

**IDRC-MR56e**

International Development Research Centre  
**MANUSCRIPT REPORTS**

**Approaches to Process Improvement  
for Small-Scale Food Industry  
in Developing Countries**

**Compiled by A.M. Anderson**

**March 1982**



The International Development Research Centre is a public corporation created by the Parliament of Canada in 1970 to support research designed to adapt science and technology to the needs of developing countries. The Centre's activity is concentrated in five sectors: agriculture, food and nutrition sciences; health sciences; information sciences; social sciences; and communications. IDRC is financed solely by the Government of Canada; its policies, however, are set by an international Board of Governors. The Centre's headquarters are in Ottawa, Canada. Regional offices are located in Africa, Asia, Latin America, and the Middle East.

### **IDRC Manuscript Reports**

**This series includes meeting documents, internal reports, and preliminary technical documents that may later form the basis of a formal publication. Manuscript Reports are given a small distribution to a highly specialized audience.**

APPROACHES TO PROCESS IMPROVEMENT  
FOR SMALL-SCALE FOOD INDUSTRY  
IN DEVELOPING COUNTRIES

A manual prepared by workshop teams  
at the Thailand Institute  
of  
Scientific and Technological Research  
in  
February 1981

Compiled by  
A.M. Anderson



## FOREWORD

It has been suggested to IDRC that the small- and medium-scale food processing sector in many developing countries is generally made up of family-run businesses, which have evolved over the years, with little access to capital or technical services. Inefficiencies in operation and control of food processes result in erratic quality and product yields. Inevitably this leads to reduced returns to the processor and jeopardizes his position as a reliable supplier in the marketplace. For the thousands of small family-owned food factories in Thailand, these conditions are common, meaning that there is significant wastage of food, capital, and human resources due to inefficient processing procedures and operational management at these factories. Of special concern is the relatively low efficiency with which energy sources are used. Additionally, the existence of these small businesses is being increasingly threatened by reliance of retailers and customers on the more secure supplies of processed foods from larger, more highly mechanized, food companies, many of which are subsidiaries of foreign companies. These small processors are a vital link in the food chain for both the urban poor and the rural poor who depend on traditional food-stuffs as a part of their diet. These small industries also provide employment in both urban and rural areas.

IDRC is therefore supporting projects involving on-site studies in small factories, thereby developing methodologies for improving the operational management, processing and control procedures and allocation of resources.

This publication follows on the recommendations of the recent IDRC-sponsored workshop on Approaches to Process Improvement for Small Food Industry in Developing Countries held in Singapore in October 1980 (MR 48E) and describes some of the quantitative operations-research techniques, used successfully in larger-scale industries, that may be adapted to smaller scale-plants. These techniques were introduced to the group at Thailand Institute of Scientific and Technological Research in Bangkok during a workshop held there in February 1981, as approaches to be tested in their forthcoming project in noodle factories. The final chapter describes some of these ideas applied in particular factories during the workshop.

IDRC appreciates the contribution the group of consultants and the research team made to focusing on particular techniques and particularly to Dr. A. Anderson, for compiling the information in this publication, so that the ideas can be more widely shared and can stimulate others interested in this important applied-research area.

Dr. William Edwardson  
Program Officer  
Post-Production Systems  
IDRC, Edmonton



## DESCRIPTION OF MANUAL

The preparation of this manual on process improvement for small food businesses in developing countries was sponsored by the International Development Research Centre, Canada.

The manual is a direct result of a workshop on process improvement held in Bangkok in February 1981. The format for that workshop was highly successful and the material presented by the visiting tutors proved to be relevant to the Thai situation. It was therefore decided to prepare a manual which could be used as a basis for future process improvement workshops in other developing countries.

The manual is divided into 3 parts. Part 1 describes the background to the preparation of the manual and the programme for the workshop. Part 2 contains a selection of techniques which may be applied to process improvement. These are under 3 headings - Production management, Operational research/systems analysis and Experimentation. Part 3 contains two case studies which were prepared at the Thai Workshop and which demonstrate the systematic approach to process improvement presented in the workshop.

Emphasis throughout the manual is on a systematic and, wherever possible, a quantitative approach to process improvement.



## CONTENTS

	<u>Page</u>
<u>PART 1</u> THE WORKSHOP	1
1.    Background	3
2.    The Thai workshop	6
3.    The basis for a process improvement workshop	9
<u>PART 2</u> TECHNIQUES AND METHODOLOGY	14
4.    Introduction	18
5.    Production management	19
6.    Operational research and systems analysis (OR/SA)	76
7.    Experimentation	132
<u>PART 3</u> CASE STUDIES	162
8.    Case studies from the Thai workshop	164

NOTE: Detailed Contents are included at the beginning of each part.



1.

## **PART 1**

# **THE WORKSHOP**

## CONTENTS

	<u>Page</u>
1. Background	3
2. The Thai workshop	6
2.1 The venue	6
2.2 The participants	6
2.3 The tutors	6
2.4 The Thai food industry	6
2.5 Aim of the workshop	7
3. The basis for a process improvement workshop	9
3.1 An outline of the workshop	9
3.2 Workshop programme	12

## 1. BACKGROUND

In October, 1980 the International Development Research Centre (IDRC) organised, in Singapore, a workshop on Process Improvement for small businesses in developing countries.

It had been suggested to IDRC that the small to medium scale food processing sector in many developing countries was neglected in terms of research and development. This sector is generally made up of family run businesses with little access to capital and technical services. In many countries this group of processors is the main source of low-cost, traditional food products, such as soya sauce, fish balls, cereal-based snacks and fermented foods. Larger industries, with access to capital and technical services, are able to modernise and achieve economies of scale. The smaller processor sees his markets and profitability shrink as he finds it increasingly more difficult to match the quality standards, changing market requirements and pricing of his larger competitors.

In several countries, efforts are now being made to strengthen this small and medium scale food processing sector. These efforts promote self-reliance by encouraging development of local industry, with local skills, to meet the unique market conditions. A solid base of indigenous small industry should lead to development of medium and larger scale industries in the future.

With these suggestions in mind, IDRC sponsored its first project on process improvement in small businesses of developing countries. This project was carried out in Singapore by a small research group from the Singapore Institute of Standards and Industrial Research (SISIR).

The October 1980 workshop was aimed at evaluating the potential and direction for process improvement in developing countries on the basis of the results of SISIR project and the experiences of representatives from a variety of developed and developing countries. The workshop brought together two groups of people. Firstly, representatives from developing countries reported on the state of the food industry in their country, described the institutions and services available to small food companies and suggested changes that would improve the services provided for process improvement. These participants came from institutes which had responsibility for improvement of small food companies. The countries represented were Singapore, Chile, Philippines, Central America and Thailand. Secondly, five applied scientists from developed countries were invited to describe the approaches they had used for process improvement. These scientists came from Great Britain, Canada and New Zealand representing Research Institutes and Universities.

During the workshop, three factories were visited - wheat noodles, rice noodles and soya sauce. These factories provided the basis for discussion on the potential for application of the approaches, presented by the five applied scientists, to the specific problems of food processing in developing countries. These discussions led to certain key recommendations and conclusions:

1. The standard production management, operational research and experimental design techniques used for process improvement in developed countries were equally applicable in developing countries. Only minor modifications were required to allow for environmental conditions, management procedures and analytical facilities available. Simple techniques which can be quickly and simply applied and which can be explained to factory staff are preferable.
2. There are many advantages in using multidisciplinary personnel for industrial research. Where such people are unavailable a team comprising specialists with a variety of backgrounds might be used, e.g. food science, engineering, management, economics and statistics.
3. While university departments have the potential for offering technical services, government research institutes can probably react more quickly to industrial enquiries and have a team of more general and applied scientists to tackle industrial projects. It is important that any organisation which carries out industrial research should be as free as possible of red tape and bureaucratic procedures. Close and direct contact with industry is essential if continued success is to be achieved.
4. Training is probably the most important component in the development and use of appropriate research methodologies for process improvement in the small businesses of developing countries. This includes both training of research personnel and of individual company owner/managers and their staff. The preferred approach is to organise short courses to train small groups of researchers who in turn will pass on their knowledge to food company personnel, either through workshops/seminars or project work within the company.

