total monthly salaries of the employees involved by the number of orders placed to obtain a cost of $2.30 per order.\(^4\) The other method identified the

\[^3\text{Annual cost of replacement value} \div \text{Average value of inventory in plant} = \frac{15}{5000} \times 100 = 3\%
\]

\[^4\text{Total Salaries in dollars per month} \div \text{Approximate number of orders per month} = \frac{2300}{1000 \text{ orders}} = $2.30/\text{order}
\]
normal ordering process and with the help of the employees involved estimated the time required for each step as detailed in Table VIII. This gave a cost of $2.70 per order for normal orders but there may be extra costs such as for long distance telephone calls which can only be identified with a particular item.

The cost of being out-of-stock when an item is requested depends to a large extent on the time it takes to get additional stock. If the item is not available from local stocks and if there are no suitable replacements the cost is extremely high in that production becomes stalled. For items with lead times of one or two days, the stockout cost is the cost of placing an additional order plus the cost of delays and time spent expediting and rescheduling work. From our observations of the shop worker and supervisory personnel time involved a rough average estimate of twenty dollars has been made as the out-of-stock costs for items that are available in one or two days.

Formulation of Decision Rules

The purpose of the following analysis is to formulate decision rules, which do not necessarily give the optimum results but which provide a basis for evaluating operations research as applied to the inventory problems of Company F.
### TABLE VIII

#### ORDERING COST*

<table>
<thead>
<tr>
<th>Step</th>
<th>Activity Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Warehouseman checks stock level and records requirements</td>
<td>$0.40</td>
</tr>
<tr>
<td>2</td>
<td>Purchasing Agent phones order and signs purchase order</td>
<td>$0.50</td>
</tr>
<tr>
<td>3</td>
<td>Inventory clerk types purchase order</td>
<td>$0.20</td>
</tr>
<tr>
<td>4</td>
<td>Warehouseman receives and stocks shipment</td>
<td>$1.25</td>
</tr>
<tr>
<td>5</td>
<td>Inventory clerk records receipt and checks invoice and packing slip against order</td>
<td>$0.35</td>
</tr>
<tr>
<td></td>
<td><strong>Total Cost</strong></td>
<td>$2.70</td>
</tr>
</tbody>
</table>

*These costs estimated from the time taken to perform the function and the employee's wage rate.*
Indeed sophisticated analysis using standard techniques was not warranted because of the obvious inaccuracies of the available data and the rather unique operating characteristics of the Company. Therefore the formulation of the decision rules for ordering each of the seven items is based on an approach which is somewhat different than that which is usually found in standard texts on inventory management.

Besides the above general considerations, the following premises were made by the author for purposes of formulating decision rules in this particular inventory study.

1) Orders can be placed at semi-monthly reviews.

2) Demand is known for the succeeding one to two months based on production schedules but with certain discrete probabilities of differences between scheduled demands and actual usage.

3) The method of keeping inventory stock records will be changed to give an accurate account of quantities in raw material inventory and on order.

These premises are based on the following considerations.

In regard to the first premise the Company plans to process the inventory control system on a periodic basis at a computer service bureau and that eliminates the possibility of a perpetual control system. There are a number of factors
which suggest a semi-monthly review of inventory. Actual usage is unlikely to vary much from schedules in two weeks. The most economic ordering policy for four of the seven items that are discussed below specifies that for average demand orders should be placed approximately twice per month. Another consideration is the invoicing policy of many suppliers. Since statements of account are usually only issued for payment at the end of the month, only the items in inventory at the end of the month represent an opportunity cost for company funds. Obviously, increasing the frequency of reviews would add considerably to the cost of operating the control system, especially if it is batch processed on a computer. Since the above considerations have indicated little additional benefit from more frequent reviews, the author has concluded that the inventory control system should be processed twice per month.

The second premise is the direct result of the Company's plans in establishing a material requirements system which can be easily processed to state the quantities of each item that are required for a two month production schedule. However, as stated earlier, the actual usage can be somewhat greater through replacement part sales and changed schedules to meet rush orders.

The last premise is based on the information require-
ments of a closely controlled inventory system. Stock levels and quantities on order must be explicitly known in order to determine if an order should be placed and how much should be ordered.

The formulation of the decision rules is thus based on a system in which material requirements are known for up to two months in the future, perpetual inventory records are kept or at least updated before each review and the inventory control system is processed twice a month on an electronic computer.

**Item A**

This item is fairly representative of much of the Company's purchased material in that it is available from local stock and its demand is fairly well known from production schedules. Replacement demand for this part is very small and the item has no substitute in the company's inventory. In one respect it is unusual, that is, it is used in fractions of a unit.

The total variable inventory costs are represented in the following equation:

\[
T.C. = \sum_{x} C_{o} + cP(x + r) + p(r)Cu - - - - - - 1
\]

where T.C. = the total variable monthly inventory cost of any decision rules.
\[ S = \text{scheduled demand for one month.} \]
\[ x = \text{the order quantity.} \]
\[ C_0 = \text{the cost of an order independent of the quantity.} \]
\[ c = \text{the cost of carrying inventory for one month, as a percentage of item price} \]
\[ P = \text{the price of the item.} \]
\[ p(r) = \text{the probability that actual usage between reviews exceeds the scheduled demand plus the reserve stock.} \]
\[ Cu = \text{the out-of-stock cost and} \]
\[ r = \text{reserve stock or the stock that is maintained for unexpected demands.} \]

The first term on the right hand side takes account of the cost of ordering and is of course dependent on the number of orders placed during the month. The second term represents the cost of carrying average inventory for a month. This assumes that all of the reserve stock remains in inventory for the full period and this is not entirely correct. There is a significant probability that some or all of the reserve stock will be used before the end of the period but considering that in general the reserve stock will be small compared to scheduled demand, it can be assumed that if the reserve stock is used it will be used at the end of the period and therefore the above term represents a good
approximation of the correct cost. The final term on the right hand side is the expected cost of stockouts and as such is a function of the amount of reserve stock.

Ignoring, for the moment, the stock-out costs, we wish to determine whether orders should be placed at each semi-monthly inventory review. Therefore, using the standard economic order quantity formula the following order quantities, \( x_0 \), are calculated for average scheduled two month demand of 20 units:

\[
x_0 = \sqrt{\frac{2(S:\)C_o}{cP}} - - - - - - - - - 2
\]

\( x_0 = 5.7 \) if \( C_o = $2.70/\text{order} \)

\( x_0 = 5.3 \) if \( C_o = $2.30/\text{order} \)

The difference in the estimated ordering costs\(^5\) have very little effect on the economic order quantity and therefore $2.50 will be used in all subsequent analyses. For approximate maximum two month demand of 26 units and for a slow demand of, say, 10 units the economic order quantities are 6.4 and 3.9 units respectively. Except for the last figure, all of these quantities are approximately one quarter of the corresponding demand and therefore orders should generally be placed at each semi-monthly review. The economic order quantity for slow demand is considerably more than one

\(^5\)See page 91.
quarter and therefore it suggests that a minimum order quantity should be specified. This will be analysed after determining how much reserve stock should be carried to protect against stockouts.