In conclusion the workshop recommended that

SUPPORT BE PROVIDED FOR RESEARCH ON PROCESS IMPROVEMENT IN THE SMALL FOOD INDUSTRIES OF DEVELOPING COUNTRIES THROUGH IDENTIFICATION AND DEVELOPMENT OF APPROPRIATE APPROACHES IN THIS RESEARCH AND THE SUBSEQUENT DEVELOPMENT OF SHORT COURSES FOR MORE EXTENSIVE TRAINING.

As a result of the recommendations and conclusions from the Singapore workshop it was decided that IDRC should sponsor a training workshop in Thailand with a view towards a longer term project on process improvement in that country.

## 2. THE THAI WORKSHOP

### 2.1 The Venue

The workshop was held at the Thailand Institute of Scientific and Technological Research (TISTR) in Bangkok between February 16 - 27, 1981. TISTR is a non-profit making state enterprise, under the Ministry of Science, Technology and Industry. The Institute is entrusted with the main task of bringing the results of research to application for the benefit of the economic and social development of the country. TISTR is staffed with 185 graduates in 32 disciplines, viz. science, engineering, technology, economics and social science.

### 2.2 The participants

The workshop was attended by 12 members of the TISTR staff. Six were considered active participants of the workshop and were the proposed members of the research team for a longer term IDRC project. The other six were observers who would act as support staff to the research team. The 12 participants represented a variety of disciplines including food science, food technology, engineering and economics.

### 2.3 The tutors

Tutors for the workshop represented research institutes and universities from 3 countries. Allan Anderson from the Food Technology Department at Massey University in New Zealand has experience in the application of quantitative techniques for product and process design in small companies. David King from British Columbia Research Centre, Canada, is responsible for a management services programme which encourages developments in technology, productivity and management in small business. Graham Rand from the Department of Operational Research at the University of Lancaster, England, is involved in production planning, distribution studies, job evaluation and assessment of communication effectiveness for a variety of industries.

### 2.4 The Thai food industry

Thailand is a country rich in natural resources. Its agricultural crops include fruit, vegetables, cereals, oil seeds, root crops and fish. Although these crops have considerable value in the fresh form, there is an obvious need for processing facilities to provide a year round supply of food products to the market place and to add value to the crops, both for the domestic and export market.

The food industry is, therefore, considered to be one of the most important to the socio-economic development of the country. The Thai food industry may be classified into three levels - large, small and cottage - according to the number of employees, the production capacity and the technologies used. Approximately 65 percent of the registered factories employ less than 10 persons and 30 percent fall into the 10-49 employee category. Therefore, the small and cottage style industries account for 95 percent of the total number of manufacturing enterprises.

Large industry is considered to be capital and labour intensive. The plants have modern equipment, most of which is imported. The products are mainly for export, using imported technologies. The level of technology, efficiency and quality control is generally high.

The village or cottage industry is generally labour intensive and uses unsophisticated plant. Processing methods are simple and traditional. Production is small and directed to local areas. Quality control and hygiene standards are generally low. Management of the factory is normally by the owner or members of his family.

Small size industry is similar to cottage industry but normally has a higher capital input and greater mechanisation. The products are of a higher and more consistent quality.

The vast majority of Thai food companies are, therefore, small, lacking in technological expertise and producing products of inconsistent quality with limited quality control. Probably, the most serious problem is lack of basic technological education.

Traditional methods are repeatedly practised without proper modification. Improvements have been through trial and error and there is frequent use of unsuitable additives such as colours and preservatives without proper knowledge of their effects on the consumer.

#### 2.5 Aim of the workshop

TO PROVIDE A FORUM FOR DISCUSSION ON THE POTENTIAL FOR FOOD PROCESS IMPROVEMENT IN THAILAND AND TO PRESENT RECOMMENDATIONS ON THE GENERAL DIRECTION FOR PROCESS IMPROVEMENT IN THAILAND AND ON THE SPECIFIC CONTRIBUTION TO BE MADE BY TISTR.

The recommendations from the Singapore workshop and the current state of processing in the cottage and small Thai food industries suggest technological education is a high priority for process improvement. The workshop at TISTR provided an

opportunity to bring together a multidisciplinary group of researchers, to present to them some methods for process improvement and to evaluate the potential for application of these methods in Thailand. It was intended that at the end of the workshop this group should be able to demonstrate the value of these methods by practical application to problems in specific Thai companies.

### 3. THE BASIS FOR A PROCESS IMPROVEMENT WORKSHOP

The format of the Bangkok workshop proved to be very successful and the material presented by the 3 tutors had obvious applications to the Thai food industry. It was suggested, therefore, that this format and material should be presented in a single volume to act as a manual for future workshops, either in Thailand or other developing countries.

#### 3.1 An outline of the workshop

The workshop outline which is presented in the remainder of this manual is based on the experiences of the Thai workshop but is designed for general application in other countries.

The workshop is based on a systematic and integrated approach to process improvement. Emphasis is placed on process improvement within the total company framework and with reference to all company functions - marketing, finance, administration and production. The procedure for process improvement taught in the workshop follows a systematic analysis by:

1. Understanding the company structure and the role that processing plays.
2. Gaining complete knowledge of the process - product, raw materials, processing steps, quality control and labour.
3. Representing the process flow by a process flow chart to demonstrate the process operations, transports, delays and inspections.
4. Identifying the key operations in the process.
5. Screening the key operations to select those with greatest potential for improvement.
6. Choosing systematic methods for experimentation on the selected key operation(s) - experimental design, operational research or systems analysis techniques.
7. Following through the process improvement experimentation from laboratory to pilot plant and finally to the factory wherever possible.

The exact format for a workshop on process improvement will depend on the experience and requirements of the participants. A general outline of the workshop is presented in Figure 3.1 and a more detailed daily programme is presented in Section 3.2.

The success of the workshop will depend to a large extent on its application to local conditions and problems. Factory visits and ample feedback from the participants are essential. The outline in Figure 3.1 suggests that day 1 to day 6 be spent on lectures by the tutors and discussions based on the first set of factory visits. The evaluation of these factories should initially be directed by the tutors with increasing involvement by the participants as they gain confidence in the methods being employed. Day 7 to day 10 then give an opportunity for a strong emphasis on the participants' analyses of a second set of factories with only minor contributions from the tutors.

It is suggested that although flexibility is necessary in the workshop programme, the basis should always be the process flow chart and identification of key operations. This forces the researcher to gain a complete understanding of a process and provides an excellent foundation for implementation of process improvement strategies. The researcher should also be fully aware of the company structure and the other company functions. He should not restrict himself to a study of the process in isolation. Market requirements, raw material supply, management structure, socioeconomic status of the labour force and many other factors, both internal and external to the company, may have a dramatic impact on the selection of process improvement strategies.

The vast range of experimental design, operational research and production management techniques available to the process improvement researcher prohibits a full coverage in a 10 day workshop. Two solutions to this problem are possible. Firstly, to teach a selection of the techniques and then look for potential applications during the factory visits. Or, secondly, to visit the factories first and select areas for process improvement. Specific techniques can then be taught by application to these specific cases. The second approach is preferred and forms the basis for the detailed workshop programme presented in the next section. A selection of techniques which may be applied is presented in Part 2 of this manual.

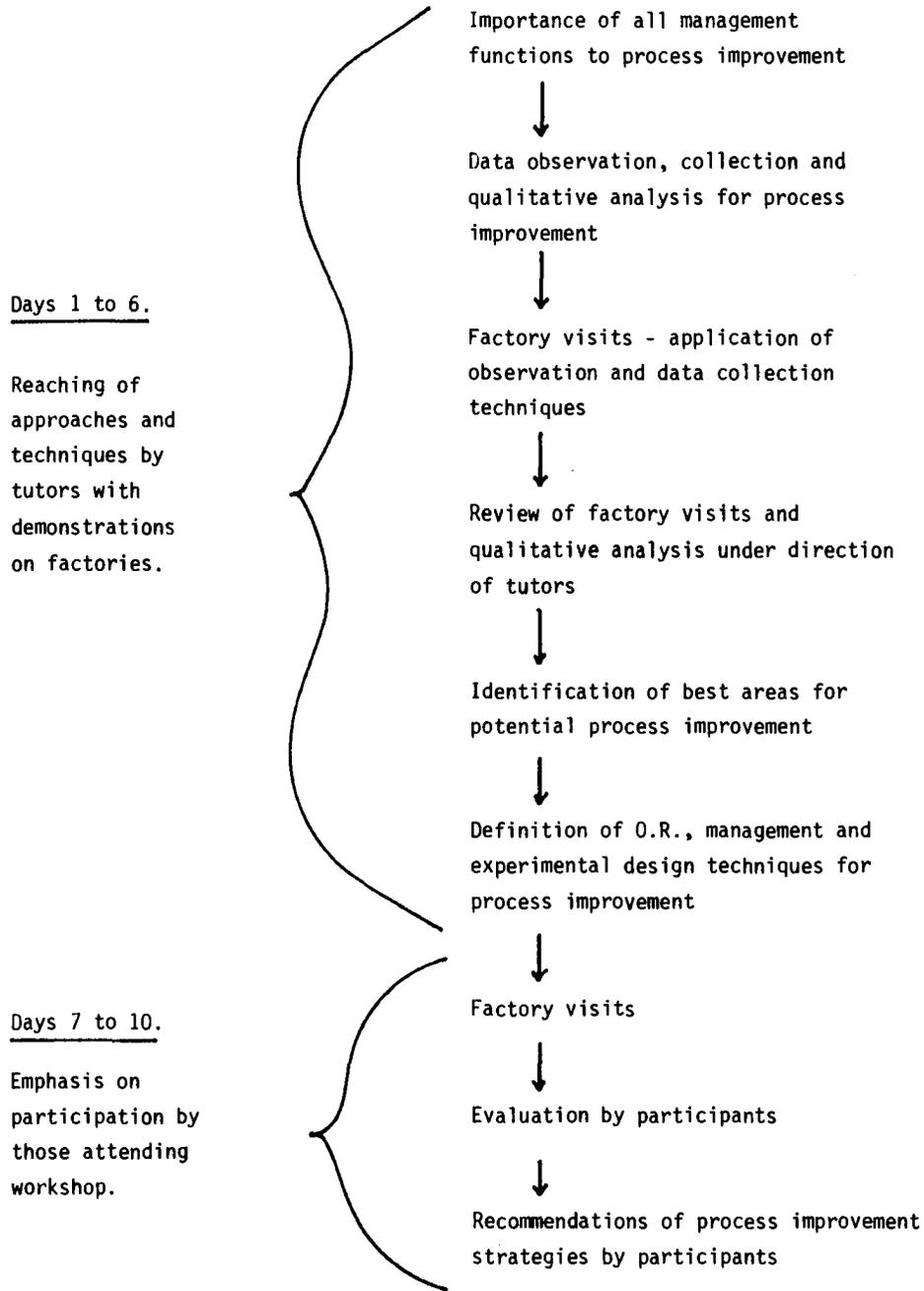


Figure 3.1 Workshop Outline

### 3.2 Workshop programme

The programme outlined below is purposely quite flexible to allow for the tailoring of the course content to meet the individual requirements of the participants.

#### Day 0. Orientation and preparation by the tutors.

At least one day is required to familiarise the tutors with the environment of the host country and to prepare a suitable programme. The length of this preparation period will depend on the familiarity of the tutors with the host country and on the number of times they have worked together.

#### Day 1. Introductions and presentation of the company in overview.

Emphasis should be placed on the importance of all functions to the successful operation of a food company, in particular the interrelationship of marketing, finance, administration and production. Process improvement cannot be carried out as an exercise in science and technology in isolation from the other company functions (see section 5.1).

Discussion of the fully integrated process and product development system to demonstrate the interrelationship of all company functions.

#### Day 2. Data observation, collection and qualitative analysis.

Techniques of production management to be discussed based on method study for:

- selecting work to be studied - Pareto's law, work sampling (see section 5.5);
- recording - process charting (sections 5.6, 5.7, 5.8).

#### Day 3. Factory visits.

Two or three factories. More time should be spent at one factory for a more concentrated analysis (approximately 3-4 hours required). Emphasis should be placed on application of data collection techniques described in Day 2.

#### Day 4. Review of factory visits.

First pass evaluation. One factory to be selected and evaluation to be carried out under the direction of the tutors. Emphasis should be placed on process charting to get a full understanding of this procedure.

#### Day 5. Continuation of factory evaluation.

Selection of key operations (section 5.10). Definition of

potential improvement strategies and screening of these strategies (section 5.11).

Homework set for participants to evaluate other factories from Day 3 visits.

- Day 6.      Review of participant's factory evaluation.  
Discussion of potential areas for application of operational research and experimental design techniques (Sections 6 and 7).
- Day 7.      Factory visits - 2 factories.
- Day 8.      Factory evaluations by participants.  
Detailed evaluation by process charting, outline process chart, identification of key operations, screening key operations, suggestion of process improvement strategies.
- Further discussion of applicable operational research and experimental design techniques.
- Day 9.      Further discussion of applicable techniques.  
Presentation of project planning procedures (section 6.4.3).
- Day 10.     Planning on-going research programme for the participants of the workshop.  
Workshop evaluation and summing up.



**PART 2**

**TECHNIQUES  
AND  
METHODOLOGY**

CONTENTS		<u>Page</u>
4.	Introduction	18
5.	Production management	19
5.1	Structure of a company	19
5.2	Product and Process development - an integrated and multidisciplinary approach	22
5.3	Setting corporate objectives	22
5.4	Management by emphasis	29
5.5	Method study - selecting the work to be studied	32
5.5.1	Pareto's law	35
5.5.2	Standardized list of points to be covered	35
5.5.3	Work sampling	37
5.6	Method Study - Recording (introduction)	49
5.6.1	Introduction	49
5.6.2	Objectives	49
5.6.3	The relevant facts	49
5.6.4	Scale	49
5.6.5	Recording techniques	49
5.7	Method study - Recording (charting-conventions)	51
5.7.1	Introduction	51
5.7.2	Objectives	51
5.7.3	Process chart symbols	51
5.7.4	Process chart conventions	53
5.7.5	Multiple activity chart conventions	58
5.7.6	Chart identification	58
5.8	Method study - Recording (outline process chart)	59
5.8.1	Introduction	59
5.8.2	Description of outline process chart	59
5.8.3	Use of outline process chart	60
5.9	Method study - Recording (charting-application)	60
5.10	Method study - Selection of key operations	61
5.10.1	Key operations	61
5.10.2	Statement of achievement/end result	63
5.11	Deciding on process improvement alternatives	63
5.12	Plant layout	65