There is no recorded data as to how much actual demand has varied from the one month schedules. The only guide is the data used in the simulation of the decision rules (see Table X). These estimates indicate that actual usage exceeded scheduled demand by about one unit in seven of the nine months. However the Company's managers suggested that in general this frequency would be too high and then suggested the following probability distribution for one month demand of item A:

\[
\begin{align*}
p(D = S) &= 0.5 \\
p(D = S + 1) &= 0.4 \\
p(D = S + 2) &= 0.1
\end{align*}
\]

where \( D \) = actual total demand, and \( S \) = scheduled demand.

Similar distributions were obtained for many of the other items that are subsequently studied. In all instances the distribution is assumed to be independent of the rate of scheduled demand.

However, we require the probability distribution for half of a month to obtain the probabilities that actual usage will exceed scheduled demand by various amounts between inventory reviews. If the semi-monthly distribution is known,
the monthly distribution can be obtained by a binomial expansion. In this case the reverse procedure was accomplished using a trial and error method to obtain the approximate semi-monthly distribution which when binomially expanded gives rise to the known monthly probability distribution. The following is the semi-monthly probability distribution that actual demand, D, will exceed scheduled demand, S, by the indicated amounts.

\[
\begin{align*}
  p(D/2 \leq S/2) &= .70 \\
  p(D/2 = S/2+1) &= .29 \\
  p(D/2 = S/2+2) &= .01 
\end{align*}
\]

To determine the amount of reserve stock, r, which should be carried, we minimize the cost of being out of stock plus the cost of carrying reserve stock assuming there is no carrying cost if Item A is used up in the same period in which it is purchased, that is: T.C. in Equation 1 is minimized with respect to r. Since the probability distribution is not continuous the calculus cannot be used. Instead a decision table, Table IX, is utilized to identify the value of r which results in the lowest cost. Note that the probabilities used are taken directly from the semi-monthly probability distribution.

---

The table indicates that the policy of buying one unit more than scheduled demand gives the least total cost. If scheduled demand is, say, 2.5 units the above cost matrix suggests that, because of the low cost of carrying one unit for two weeks, an order should be placed for four units assuming no stock is in inventory.

**TABLE IX**

**RESERVE STOCK DECISION TABLE**

<table>
<thead>
<tr>
<th>Reserve Stock Policy</th>
<th>Actual Demand, D</th>
<th>Variable Cost of Policy/$/review period</th>
</tr>
</thead>
<tbody>
<tr>
<td>S + r</td>
<td>S</td>
<td>S + 1</td>
</tr>
<tr>
<td>S</td>
<td>0.0</td>
<td>20.0</td>
</tr>
<tr>
<td>S + 1</td>
<td>0.83</td>
<td>0.0</td>
</tr>
<tr>
<td>S + 2</td>
<td>1.66</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Probability .70 .29 .01

But what is the minimum order quantity? The analysis in determining the most economic order quantities for various demand levels indicated that during periods of slow demand orders for item A should be placed only once a month. Thus
we determine the scheduled demand rate at which the cost of carrying inventory for an extra half month is less than the expected saving of not having to place another order at the next review, that is,

\[(S + 1) c_P \leq p(D > S + 1) C_r\]

\[S \leq 4\]

In other words, if the scheduled requirements for the succeeding month is four units or less, only one order should be placed.

The decision rules can now be stated based on the above analysis:

Reorder if \(I < S + 1\)

Order quantity, \(x_o = S + 1 - I\), if \(S > 2\)

\[x_o = 2(S + 1) - I, \text{if } S \leq 2,\]

where \(I = \text{quantity in inventory}\).

As stated at the beginning the item must be ordered in whole units although it is used and may be scheduled in fractions of units. More detailed analysis would be required to state the decision rules in fractions. Considering the low cost of carrying this item, it is sufficient to state that the order quantity should be for the next largest whole unit, although admittedly this may not be the optimum policy.

The ordering decision rules may not result in the absolute minimum cost inventory operation for other reasons. For example, the probability distribution of actual usage
exceeding scheduled demand by various amounts is not well known and almost assuredly varies with the activity level. Also the cost of stockouts is a very rough estimate which varies with the situation, although sensitivity analysis on the decision table (Table IX) indicates that even a 100% error would not change the result.

To assess the value of this decision rule as compared to past practice, the last ten months experience was simulated in Table X using actual production schedules of completed machines and estimates of item withdrawals. Note, that as is in the past, the production schedules are for one month, only. Using the OR formulated decision rules would have reduced the value of the average semi-monthly inventory level by $700 and thus resulted in a total saving of $33,000 in the seven months operation after the decision rules took effect. This does not include the possibility that stockouts occurred in actual practice because the data is too inaccurate to even suggest this.

The foregoing description has been in considerable detail. The analysis of the following items will be described only to the extent of outlining variations due to different characteristics. For instance, the simulation tables are the same for all items and therefore the simulations for the remaining items will not be displayed.
<table>
<thead>
<tr>
<th>Month</th>
<th>Scheduled Demand</th>
<th>Decision Rule</th>
<th>Amount Used</th>
<th>End of period Inventory</th>
<th>Actual Orders</th>
<th>Actual Estimated Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July 1</td>
<td>5.25</td>
<td>0</td>
<td>2.1</td>
<td>17.9</td>
<td>0</td>
<td>17.9</td>
</tr>
<tr>
<td>July 2</td>
<td>5.25</td>
<td>0</td>
<td>2.1</td>
<td>15.8</td>
<td>0</td>
<td>15.8</td>
</tr>
<tr>
<td>Aug. 1</td>
<td>4.5</td>
<td>0</td>
<td>4.8</td>
<td>11.0</td>
<td>0</td>
<td>11.0</td>
</tr>
<tr>
<td>Aug. 2</td>
<td>4.5</td>
<td>0</td>
<td>4.8</td>
<td>6.2</td>
<td>0</td>
<td>6.2</td>
</tr>
<tr>
<td>Sept. 1</td>
<td>4.2</td>
<td>0</td>
<td>4.6</td>
<td>1.6</td>
<td>0</td>
<td>1.6</td>
</tr>
<tr>
<td>Sept. 2</td>
<td>4.2</td>
<td>4.0</td>
<td>4.6</td>
<td>1.0</td>
<td>4.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Oct. 1</td>
<td>5.2</td>
<td>6.0</td>
<td>6.7</td>
<td>0.3</td>
<td>10.0</td>
<td>4.3</td>
</tr>
<tr>
<td>Oct. 2</td>
<td>5.2</td>
<td>6.0*(8.0)</td>
<td>6.7</td>
<td>7.6</td>
<td>10.0</td>
<td>7.6</td>
</tr>
<tr>
<td>Nov. 1</td>
<td>6.9</td>
<td>0</td>
<td>4.9</td>
<td>2.7</td>
<td>0</td>
<td>2.7</td>
</tr>
<tr>
<td>Nov. 2</td>
<td>6.9</td>
<td>5.0</td>
<td>4.9</td>
<td>2.8</td>
<td>12.0</td>
<td>9.8</td>
</tr>
<tr>
<td>Dec. 1</td>
<td>5.8</td>
<td>5.0</td>
<td>6.3</td>
<td>1.5</td>
<td>0</td>
<td>3.5</td>
</tr>
<tr>
<td>Dec. 2</td>
<td>5.8</td>
<td>5.0</td>
<td>6.3</td>
<td>0.2</td>
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<td>8.1</td>
<td>1.4</td>
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Item B

This item is used in nearly all machines of the main product line, but there is very little replacement demand for the machined part which is made from this item. Average demand for the past eighteen months has been about five per month. It is stocked by a local supplier with delivery in one or two days.

Item B is machined by the Company in lots of six at a time. There is some question as to whether six is the most economic quantity to machine at one time for all production rates. This problem will not be analyzed here as it is a production problem and thus entails an investigation of its interaction with the scheduling of other machining. Sufficient to say that six of these items can be machined in one set up and therefore the present scheduling policy will be assumed to be correct.

Obviously, there is no benefit in buying in quantities of less than six. However, the possibility of ordering more than six at a time must be examined. For maximum production demand of twelve in two months, the most economic order quantity, \( x_o \) is:

\[
x_o = \sqrt{\frac{2S \cdot c^2}{c \cdot P}} = 2.6 - - - - - - - - - - - - - - - 5
\]

Therefore, six units should be ordered at one time.

Since the machine shop foreman knows for some time
ahead when these parts will be machined and the lead time is a few days, this item should not be stocked as raw material on a regular basis but ordered on advice from the foreman to meet the production schedule of the machine shop. Therefore the decision rule may be stated as:

Reorder, as required by the machine shop on three days notice from the foreman.

Order quantity, $x_0 = 6$.

The six units would then be machined soon after they arrived in the plant and therefore they would not be carried in raw material inventory.

The experience of the past twelve months indicates that the average end of the month inventory of item B was ten units and that ten orders were placed. In addition the records suggest that a stockout occurred at least once. The imputed costs of last year's performance are $25.00 for ordering, $520.00 for carrying charges for a total cost of $545.00 versus an expected cost of $25.00 for ordering if the decision rule had been followed. Thus a saving of $520.00 per year could be expected by using this decision rule.

**Item C**

This item is also used in all machines in the main product line. Item C is made to order by the supplier with delivery in about three weeks from receipt of order. Company practice is to machine these one at a time.
Scheduled demand is known for two months at end-of-the-month inventory reviews and for six weeks at middle-of-the-month reviews whereas the lapsed time between placing one order and receiving the next is five weeks. Therefore, purchases can be made to scheduled demand, $S$, but with the following probabilities that actual usage will exceed scheduled demand for the month:

- $p(D = S) = 50\%$
- $p(D = S+1) = 40\%$
- $p(D = S+2) = 10\%$

These probabilities are based on past data and management's subjective opinion as explained for Item A. To be strictly correct, the distribution should be adjusted to the five week lead time plus review period but since the difference between one month and five weeks is small and since the accuracy is poor, the above distribution gives the approximate probabilities that actual demand, $D$, will exceed scheduled demand, $S$, in the five week period between placing one order and receiving the next. The variable inventory cost for this item is,

$$T.C. = \frac{S}{x} C_o + c \left( \frac{x}{2} + r \right) + p(r)K_o$$

where the symbols have the same meanings as used in Equation 1 with the exception that $K_o$ is the out-of-stock cost as it is much larger because this item is not available from stock.
The actual cost is practically impossible to determine by direct measurement. It may be imputed from management's policy as to the reserve stock normally carried if it could be assumed that management explicitly knows the cost of carrying the reserve stock. In this case it was not possible to impute a cost because of the inadequacy of the data. Therefore an arbitrarily high figure of $2000.00 is used as the cost of running out of item C. The accuracy of this figure could be improved as better data is generated through operation of the proposed inventory control system.

Using Equation 6, the economic order quantity, $x$, is 1.7 units for the average monthly demand of 5 units. Since this is less than one half of the average monthly demand, item C should be ordered at each review period with no minimum quantity. The amount of reserve stock, $r$, to be carried can be determined using a decision table similar to Table IX. It specifies a reserve stock of two as the most economic. Therefore the decision rules for ordering item C are:

Reorder if $I + O < S + 2$;

Order quantity, $x_o = (S + 2) - (I + O)$,

where $O =$ the amount on order.

Simulated use of these rules using data on the Company's operations for the past seven months resulted in an average end-of-period inventory of one, whereas the
estimated actual inventory level was about eight units on the average. The prospective cost saving is then approximately $400.00 for the seven months.

**Item D**

This item is used in most but not all of the machines produced by the company at an average rate of four per month. It is stocked for the Company locally so that delivery is made within two days. A group of fitters prepare these items, generally one at a time, for installation in the finished product.

The high price and two day delivery time of this item indicates that it should be ordered one at a time as required by the fitters. However, because of a special purchasing arrangement, the Company is not invoiced for item D until it is taken into the plant to be worked on. Therefore orders should be placed at each review period to meet scheduled demand.

The stockout cost of this item is somewhat higher because the men that work on it have very little else to do if one is not available for fitting. A cost of fifty dollars is therefore assigned to stockouts. The probability of actual demand exceeding scheduled demand is somewhat less than for the three previous items, having occurred only three times in the past twelve months. Therefore, using fifteen per
cent as the probability of running out of stock during the review period, analysis by means of a decision table indicates that inventory at the start of the review period should be equal to scheduled demand plus one unit for reserve stock. Thus the decision rule is:

Order if \( I < S. + 1 \)

Reorder quantity, \( x_o = S. + 1 - I \).