	<u>Page</u>
6. Operational research and systems analysis (OR/SA)	76
6.1 The nature of operational research and systems analysis	76
6.2 Significant features and problems of small firms	78
6.3 Problem areas in a food company	79
6.3.1 Production	79
6.3.2 Inventory	81
6.3.3 Distribution	81
6.4 Potentially useful techniques	81
6.4.1 Systems analysis	81
6.4.2 Linear programming	91
6.4.3 Network analysis	104
6.4.4 Calculus	107
6.4.5 Quality control	109
6.4.6 Forecasting	113
6.4.7 Simulation	117
6.5 Implementation of OR/SA	121
6.6 Implementation of OR/SA in developing countries	123
6.7 Some recommendations	128
6.8 References	129
7. Experimentation	132
7.1 Experimental design for process improvement	132
7.1.1 Systematic approach to experimental design	133
7.2 Experimental design methods	136
7.2.1 Screening experiments	136
7.2.2 Factorial experiments	138
7.2.3 EVOP (Evolutionary operations)	140
7.2.4 Mixture designs	140
7.3 References	143
7.4 Example of screening experiment	143
7.4.1 Problem definition	143
7.4.2 Objective	143
7.4.3 Experimental variables	143
7.4.4 Analysis	145
7.4.5 Calculation of effects and error	146
7.4.6 Discussion of results	147
7.4.7 Conclusion	148
7.5 Example of a factorial experiment	148
7.5.1 Introduction	148
7.5.2 The dehulling process	149
7.5.3 Experimental design	149
7.5.4 Results	152

	<u>Page</u>	
7.5.5	Discussion of results	153
7.5.6	Appendix of analyses	154
7.6	Example of a mixture experiment	156
7.6.1	Problem definition	156
7.6.2	Aim of experimental formulation	156
7.6.3	The mixture design	156
7.6.4	Study of effects	158
7.6.5	New area for experimentation	159
7.6.6	Conclusion	161

#### 4. INTRODUCTION

This part of the manual describes techniques and methodology which could prove useful for process improvement in developing countries. These techniques are divided into 3 broad categories:

Production management

Operational research/systems analysis

Experimentation

There will normally be insufficient time during a 10 day workshop to cover all the material included in the following sections. Some material may be omitted but it is suggested that the following be included in all workshops:

The company structure (Section 5.1)

Setting corporate objectives (Section 5.3)

Management by emphasis (Section 5.4)

Method study - recording (Section 5.6 and 5.7)

Use of the outline process chart (Section 5.8)

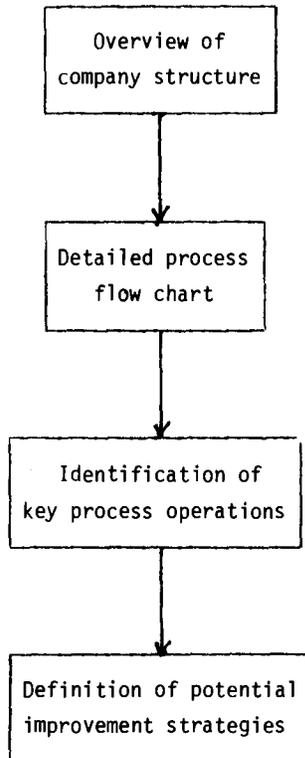
Method study - selection of key operations (Section 5.10)

Plant layout and techniques in experimentation and operational research should be included when and where the need arises as a result of potential applications noted during the factory visits.

## 5. PRODUCTION MANAGEMENT by D.A. King

Process improvement is not a technological or engineering function which can be carried out in isolation from all other company functions.

This section begins with an overview of the company structure and corporate objectives. This is followed by a discussion of methods leading to the identification of key processing operations and the definition of potential improvement strategies.

5.1 Structure of a company

Contrary to traditional thinking, a company is not an "up and down" structure shaped like a pyramid. It is, or should be, a structure which recognizes the need to have communication and cooperation at all levels and through all levels.

While it is true that planning and setting of objectives must be a top managerial function, the information on how we are achieving and what we can do to improve the company performance must come from the bottom.

Normally we have a simple organization chart which looks something like Figure 5.1 which follows:

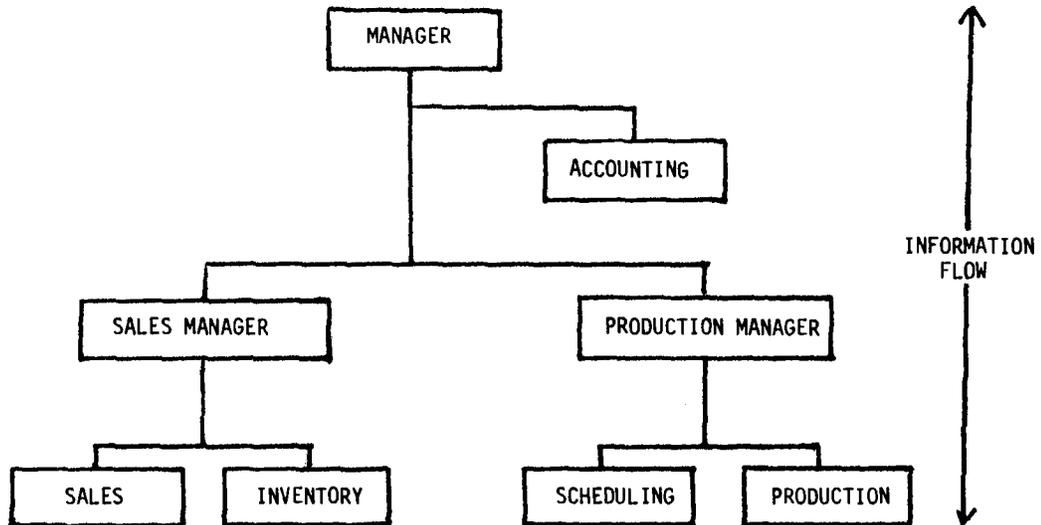


Figure 5.1 Company Organisation

This type of chart leads to the thinking that information must flow up and down and ignores the important interrelationships which occur at identical levels (horizontally) within the structure.

We would recommend a chart such as shown in Figure 5.2.



Arrows Denote  
Information Flow

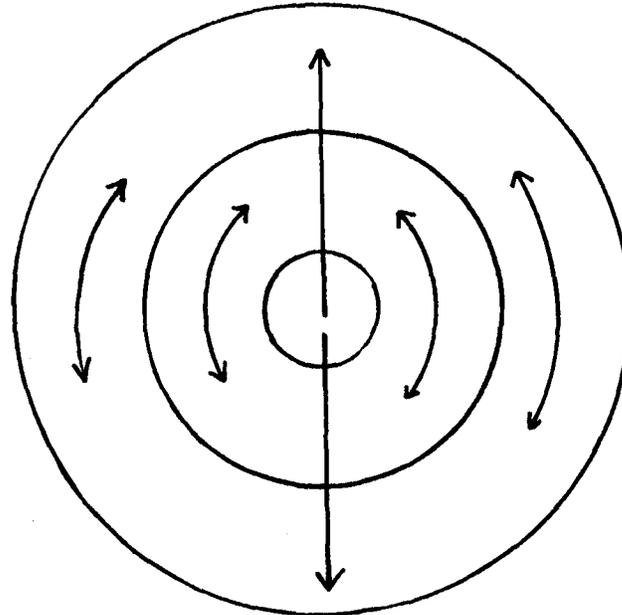


Figure 5.2 Interrelationships in company structure

In this concept of an organization an attempt is made to show the inter-relationship of functions - not of people. It is quite possible that one person may be in charge of more than one function, therefore it is important to show the relationships of the functions to each other, not of one person to another. The information flows in and out, to and from the middle, and also around the same levels.

### 5.2 Product and Process Development - an integrated and multidisciplinary approach

Product and process development are often considered as purely technical functions within the company divorced from marketing and economics. Product development may be thought of as an exercise in formulation while process development is the calculated engineering of pieces of equipment to improve throughput, product characteristics or to achieve economies of space.

Product and process development can be much more successful when they form the very centre of a company's operation, integrating the functions of marketing, processing and financial management. This ensures that products are manufactured in accordance with market requirements; under the best processing conditions; and subject to strict financial control. An integrated approach to product and process development is shown in Figure 5.3.

This approach requires the interaction and working together of all functions - an integrated and multidisciplinary approach.

### 5.3 Setting Corporate Objectives

Although the process improvement researcher is not necessarily part of the management team, it is important that he has some understanding of the company's current state of activity and its objectives - both short and long term. A proper decision on key areas for process improvement cannot be made without regard to total company objectives.

#### Why Plan?

1. Pressure for growth.
2. Accelerating pace of change.
3. Vulnerability of changing conditions and trends.
4. Forecasting personnel requirements.
5. Crystallization of management thinking about the future.
6. Forces a systematic review of company strengths and weaknesses.
7. Beneficial effect on motivation and co-operation amongst managerial personnel when plans and objectives are known.

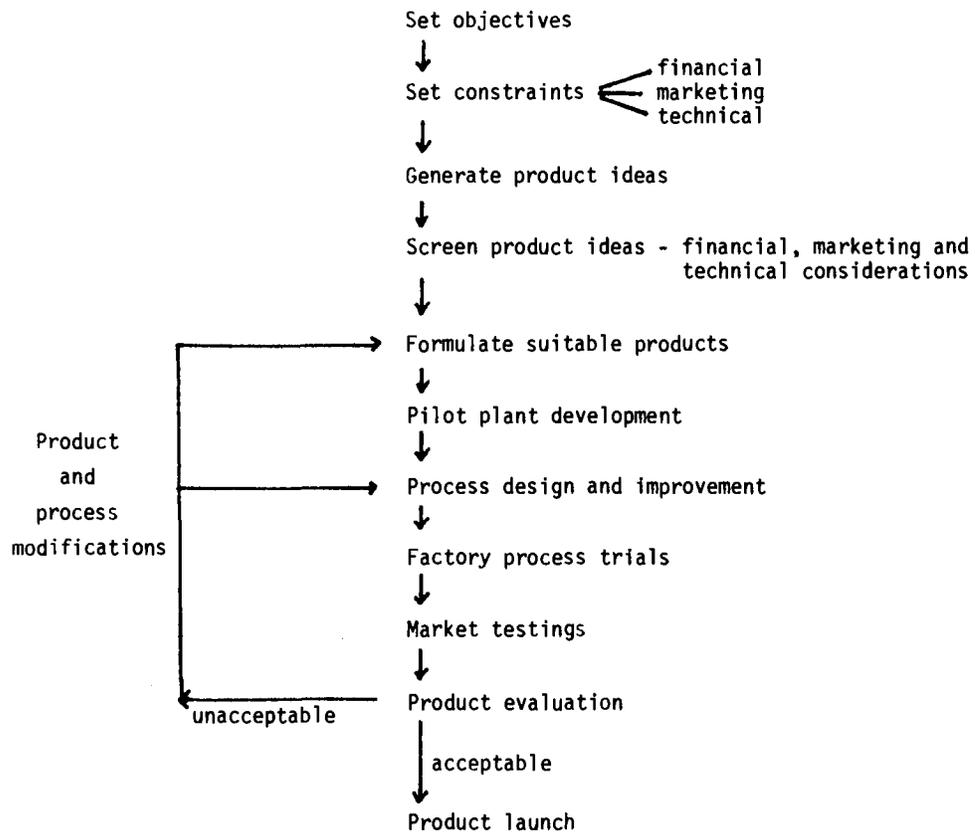


Figure 5.3 Integrated Product and Process Development

### What Is Involved In the Planning Process?

The word planning as used here will be taken to mean more formalized planning than is presently done by most companies. We are already planning the company's future in some fashion, but, in most cases, not on a regular basis.

Essentially this more formal approach to planning involves the following:

- A. A decision on the basic mission of the company. What do we want this company to be or become? Why does it exist?
- B. An appraisal of where we are now in terms of profitability, size, competitive position, strengths, weaknesses, etc.
- C. An examination (External Appraisal) of outside factors influencing our business, now and in the future.
- D. Evaluation of possible alternative strategies for future plans.
- E. Development of specific objectives, plans and programs.

#### A. What do we Want?

Figure 5.4 shows three basic long term objectives one or more of which are the aims of every business. For some the fundamental objective is merely to survive on a reasonably profitable basis. Others are interested in achieving the maximum profits available. In many small firms or even larger family businesses, the goal may simply be gainful employment for the proprietor and/or other family members.

It can be seen from Figure 5.4 that no matter which of these goals is of primary importance to the manager, the basic strategies for getting there through major change are much the same:

- Grow larger
- Diversify or broaden the base
- Concentrate or specialize
- Consolidate

A fifth should probably be added. That is, the improvement of present operations. Where significant improvement is possible this is the obvious start point before embarking on other major programs.

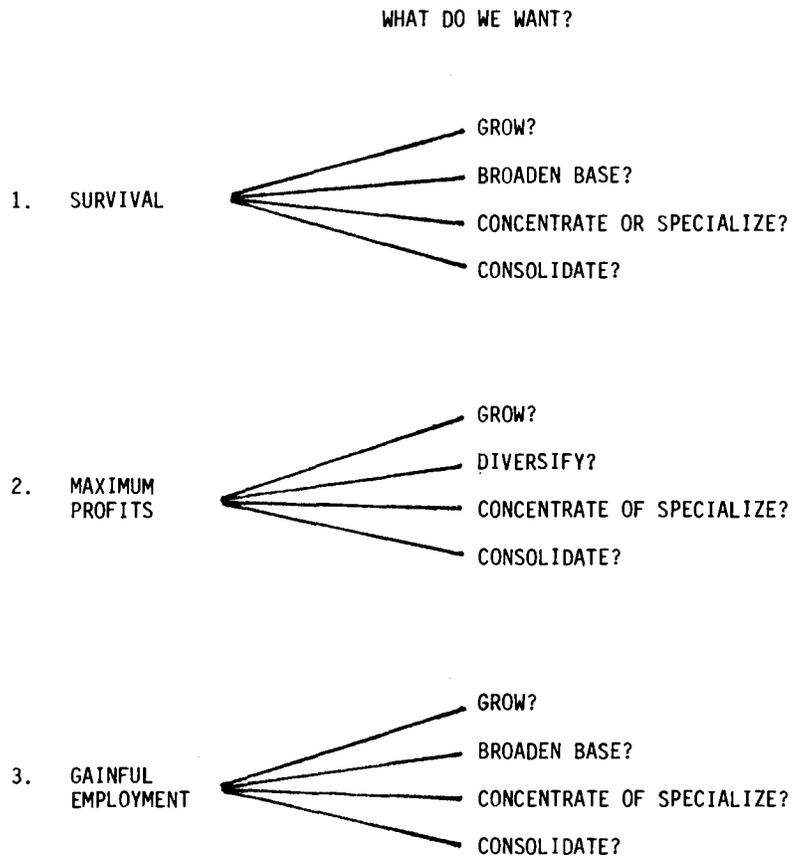


Figure 5.4 Planning the Company's Future

B. Where Are We Now?

Figure 5.5 can be used to make a simple analysis of our present position against what we would like to be. **It provides** a framework for an objective, soulsearching appraisal of present strengths and weaknesses, without an inordinately heavy time involvement.

	INFLUENCE ON SUCCESS		
	CONTRIBUTOR	PROBLEM	COMMENT
One Key Individual?			
Management Strength?			
Timing, "Market Sense"?			
Technical Know-How?			
Low Margins?			
Specialization?			
Versatility?			
Size?			
Competition?			
Broad, Stable Base?			
Financing?			
Other?			

Figure 5.5 Check List of Questions for Internal Appraisal

C. External Factors

Figure 5.6 is provided as an aid in looking at the factors outside the company which bear upon future success. To be useful, the answers to the questions contained therein should be put in writing and should be based on whatever statistical information on the trade is available.