Simulated use of these rules for the past eleven months experience indicates a saving of about $300.00. This result is very interesting because the potential saving is rather small for such a high priced item. The main reason for this is the supplier's policy on invoicing which results in a rather low carrying cost. There is the possibility that a hidden charge exists for this privilege but the author was not able to determine it explicitly.

**Item E**

This item is a matching set of parts manufactured by an American supplier to the Company's orders. Average demand is about four sets per month. To take advantage of the maximum quantity discount an order is placed for sixty-four sets but smaller quantities can be released as required with delivery in two weeks. Therefore, the problem is to determine the optimum frequency of releases and the
most economic reserve stock.

The economic order quantity is 4.1 sets for average demand of four per month, with the order cost of $4.50 suggesting that orders should be placed once a month so that the effective lead time will be six weeks. The probabilities that actual usage, D, will exceed scheduled monthly demand, S, in six weeks are:

\[
\begin{align*}
p(D \leq 1.5S) &= .50 \\
p(D = 1.5S+1) &= .35 \\
p(D = 1.5S+2) &= .10 \\
p(D = 1.5S+3) &= .05
\end{align*}
\]

Using an arbitrarily high stockout cost of $2000, the decision table indicates that three extra sets should be carried in stock.

However there is the possibility of ordering again at the mid-month review if the usage in the first half of the month exceeds scheduled demand. Using the convolutions of the above probability distribution, the likelihood that actual usage will exceed scheduled demand in the remaining one month by more than two is negligible if actual usage

\footnote{Deliveries are usually requested by long distance telephone call ($1.00) and there is also a fixed customs brokerage charge ($1.00)}
equals or is less than scheduled demand in the first two weeks of the month. Thus, rather than carry three extra sets, two extra sets are carried and a mid-month order is placed if usage exceeds scheduled demand in the initial two weeks after placing an order. Reducing the probabilities to two week periods shows that \( p(D > S/2) = 0.20 \). The expected cost of the additional order is $0.90 whereas the expected cost of carrying the extra unit is $1.50. Therefore the following decision rule applies:

Order if \( I < S + 2 \)

Order quantity, \( x_0 = 1.5S + 2 - I \).

Simulated use of these decision rules on the past nine months' production schedules and inventory withdrawals resulted in a reduction of average inventory from fifteen to three sets. The resultant expected savings in inventory costs for the nine months are $170.00.

Item F

The average demand for this item is seven units per month. The demand tends to fluctuate widely and ranges between three and ten per month because it is sometimes replaced by different brands and the number used in each machine can vary. The current ordering practice is to place blanket orders from which releases are periodically issued.
The delivery is effected in about two weeks after issuing a release.

The order cost for this item is $6.00 because of long distance telephone and brokerage charges. The economic order quantity for average demand is 3.5 units. This result indicates that orders should be placed twice every month. There is a significant probability that scheduled demand can be exceeded by up to three units in one month. Therefore without further discussion of the analysis which is similar to item E the decision rules are stated:

Order if, \[ I < S + 3 \]
Order quantity, \[ x_o = S + 3 - I \], if \( x_o = 3 \), \[ x_o = 3 \], otherwise

The minimum order quantity is included because the supplier is opposed to sending just one or two units.

Simulated use of these rules results in an average inventory of four units compared to actual average stock of 13 units in the past six months. The cost of ordering plus carrying charges would have been $234.00 using the decision rules, as compared to the actual estimated cost of $569.00.

Item G

Item G is a rather complicated component which is made to the Company's orders. This last item to be dealt
with is the most difficult from a quantitative point of view. It is an expensive item, $1,760 per unit, with a long lead time of ninety days from receipt of order. Twenty-five units are ordered at one time so as to take advantage of the maximum quantity discount, and deliveries are scheduled as required. If the inventory level starts to build up the deliveries can be delayed if sufficient notice is given. For our purposes we have assumed that items can be released as required for delivery in three months, so that the effective lead time is three and one half months if releases are made at every inventory review.

Production schedules will extend for only two months ahead so that orders for this item can not be based on scheduled demand. Statistical forecasting techniques, such as exponential smoothing, have been tried but with very poor results. Therefore orders must be based on managements' subjective estimate of four-month demand with proper cognizance of two-month scheduled requirements. Fortunately this item is used in almost all machines so that demand is relatively stable.

The question remains of how frequently the deliveries should be scheduled. The economic order quantity is 2.8 units for average demand using an order cost of $16.00.

---

8The ordering cost includes brokerage charges, $1.00, long distance telephone charges, $2.50 and the cost of executive time in predicting demand, $12.00.
Therefore orders should be placed at every review period to meet the maximum expected, three and one half month requirements. The minimum release order that can be placed as set by the supplier is 3 units. The resulting decision rules may be stated as follows:

Order if \( F(S) \leq I + 0 \)

Order quantity \( x = F(S) - (I + 0) \), if \( x_o \geq 3 \)

\( x_o = 3 \), otherwise

where \( F(S) = \) maximum expected demand for 3½ months, recognizing production schedules for up to 2 months, and

\( 0 = \) quantity on order.

The simulated use of these rules is not very meaningful because there are of course no records as to the maximum expected demand. However by using scheduled demand for 60 days and maximum possible demand for the remaining 45 days of the lead time, a simulation was made and compared to actual performance. Average inventory would have been reduced by five units if the ordering had been based on the decision rules. The resultant cost saving is estimated at $1400 for twelve months.

**Evaluation of the Proposed Inventory Control System**

The foregoing analysis was based on the premise that information on scheduled requirements, items on order and stock levels would be readily available for use in the
decision rules. Thus the cost and benefits of improved data collection and generation must be assessed in order to determine the practicality of the new inventory control system. For this reason, some recommendations for implementing the control system are made particularly with respect to generating and processing the required data. Subsequently the costs of implementing and operating the system are approximated and compared to the benefits to be derived from operating the system for a three year period.

The requirements of the data processing phase are:

1) material requirements of scheduled production for the succeeding two months must be explicitly stated for all important items,\(^9\) 2) the stock level and amount on order for every important item must be known at each review period, and 3) the system must be easily updated to take effect of design and price changes. As mentioned earlier, the engineering department is undertaking a programme to develop an easily processed system for determining the material requirements of production schedules. This represents a formidable task because of the large number of items and the frequency of design changes which must be easily incorporated. One method of approaching this problem is to use a matrix formulation similar to the Lieberman proposal for designing information systems.\(^10\) Using this

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\(^{9}\)Important items are those for which there is a large enough dollar volume to make its formal control worthwhile. For instance, inclusion of odd sizes of nuts and bolts is
method, all material is considered in four levels, namely, raw material, parts, sub-assemblies and finished machines. Matrix multiplication will, for example, give the amount of each item of raw material used in a given set of sub-assemblies, or the numbers of each part required for a certain production schedule. Also design changes can be easily incorporated and the matrix formulation is very amenable to computer processing in that each part or sub-assembly used in the machine is identified by its position in a matrix. The development and use of this proposal is illustrated in Appendix II. Using this method the first and third requirements of the data processing phase would be accomplished.