1. How Big Is Our Market? (Estimate) \_\_\_\_\_
2. What Share Do We Have? (Estimate) \_\_\_\_\_
3. Is the Market Expanding? \_\_\_\_\_
4. Which Segments Represent Good Opportunities?  
     - Geographic? \_\_\_\_\_  
     Other Comment \_\_\_\_\_
5. Do We Know Who Our Major Competitors Are?  
     \_\_\_\_\_
6. What Strengths Or Advantages Do We Have Over Them?  
     \_\_\_\_\_
7. What Do They Do Better Than We?  
     What Weaknesses Do We Have By Comparison?  
     \_\_\_\_\_  
     \_\_\_\_\_
8. Are There Any Other External Factors Which May Influence Our Future  
     Opportunities For Success?  
     \_\_\_\_\_  
     \_\_\_\_\_

Figure 5.6 Check List for External Analysis

D. Evaluation of Alternative Strategies

In dealing with strategy considerations one thing has to be kept in mind. That is that there must be a strategy even if that strategy is to do nothing. In view of the pace of competition in industry this strategy is unlikely to result in success or even survival.

The Manager then should decide - Shall I attempt to attain my goals by:

- Internal improvement? If so what and how?
- Merger or acquisition? What market segment? Who?
- Diversification without merger?
- Consolidate - cut back to improve profitability and perhaps manageability?

A simplified framework for this analysis is provided in Figure 5.7.

1. No Major Strategy or Policy Change Required: \_\_\_\_\_
2. Acceleration of Growth Rate: YES \_\_\_\_\_ NO \_\_\_\_\_  
If YES - Merger or Acquisition \_\_\_\_\_  
- Internal Growth \_\_\_\_\_
3. Diversification: YES \_\_\_\_\_ NO \_\_\_\_\_  
If YES - New Geographic Market? \_\_\_\_\_  
- Expanded Range? \_\_\_\_\_  
Specify Possibilities Worth Considering \_\_\_\_\_  
\_\_\_\_\_
4. Specialization or Concentration: YES \_\_\_\_\_ NO \_\_\_\_\_  
If YES, In Which Market Segments Should We Consider Specializing Or  
Concentrating Our Efforts? \_\_\_\_\_  
\_\_\_\_\_
5. Consolidation: YES \_\_\_\_\_ NO \_\_\_\_\_  
How? \_\_\_\_\_  
\_\_\_\_\_
6. Improvement of Existing Operations:  
Manpower \_\_\_\_\_  
Sales Strategy \_\_\_\_\_  
Systems and Methods \_\_\_\_\_  
Other \_\_\_\_\_

Figure 5.7 Summary Of Strategy Change Required

#### E. Establishing Specific Objectives

Having turned our operation inside out and upside down, and having decided what strategy we want to follow, we are now in a position to commit to paper a set of specific targets we want to achieve. These objectives represent a full fledged commitment for the future and thus deserve considerable thought. If we have done our homework well the task of spelling out these objectives is now considerably easier than if we had attempted to do it without the critical analysis of our business which we just discussed.

#### Guidelines for Developing Statements of Objectives

1. Objectives should be written.
2. Written statements should be kept simple and understandable.
3. To the maximum extent possible objectives should be expressed in quantitative terms, and should be measurable with reasonable accuracy.

4. All of the important result areas of the business should be covered.
5. Objectives should be realistic and obtainable.
6. Those responsible for achieving established targets should participate in their development.
7. Overall objectives should be broken into sub-objectives corresponding to areas of management responsibility.

#### 5.4 Management by emphasis

##### Pareto's Law

Pareto's Law is the law or model, not the technique, of Management by Emphasis.

Vilfredo Pareto was a nineteenth century economist who studied the distribution of wealth and income in society. Pareto's analysis is the term now used for the systematic classification of collections of any kind (products, ideas, invoices) into a form suitable for profitable decision making - the vital few, and the trivial many.

Five letters of the alphabet take up about 45 percent of the white pages of your telephone book. This comes as no surprise to any of us. No manager would send out 26 salesmen, assigning each man one alphabetical section. Yet the same manager will treat his inventory, his production and sales, or his personnel as if they consisted of units of equal importance. Worse yet, he may even place greater emphasis on units of lesser importance.

##### PARETO'S LAW

"In any series of elements to be controlled, a certain small fraction, in terms of numbers of elements, always accounts for the major portion in terms of effect."

Pareto's Law says that in every group or collection there are a vital few and a trivial many.

For example, there may exist ten thousand different catalogue items in your inventory. It is always true that the first few percent, perhaps 10 or 15%, of that ten thousand items, will account for perhaps 80 per cent of the total value of the inventory. In the same way you may have a hundred different catalogue items in a product line. It is always true that the first few percent of the items will account for about three-quarters of all your dollar sales. The last 80 percent of the items in the product line will account for only a small percent of the total dollar sales.

In the same way, a few percent of the total employees on your payroll account for the bulk of the personnel headaches, accidents, suggestions, etc.

Any group of elements breaks down into the vital few and the trivial many. 20/80 is a good rule to start with: 20% of the group accounts for 80% of the results.

- 20 percent of the various parts making up the final order account for the bulk of the scheduling and delivery date failures.
- 20 percent of your purchase orders account for the bulk of your dollar purchases. The trivial many purchase orders account for a small percentage of total dollar purchases.
- 20 percent of a bank's customers account for 80% of the dollars deposited.
- 20 percent of your patients have 80% of the medical need.
- 20 percent of all your customers account for the bulk of your credit losses or the bulk of unjustified returns.
- 20 percent of the people in this room hold the large percentage of all the cash in this room. Among those few with the cash, 20% of these are heavy gamblers. Identify those few persons in this room, and you can have the crap game of your life.

A vital few of the decisions you make account for the bulk of the total effect of all your decisions.

The whole idea of delegation is based on the premise that there are a vital few decisions which really decide what happens.

Nothing of real significance happens unless it happens to the vital few.

#### THE STEPS IN PARETO'S ANALYSIS - SEPARATING THE VITAL FEW FROM THE TRIVIAL MANY

Now let us consider the principle of separating the vital few from the trivial many. The technique consists of a written list of the problems in order of their importance - the types of accidents in order of frequency, the types of defects in order of amount of loss caused, the elements of cost in order of amount, etc. Such a written list automatically shows the "vital few" at the head of the list; the "trivial many" are at the foot of the list. Each of these groups has its usefulness. The vital few must be identified if a program of improvement, of planning, of control is to succeed. The trivial many must be identified if there is to be any balance between the cost of planning and control vs. the value of planning and control.

Many people have problems, lots of problems. But few people have a list of those problems, which is quite a different thing, and a more useful thing. Still fewer have such a list in the order of importance, which is even more useful.

Again, the importance of the vital few lies in the fact that nothing of significance can happen unless it happens to the vital few.

One precaution is in order. The trivial many bulked together as a class become one of the significant few. For example, in the case of employees, there are a significant few employees, John, Peter and Mary, who account for say 70% of the total absentee days. There is also that significant single group of employees, consisting of all the remaining employees who account for 30% of the total absentee days. Corrective efforts directed toward John, Peter and Mary and the remaining group will produce significant results. Efforts directed towards individuals in the latter group will produce no significant results.

STEP 1. Step one in Pareto's analysis is to choose the elements to be analysed. (These can be any one of products, parts, inventory, management duties, invoices, customers, defects, scrap, absenteeism reports, managers, letters of the alphabet, etc.) When there are more than about ten elements, some of these can often be grouped together into larger classifications.

STEP 2. List each of the elements along with its total value for the period or operation in question, where this is readily available.

STEP 3. Arrange the elements in descending order of value, the most valuable at the top, the least valuable at the bottom.

There are three ways in which this ranking step can be carried out.