A method of generating stock level information including quantities on order is an important consideration. The Company's present method of keeping inventory records would have to be changed so as to provide accurate, readily available data on receipts and withdrawals. This would involve the addition of a check-out system for material being transferred from inventory to production. Alternatively, a semi-monthly inventory count is possible but probably more expensive. Also, the quantities already on order but not yet received must be known and likely could be obtained from not regarded as worthwhile.

within the data processing system using past order decisions and receipt records.

Ordering rules, for the approximately two thousand items of importance, must be formulated. The seven items studied provide a clear indication of the variety involved but also they are fairly representative so that the rules for most other items can be based on the analysis already done. Thus the ordering decision rules for many of the other items, perhaps even a majority, can be based on the order rule of one or more of the seven items with some adjustment for prices. Even so, each one of the items would have to be examined to ascertain their relevant characteristics. Detailed analysis will be necessary to develop ordering rules for the other items. Also the ordering policies will have to be reviewed periodically to take effect of changed supplier policies, different production practices and improved data which become available for more exact analysis, thus permitting a closer approximation of the optimum ordering policies.

Preferably the data processing for updating inventory levels, calculating material requirements and determining order quantities will be done on a computer. The inputs would then be material withdrawals and receipts on a semi-monthly basis, and price and design changes and production schedules on a monthly basis. All of this data would have to be put
into a computer-acceptable form. The outputs would be current inventory levels, usage rate, material cost, total material requirements and reorder quantities. The purchasing department would use the results, perhaps adjusted with consideration of prospective strikes and other important random factors, to place orders using the present clerical procedure.

These considerations for implementing a total inventory control system suggest that the costs involved are appreciable. The task of incorporating bills of materials into a system for specifying the material requirements of production schedules is formidable even using the matrix formulation. Considerable professional and clerical time would be required, perhaps as much as 1,000 hours. However, there are benefits other than improved inventory control so that not all of the costs would be assigned to the inventory control system. Based on the experience of the author in dealing with the seven items that were discussed above, the cost of formulating the remaining items has been subjectively approximated as $7,000 considering the staff and consultant time involved. Programming the inventory control system would require approximately two months of a competent programmer's time and therefore would cost about $3,000. The present purchasing department staff could probably handle the data collection tasks but keypunching the data would be an addi-
tional operating cost as would the electronic data processing. Again using past experience as a criterion, the cost would be in the order of $500 per month. These rough estimates are listed in Appendix III which is a calculation of the net present value of the inventory control system. Further preliminary design of the system by a systems analyst would be necessary to refine these cost estimates.

To assess the feasibility of the system, some estimation of the benefits is also necessary. The simulated use of OR formulated decision rules for ordering seven items of Company F's inventory has indicated substantial benefits in terms of reduced inventory levels. These benefits are extrapolated for a one year period and displayed in terms of reduced inventory levels and ordering, out-of-stock and carrying costs in Table XI. The indicated seventy per cent reduction in inventory is somewhat misleading. About one half of the reduction is accounted for by item D to which no opportunity cost of funds can be associated because the Company is not invoiced for it until it is taken into the production process. Also these items tend to be among the most important to the Company in terms of dollar volume, replaceability and lead times.

Unfortunately, the prospective savings can not be used to accurately estimate the similar savings for the total inventory because the seven items do not represent a
<table>
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<th>Item</th>
<th>Average End-of-Month Inventory Level - $</th>
<th>Carrying Cost $/year</th>
<th>Ordering Cost $/year</th>
<th>Total Cost $/year</th>
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<td>Stock-out Cost $/year</td>
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random sample. A rough estimate based on the proportion of high-valued inventory, and assuming savings of the same proportion as for the seven items, indicates that as much as $15,000 per year could be saved. In addition, implementation of a formal inventory control system would reduce the necessity of informal communications and as a consequence increase labour productivity and reduce employee frustration. Also the accumulated data would be useful for further improving inventory control, for cost accounting and pricing, for parts books and for operations research in related areas.

The above discussion has provided estimates, though very rough, for evaluating the proposed inventory control system. Although the estimates are open to question, the calculation of the net present value of incorporating the inventory control system is informative for purposes of demonstrating a general approach to assessing the feasibility of operations research and systems design and implementation. The calculation is made in Appendix III using a three year time horizon. Future net benefits are discounted at twelve per cent to give a net present value of $9,500. This figure together with the other benefits already mentioned is evidence that operations research coupled with adequate information systems would be effective as an aid to inventory control in this small business.
V. OPERATIONS RESEARCH IN OTHER AREAS

Sales Forecasting

Section III of this chapter has outlined problems in other areas of the Company's operations. The problem of sales forecasting is all pervasive, particularly affecting production scheduling, inventory control and capital budgeting. Forecasting for equipment purchases is virtually impossible because it requires at least a three year forecast. However, the task of forecasting for inventory control and production scheduling is not as imposing.

In terms of the company's intention to gradually convert to modular production, sales forecasts are required for determining which and how many of each sub-assembly to build in the succeeding two months. Without actually formulating a production scheduling model, the required projection time is difficult to specify. Forecasts for one year would certainly be sufficient for production scheduling and inventory control.

There is some evidence that economic factors such as interest rates could be used for predicting the general level of demand. Past data on these factors could be used in a regression analysis to determine what effect they had on Company sales. If the regression coefficients were
statistically significant, the resulting equation could be used to forecast an approximate level of demand. This could be adjusted by the sales division's assessment of market share, client attitudes and other factors that become known to them through their contacts in the market.

This type of forecast is not sufficient for planning purposes. An estimate of the equipment types and models that will be demanded must also be made so as to determine the number of each sub-assembly that should be produced in a given time period. Initially, the subjective opinions of salesmen can be used for predicting the distribution of sales by type and model but careful analysis of client operating needs may refine the estimate. The seasonal pattern of demand is also necessary for planning. Statistical analysis of past sales should be sufficient to identify the seasonal factors in demand.

The application of operations research to sales forecasting is a means of relating all of these factors for formulating a comprehensive model which predicts the general level of demand, the components of forecast sales and the seasonal variation. Thus the sales of machines by type and by month is predicted so that the sub-assembly requirements for a two month period are obtained. The accuracy and thus the value of the model would be impossible to determine beforehand. Certainly export orders would produce considerable

random variations. Even so, the very large benefits that could be derived from accurate sales forecasting suggest that considerable effort should be expended in an operations research approach to this problem.

Production Scheduling

The problem of production scheduling breaks down into specifying completion dates and allocating tasks between production machines. With reference to the problem of specifying completion dates and given that sales do fluctuate, there exists separately or in combination a limited number of alternative courses of action. Listing them separately, they are: 1) maintain finished goods inventory, 2) backorder during periods of peak demand, 3) hire and lay-off workers as required, 4) maintain a full production complement while varying production rate or 5) use overtime labour during peak demand.

As suggested before the problem is to determine which alternative or, more likely, which combination of alternatives provides the minimum cost operation for a given sales forecast. In this regard considerable investigation is necessary to obtain the relevant costs. For instance, the cost of maintaining finished goods in inventory including the possibility of obsolescence must be determined.

A number of methods have been formulated for solving this type of problem. A series of models based on the linear
decision rules of Holt, et al. have been developed.\textsuperscript{12,13,14} Linear programming can also be used for this type of problem.\textsuperscript{15} No doubt there are other OR techniques that could be applied but to determine which of these models is most suitable for this situation would require considerable analysis and is beyond the scope of this thesis.

The aspect of allocating tasks to production machinery could be incorporated into a linear programming or simulation model which is also used for scheduling completion dates. Such a model would be complex and expensive to formulate. Rather, it is recommended that a small simulation model could be formulated to test various strategies. Only machines which can do similar tasks, would be incorporated. Perhaps even more benefit would accrue from doing economic lot size analysis for major parts with relatively high usage rates such as item B in the "Inventory Study".

**Capital Budgeting**

The problem of determining the production equipment

\textsuperscript{12}Holt et al, \textit{op. cit.} pp. 47-63

\textsuperscript{13}E.H. Bowman, "Consistency and Optimality in Managerial Decision Making" (1966) pp. 479-492.

\textsuperscript{14}E.S. Buffa, "Aggregate Planning for Production" (1967), pp. 87-97.

\textsuperscript{15}E.H. Bowman, "Production Scheduling by the Transportation Method of Linear Programming" (1966) pp. 475-479.
to buy so as to obtain a high return on investment while providing for rapid growth is extremely complex. Not only are there hundreds of alternatives but also an assessment of future requirements is nearly impossible. The large variety of parts required and the equally large number of machine tools available give rise to the multitudinous alternatives. The rapidity of technological change and the highly fluctuating demand for the Company's products give rise to the difficulties in determining future requirements.

In spite of the complexity of the problem, the decisions must be made either by "seat-of-the-pants" or varying degrees of analysis. The task of evaluating all possible alternatives to obtain rates of return for each is not feasible particularly because of the interacting nature of the alternatives. Perhaps a simulation model could be formulated but at this point it is difficult to envisage a workable model. A linear programming model could be formulated for selecting the best combination of production machines. In this model, the independent variables would be hours of machine time, the constraint equations would be based on the production requirements and the coefficients in the objective equation would be the charge-out rates which would be necessary to give an adequate rate of return on the capital invested in each machine. These proposals may not be practical but the complexity of the task and its importance to the Company's goals indicate that considerable operations analysis is warranted in the area of capital budgeting.
CHAPTER VI

SUMMARY AND CONCLUSIONS

This study was undertaken to determine the practicability of using operations research in small business. In the study, operations research is considered to be a separate management function in parallel relationship with systems analysis, industrial engineering and others, and is defined as research on the operations of goal-directed organizations. For purposes of this study, a business is considered to be small if the volume of its business as measured by value added is less than five million dollars per year.

The prevalence and effectiveness of OR in industry and the management needs of small businesses were examined to determine whether operations research should be used as a small business management aid. A number of surveys on the use of operations research in the United States, Canada and Britain indicate that OR is used by a significant and growing proportion of large companies, that it is proving to be an effective aid to management and that rather few small companies use OR. On the other hand, causes of small business failures and published research indicate that small business management is weak in areas where operations
research can be applied.

A survey of local small businesses was conducted by the author to assess the extent to which operations research is used in small business, to determine management's familiarity with operations research and to identify the reasons why it is not used more extensively. Managers of twelve firms were personally questioned according to a standard format. By and large the managers displayed considerable interest as evidenced by the length of the discussions which carried on for as much as three hours and never less than one hour in each case. As a result, the author gained considerable insight as to the attitudes of small business managers, the reasons for non-use of operations research and the operating problems of small business.

This survey, a survey on the use of modern management techniques by small businesses in the Atlantic provinces and conversations with consultants and others dealing with small business management problems have provided considerable evidence that operations research is used to a rather limited extent by small businesses generally. In the present survey, four out of twelve companies had used OR but then only as applied to one or two specific problems and not as a general activity. However, OR has proved effective in virtually all instances where it has been applied by companies in the survey and by other small businesses as reported in the literature.

The survey and research sponsored by the United States Small Business Administration have identified the following as
reasons why operations research is not used more extensively by small business:

1) The non-analytical approach of management to operating problems,
2) Management's lack of familiarity with OR,
3) The lack of small business personnel who are capable of doing operations analysis,
4) The unavailability of accurate, relevant data,
5) The cost and availability of electronic computers,
6) Managements' appraisal that costs are high and benefits small in using OR.

To varying degrees the above reasons are relevant to large companies but this study indicates that they are more prevalent in small businesses.

The survey confirmed the existence of problems to which operations research might well be applied. Inventory control, production scheduling and capital budgeting were identified as major areas in which problems exist that might be effectively solved by the application of operations research. The Small Business Administration sponsored research has indicated other problems, such as job cost estimating which could be solved by the use of OR.

The employment of consultants and the availability of inexpensive electronic data processing were examined as means of overcoming the lack of trained analysts and the high cost of leasing and operating computers both of which are hindrances
to the use of OR in small business. The high cost of retaining qualified consultants tends to overshadow the obvious benefits of their services. Examination of the reasons for the high cost of consultant's services suggests that they can be more effectively retained for applying operations research to a small business under the following conditions:

1) The consultant maintains a continuing relationship with the small business and is able to offer assistance in other functional areas.

2) The consultant has a small and flexible operation which uses the services of other qualified persons in periods of peak activity.