- (a) When the value of each element is known precisely SIMPLE RANKING may be used.
- (b) Where the value of each item is not known, but PAIRED COMPARISONS are possible, the EMPHASIS CURVE may be used. The emphasis curve is the name given to a particular method of establishing priorities by using paired comparisons. Each element is compared singly with each other element, one at a time. The most valuable of each pair is noted and inserted in a pairing matrix. Then a simple mathematical exercise can be used to rank all of the elements.
- (c) Where the value of each item is not precisely known or where paired comparisons are not considered applicable, ALTERNATION RANKING may be used. Using this procedure the most valuable element is identified and written at

the top of a fresh page, and deleted from the previous list. Then the least valuable is written at the bottom of the page. From the remaining elements, the most valuable is determined and placed in second rank on the fresh page, and so on. Alternation ranking is easy for the few most valuable and few least valuable elements, and more difficult for those in the middle. However, since the primary purpose is to identify the vital few at the top of the list, this difficulty is often academic.

STEP 4. For each element calculate or estimate its percent of the total value of all the elements. Also calculate the cumulative percent of total value.

STEP 5. Plot the cumulative percent of total value against the cumulative percent or the number of elements.

Step 5 is illustrated in Figure 5.8.

(Inventories are often broken down into A items, the vital few; B items, the middle ones; and C items, the trivial many. Each class of inventory is then handled in a different manner, with the bulk of the control applied to the A items - ABC INVENTORY ANALYSIS AND CONTROL.)

Once the vital few have been isolated from the trivial many, you are in a position to take action which will result in greater emphasis on the operation, inspection, and control of the few important items, and less in the case of the trivial many. In other words, for the first time you are in a position to give each category the attention it deserves.

Pareto's Law is closely allied with the concept of SENSITIVITY ANALYSIS and with Nadler's concept of REGULARITY.

#### 5.5 Method Study - Selecting the work to be studied

The first step is the selection of the work to be studied. This must not be left to chance if full benefit is to be gained from the efforts put into Method Study.

Certain factors should be kept in mind. These are:

1. Economic considerations
2. Technical considerations
3. Human reactions

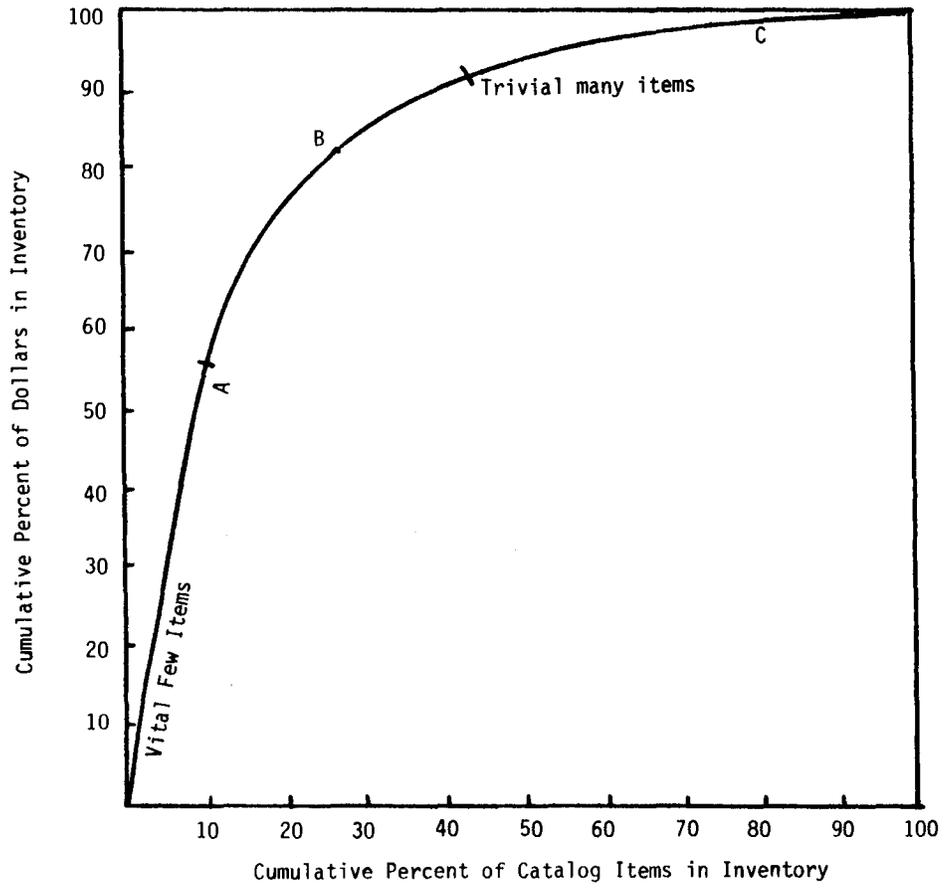


Figure 5.8 Typical Pareto Distribution

1. Economic considerations will be important at all stages. It is obviously a waste of time to start or to continue a long investigation if the economic importance of the job is small, or if it is one which is not expected to run for long. The first questions must always be:

"Will it pay to begin a method study of this job?"

"Will it pay to continue this study?"

Obvious early choices are

- "bottlenecks" which are holding up other production operations;
- movements of material over long distances, and/or operations involving a great deal of manpower and equipment;
- operations involving repetitive work, proportionately heavy in labour and liable to run for a long time.

2. Technical considerations will normally be obvious. The most important point is to make sure that adequate technical knowledge is available with which to carry out the study. Examples of this are:

- a. The loading of green lumber into kilns. A change in method might bring increased productivity of plant and labour, but there may be technical reasons why a change should not be made. This demands the advice of a specialist.
- b. A machine tool forming a bottleneck in production is known to be running at a speed below that at which the high-speed cutting tools will operate effectively. Can it be speeded up, or is the machine itself not solid enough to take the increased cut? This is a problem for the machine-tool expert.

3. Human reactions are among the most difficult to foretell, since mental and emotional reactions to investigation and changes of method have to be anticipated. Experience of local personnel and local conditions should reduce the difficulties. Trade union officials, workers' representatives and the operatives themselves should be instructed in the general principles and true objectives of method study. If, however, the study of a particular job appears to be leading to unrest or ill-feeling leave it alone, however promising it may be from the economic point of view.

Method study will be more readily accepted if the first subjects selected are ones which are unpopular, such as dirty jobs or those calling for lifting heavy weights. If these jobs can be improved and the unpleasant features removed from them method study will be reducing the effort and fatigue of the workers and will be welcomed accordingly.

### 5.5.1 Pareto's Law

The application of the basic concepts involved in "Pareto's Law" can be of great use in selecting a task, operation or product to be studied.

For example, there may exist ten thousand different catalogue items in an inventory. It is always true that a few percent of the ten thousand items will account for approximately 80 percent of the total value of the inventory.

In the same way we may have a thousand different catalogue items in a product line. It is always true that a few percent of the items will account for about three-quarters of all the dollar sales. Moreover, the last 80 percent of the items in the line will account for only a few percent of the total dollar sales.

In the same way, a few percent of the total employees on the payroll account for the bulk of the personnel headaches, accidents, suggestions, etc.

A few percent of the quality characteristics account for the bulk of the customer complaints and the bulk of scrap and rework.

A few percent of the various piece parts entering the final product account for the bulk of the scheduling and delivery date failures.

A few percent of the purchase orders account for the bulk of dollar purchases.

A few percent of all customers account for the bulk of credit losses or the bulk of unjustified returns.

A few percent of the decisions made account for the bulk of the total effect of all decisions.

All of these foregoing examples bear out the principles involved in Pareto's Law.

### 5.5.2 Standardized Lists of Points to be Covered

Another useful technique which can be used when selecting a job for Method Study is to have a standardized list of points to be covered. This prevents factors being overlooked and enables the suitability of different jobs to be easily compared. A sample list is given below which is fairly full, but lists should be adapted to individual needs. This list is designed for a manufacturing operation; one for a service operation would look considerably different.