Computer service bureaus, computer time-sharing services and small, leased computers are discussed for purposes of identifying their suitability as tools in formulating and implementing operations research in a small business. Small computers are fairly expensive in terms of rental and operating costs and therefore they are only feasible if the small business has many other EDP jobs besides operations research. Also, they may not be capable of efficiently handling the large models which might be formulated in the course of operations research activities. The time-sharing service is an economical and flexible tool for obtaining solutions to capital budgets, linear programmes and other OR techniques of limited size. Maintaining proprietary
programmes and data on-line in disc storage at time-sharing facilities may be warranted for ease of updating and accessing data files and for quick decision making such as calculating a reorder quantity. This service will become increasingly attractive with the development of computers with even greater capabilities but will be limited in remote areas by the relatively high cost of communication lines; For periodic batch processing of computer programmes based on operations analysis, the computer service bureaus offer an inexpensive service.

The preceding summary has indicated that in general operations research might well be applied to small business management problems and that in particular it has been successfully applied in a number of cases. The reasons which up to the present have limited the use of operations research in small business have been identified and suggestions given for overcoming these hindrances. However, the practicability of using OR in small business can only be determined in a particular situation. To this end a case study of a local small company was made to identify problems to which effective solutions might be found through operations analysis and to assess the value of operations research as applied to one of the problems.
Many hours were spent with the Company's executives in discussing the business, organization and operations of the Company and in identifying major operating problems. The main objective of the Company is rapid growth with an adequate profit on sales as a manufacturer of heavy equipment which is used in one phase of a major Canadian industry. Problems in the areas of sales forecasting, capital budgeting, production scheduling and inventory control were noted as being constraints to the successful attainment of the company's objectives.

Inventory control was selected as an area to illustrate operations research as applied to a small business. The relevant characteristics of the Company's inventory were determined in discussions with purchasing department personnel and by examination of inventory records, bills of material and other data. The lack of explicitly stated information on stock levels and material requirements were identified as constraints to the effective control of inventories. The wide variety of items in terms of supplier policies, value, demand characteristics and plant production practice eliminated the possibility of using a small random sample as a basis for determining the value of an operations research based inventory control system. As an alternative seven important and representative items were selected as the basis for proposing and evaluating
The rather unusual and varied characteristics of these items made it impossible to use any one standard textbook technique for formulating the ordering decision rules. The standard economic order quantity formula was used to determine the frequency of orders recognizing that certain considerations suggested against ordering more frequently than twice a month. The concept of decision tables was adapted for determining the quantity of reserve stock which would result in the lowest expected inventory costs. In this regard, subjective probability distributions were obtained from the Company's managers for determining the expected out-of-stock cost for each item. Thus the author used a rather unique overall approach to formulating ordering policies for each of the seven items.

The ordering decision rules were then used in simulations of past experience to estimate improvements in operations as compared to actual performance. The estimated gross benefits for seven items would have been $3400 if the decision rules had been used for a recent one year period. Consideration of the requirements of an inventory control system using ordering rules based on operations research for all important items provided a basis for making rough estimates of the cost of formulating, implementing and
operating the system. These costs together with a projection for three years of the prospective economic benefits indicated that the system had a net present value of $9500 using twelve per cent as an estimate of the firm's cost of capital. The economic and other benefits of this proposed system are evidence of the practicability of using operations research in small business. Subsequently, suggestions were made for applying OR in the areas of sales forecasting, production scheduling and capital budgeting.

In conclusion, the study has provided considerable evidence to support the three propositions in the Thesis Statement.¹ That operations research is rarely used in small business was indicated by the author's survey of local small companies and by other reported surveys. The study also indicated that operations research is used to a rather limited extent in small businesses because of management's lack of familiarity with OR and because of the lack of small business personnel who are capable of doing the operations analysis; although the survey and other research identified additional reasons for non-use. Finally, many problems to which OR can be applied exist in small business; operations research has generally been effective when applied to small business problems, the effectiveness of OR has been illustrated in a case study; and many of the reasons for not using operations research in

¹See page 1
small business can be overcome. These statements, which are based on the findings of this study, support the proposition that operations research could be used more extensively as an effective aid in the management of small business.
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APPENDIX I

QUESTIONNAIRE USED IN SURVEY OF
LOCAL SMALL BUSINESSES

The author made appointments with managers of local small businesses to obtain answers to the following questionnaire. Many of the questions, particularly as to the feasibility of using OR, could only be answered in many cases after considerable explanation by the author. Thus the necessity of the interview technique.

The questions asked by the interviewer are listed as follows:

1) What is the size of this business in terms of number of employees and value added (or sales revenue if value added is not available)?

2) How many professionals (or university graduates and technologists does this firm employ?

3) Has this firm ever obtained the services of management consultants?

4) Is the management of this company familiar with the following terms?

- Operations Research
- Critical Path Methods
- Inventory Control - Economic Order Quantities
- Mathematical Programming
- Simulation
- Capital Budgeting

Depending on the knowledge displayed by the manager, the author gave brief explanations of the above terms particularly emphasizing operations research.

5) Has any member of the management team of this firm ever used OR in solving a particular problem?

A) The following questions are for those who answered #5 in the affirmative.

A6) In the management's opinion were the results effective? Can you (the executive) give concrete results?

A7) If the results were not effective, what were the main causes or downfalls?

A8) Is operations research being used on a regular basis? - in which area(s)?

A9) Are there any plans to broaden the use of operations research in this business? Are there problems in this business which OR might effectively solve?

A10) Generally, to what extent does the OR applied in this business reap benefits in excess of costs?

A11) What are the constraints on the increased use of OR in this business? (eg. suitable problems, trained personnel, data availability, dynamic changes in the environment.)

B) Questions to be answered by those who responded to #5 in the negative.
B6) Has management ever considered the use of operations research to improve operating efficiency? If not, why not? (eg. unfamiliarity, lack of trained personnel, lack of suitable problems, data availability?)

B7) What are the main problems in managing this business to which no satisfactory solution has been obtained? Would solution of these problems result in increased profits?

B8) Does the executive consider that OR might be usefully applied to find a solution to these problems?
APPENDIX II

GENERATING MATERIAL REQUIREMENTS USING
A MATRIX FORMULATION

A materials 'explosion' system has many similar properties to a business information system as perceived by Lieberman. Just as there are various reporting levels in a business information system so also are there manufacturing 'levels' in the material flow of certain industrial processes. Corresponding to the accumulation of data into reports is the accumulation of material into sub-assemblies and final products and so on.

To illustrate the use of a matrix formulation in generating materials requirements, four manufacturing levels are considered as listed below:

- Machines (Type and Model) - I, II
- Modules (Sub-assemblies) - A, B, C
- Parts - 1, 2, 3, 4
- Raw Materials - a, b, c

Engineering drawings give the amount of each material used in each part. Bills of material give the number of parts used in each module and the number of modules used in each machine. The following matrices are illustrative.
\[
M_1 = \text{Materials} \\
\begin{array}{cccc}
\text{Parts} & 1 & 2 & 3 & 4 \\
\hline
a & 0 & 2 & 0 & 1 \\
b & 0 & 0 & 1 & 0 \\
c & 1 & 0 & 0 & 1 \\
\end{array}
\]

\[
M_2 = \text{Modules} \\
\begin{array}{ccc}
\text{Parts} & A & B & C \\
\hline
1 & 1 & 0 & 2 \\
2 & 0 & 1 & 1 \\
3 & 1 & 1 & 0 \\
4 & 0 & 1 & 1 \\
\end{array}
\]

\[
M_3 = \text{Machines} \\
\begin{array}{cc}
\text{Modules} & I & II \\
\hline
A & 2 & 1 \\
B & 1 & 1 \\
C & 0 & 1 \\
\end{array}
\]

For instance, part No. 2 is manufactured from two units of material a and machine I is composed of two A modules and one B module.

Suppose that we wish to find the amount of each raw material that is required in each module. To do this we multiply \( M_1 \) by \( M_2 \), that is:

\[
M_{1,2} = M_1 \times M_2 = \text{Materials} \\
\begin{array}{ccc}
\text{Modules} & A & B & C \\
\hline
a & 0 & 3 & 3 \\
b & 1 & 1 & 0 \\
c & 1 & 1 & 3 \\
\end{array}
\]
Module A requires a unit of both a and b, module B requires three units of a and one of both b and c, etc. Similarly, the number of each part required for machines I and II can be obtained by multiplying $M_2$ by $M_1$ and the amount of each raw material required in both machines by multiplying $M_{2,3}$ by $M_1$.

\[
M_{1,2} = M_2 \times M_1 = \begin{array}{c|cc}
\text{Modules} & \text{I} & \text{II} \\
1 & 2 & 3 \\
2 & 1 & 2 \\
3 & 3 & 2 \\
4 & 1 & 2 \\
\end{array}
\]

\[
M_{1,3} = M_{2,3} \times M_1 = \begin{array}{c|cc}
\text{Materials} & \text{I} & \text{II} \\
\text{a} & 3 & 6 \\
\text{b} & 3 & 2 \\
\text{c} & 3 & 5 \\
\end{array}
\]

From this result we have determined for example, that machine I requires three units of each of materials, a, b and c.

The matrix formulation has a number of advantages, both for processing the information and for conceptual understanding. The full scale matrices for the company may be somewhat large for hand manipulation but for computer pro-
cessing they permit ease of data preparation. Each factor is identified by its position in the matrix and so it can be readily coded. Also the requirements matrix can be easily adjusted for design changes. For instance if module C is added to machine I the parts and material requirements of machine I can be adjusted by matrix multiplication without even investigating the contents of module C.

The matrix formulation also provides a means of visualizing the relationships between materials, parts, modules and machines from a logistics point of view. The effect of changing the component structure of a machine on the material requirements and consequently the material cost of a machine is easily calculated. For instance, suppose for technical improvements that an additional module B can replace one of the A modules in machine I if part No. 1 is added to module B. What effect will this design change have on the material requirements and material cost of machine I?

Multiplication of the adjusted matrices gives the following result:

\[
\begin{array}{ccc}
\text{M}_{13} &=& \text{Materials} \\
& & \text{I} & \text{II} \\
\text{a} & 6 & 6 \\
\text{b} & 3 & 2 \\
\text{c} & 5 & 5 \\
\end{array}
\]

Thus the material requirements of machine I have been
increased by 3 units of a and 2 units of c, the unit costs of which are presumably well known.

The application of the matrix formulation to an integrated system of forecasting, production scheduling and inventory control is illustrated by the following example. For this purpose, the forecasting and scheduling models for the Company are presumed to have been formulated and implemented.

Suppose that forecasted sales for the next six months are ten of machine I and twenty of machine II. The module requirements of this forecast are easily determined using matrix $M_3$, and multiplying each element under I by 10 and under II by 20 and adding along the rows as illustrated.

\[
\begin{array}{c|cc}
\text{Machines} & \text{I} & \text{II} \\
\hline
\text{Sales Forecast} & 10 & 20 \\
\text{Module} & A & 2 & 1 & = 40 \\
\text{Requirements} & B & 1 & 1 & = 30 \\
& C & 0 & 1 & = 20
\end{array}
\]

For instance forty A modules are required. Assume also that a production scheduling model has been implemented and it suggests one fifth of the module requirements should be produced in the next two months. What are the material requirements of this schedule? Using matrix $M_{1,2}$ we obtain
the following result:

<table>
<thead>
<tr>
<th>Modules</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Schedule</td>
<td>8</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Material</td>
<td>a</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Requirements</td>
<td>b</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Thus the material requirements for a, b and c are 20 units, 14 units and 26 units respectively. These quantities would be inputs to the ordering rules for items a, b and c to determine how much of each should be ordered at the present and subsequent inventory reviews as proposed in the 'Inventory Study' of Chapter V.
APPENDIX III
CALCULATION OF PRESENT VALUE OF PROPOSED
INVENTORY CONTROL SYSTEM

Costs

The cost items have been surmised from conversations on the subject with the Company's management, consultants and service bureau personnel. The cost of analysis and formulation of decision rules is based to some extent on the work by the author formulating the decision rules for the seven items.

Benefits

The estimate of the reduced costs of inventory operation are based on prospective savings through reduced inventory levels minus the additional ordering costs as indicated by the simulation results for the seven items that have been studies¹.

Calculation

The net present value is calculated using a three year time horizon and a twelve per cent rate for discounting future benefits and costs, that is, items 5 and 6.

¹The detailed calculation can not be displayed without divulging confidential information.
### TABLE XII

NET PRESENT VALUE CALCULATION OF THE
PROPOSED INVENTORY CONTROL SYSTEM

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Cost($)</th>
<th>Benefit($)</th>
<th>Present Value($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Inventory system share of developing a material requirements system - Engineering Dept.</td>
<td>$2,000</td>
<td>$2,000</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Analysis of requirements and formulation of decision rules</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- staff and consultant</td>
<td>$1,000</td>
<td>$1,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- up to present</td>
<td>$7,000</td>
<td>$7,000</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Developing a new inventory information system</td>
<td>$1,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Programming system for electronic data processing</td>
<td>$3,000</td>
<td>$3,000</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Annual cost of key punching and electronic data processing</td>
<td>$6,000</td>
<td>$15,000</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Estimated annual benefits in terms of reduced inventory costs.</td>
<td>$15,000</td>
<td>$37,500</td>
<td></td>
</tr>
</tbody>
</table>

Net Present Value $9,500