1. Product and operation
2. Person who proposes investigation
3. Reason for proposal
4. Suggested limits of the area for investigation. (Purpose and Scope)
5. Particulars of the job
  - a. How much is (many are) produced or handled per week?
  - b. What percentage (roughly) is this of the total produced or handled in the shop or plant?
  - c. How long will the job continue?
  - d. Will more or less be required in future?
  - e. How many operatives are employed on the job
    - i. directly?
    - ii. indirectly?
  - f. How many operatives are there in each grade and on each rate of pay?
  - g. What is the average output per operative (per team) per day?
  - h. What is the daily output compared with the output over a short period?
  - i. How is payment made? (team work, piece work, premium bonus, time rate, etc.)
  - j. What is the daily output
    - i. of the best operator?
    - ii. of the worst operator?
  - k. When were production standards set? On what are they based?
  - l. Has the job any specially unpleasant or injurious features? Is it unpopular (a) with workers? (b) with supervisors?
6. Equipment
  - a. What is the approximate cost of plant and equipment?
  - b. What is the present machine efficiency (actual hours worked divided by possible hours worked)
7. Layout
  - a. Is the existing space allowed for the job enough?
  - b. Is extra space available?
  - c. Does the space already occupied need reducing?
8. Product
  - a. Are there frequent changes in design calling for modifications?
  - b. Can the product be altered for easier manufacture?
  - c. What quality is demanded?
  - d. When and how is the product inspected?
9. What savings or increase in productivity may be expected from a method study?
  - a. Through reduction in the "work content" of the product or process.
  - b. Through better machine efficiency.
  - c. Through better use of labour

(Figures may be given in money, man-hours or machine-hours or as a percentage ).

Item 4 deserves some comment. The purpose of the investigation should be clearly set down and all persons involved with the study (including the line management) should agree on the objectives. Agreement at the outset can forestall misunderstandings which may develop later due to controversy in this area. It is also important to set clearly defined limits to the scope of the investigation. Method-study investigations so often reveal scope for even greater savings that there is a strong temptation to go beyond the immediate objective. This should be resisted, and any jobs showing up as offering scope for big improvements through method study should be noted and tackled separately.

Such a list will prevent the analyst from deciding to start with a small bench job which will entail a detailed analysis of the worker's movements and yield a saving of a few seconds per operation, unless this job is being done by a large number of operatives, so that the total saving will have a significant effect on the operating costs of the factory. It is no use playing around with split seconds and inches of movement when a great waste of time and effort is taking place due to bad shop layout and the handling of heavy materials.

Finally, remember the adage: "Do not use a spoon when a steam shovel is needed".

Tackle first the job most likely to have the greatest overall effect on the productivity of the enterprise as a whole.

### 5.5.3 Work sampling

#### What is Work Sampling?

By definition, Work Sampling is a method of determining the proportion of a typical work period occupied by various human and machine activities. It is a valuable tool in determining lost time and ineffective work. By a system of sampling based on statistical concepts, it provides an inexpensive and accurate way to gather facts about an operation, process, machine cycle or any other form of work. It can be used as effectively in analysing clerical and office functions as it can be used on the factory floor.

Briefly, a Work Sampling Study is carried out by observing a man or machine in operation at random intervals during the day and recording exactly what is occurring at the instant the observation is made. These observations are summarized daily and the like observations grouped. After a number of days of observing the work cycle the observations will begin to fall into a pattern which should indicate the proportion of total time occupied by each activity. The accuracy of this pattern will vary according to the number of observations made of each activity during the period of the Work Sampling Study. The number of observations required to achieve a given accuracy can be determined beforehand by a simple mathematical calculation.

### What Are the Advantages of Work Sampling?

This technique has many distinct advantages, a few of which are listed:

- a. Economical. Work Sampling studies can be made for 10 percent to 20 percent of the cost of a study requiring continuous observation. (Time study, predetermined elemental data, etc.)
- b. Easily Learnt. The technique does not require the use of specially skilled staff or personnel. Anyone who can perform addition, subtraction, division and multiplication can carry out a Work Sampling study.
- c. Acceptable. People performing the work being studied raise fewer objections to this technique than to studies requiring continuous observation.
- d. Objective. Observers carrying out the Work Sampling Study observe the work being done by the operatives; the names of people performing the work may be eliminated.
- e. Convenient. The normal work routine is not interrupted while the Work Sampling is being carried out.
- f. Accurate. The accuracy of results may be closely controlled by the total number of samples taken. Work Sampling tends to produce a balanced picture of an entire situation by accounting for all the time for which the company is paying.
- g. Practical. May be applied in situations where the use of other techniques would be too cumbersome or uneconomical (e.g. non-repetitive tasks - janitor work, etc.).
- h. Flexible. Work Sampling has a wide range of application in the "difficult-to-measure" fields of indirect costs (warehousing, clerical, maintenance, etc.), as well as in the areas of repetitive production operations.

### How to Carry Out a Work Sampling Study

Any technique used to study work should be carefully planned to obtain maximum effectiveness. It is most essential to carefully plan all preliminary and follow-up stages as well as the main study itself. The following ground rules will assist in establishing the sequence to be followed:

- a. The first step is to select the job to be studied. If this is the first study there will be no difficulty deciding which are the major cost areas of the whole operation (production, warehousing, clerical, etc.).
- b. When this has been done and an area for study selected, set down the PURPOSE of the study (i.e. the reason for carrying out the study). Next the SCOPE or "terms of reference" of the study should be clearly defined (i.e. where does it start and stop). Make sure management agrees with the objectives laid down in the "purpose" and the range

of work to be covered as defined in the "scope". This study definition must be settled initially to ensure no misunderstandings develop as to the nature and range of work contemplated.

- c. Determine the elements of work which make up the daily activity in the area where the Work Sampling Study is to be carried out. The study requirements may be such that only the percentage of time spent "working" and "not working" provides sufficient information upon which action may be taken. This is, obviously, the simplest form of Work Sampling Study. However, to determine what is occurring when "not working" is observed, this heading may be broken down into smaller categories (e.g. "waiting for work"; "absent from workplace"; "answering telephone"; etc.). The observer carrying out the study should be able to recognize these categories easily so they must be specific and clearly defined. A simple method which can be used to accomplish this breakdown is illustrated in Figure 5.9. A preliminary survey will be necessary during this stage.
- d. Decide the number of trips by the observer that can be most economically carried out during a normal working day and which will produce the desired number of observations for the accuracy required within the period of time allocated for the study. The decision concerning the number of trips to be made will be a direct function of the following major points of consideration:
  - i. The area being covered in each trip.
  - ii. The number of personnel available to make observations.
  - iii. The number of observations to be made each trip.
  - iv. The range of accuracy to be produced by the study.
  - v. The time during which the subject of the study will be available.
  - vi. The economic limitations imposed by the purpose of the study.
- e. All observations made during the course of a Work Sampling Study must be made at random intervals. Any observations which are carried out in a fixed cycle or time pattern (e.g. observations spaced 30 minutes apart throughout the day) will defeat the whole principle of the study which, as stated earlier, is based on statistical concepts. The observer will always be expected by the operators if a fixed pattern of time is followed and they will react accordingly. Machines are also likely to be in a specific stage of their cycle of operation (e.g. a fork lift truck may transport scrap material to an incinerator at 30 minute intervals although the major portion of the truck's time is spent unloading box cars). The best method of determining the time intervals between observations can be effected using a random numbers table. The table in Figure 5.10 illustrates a method of converting random numbers into random times for a Work Sampling Study. When using this method the random numbers series should always be one more than the number of trips intended (i.e. if ten

Work Sampling trips are desired there should be eleven sets of random numbers chosen to determine the times for the trips). If the quantity of random numbers chosen is identical with the number of trips to be made then the final trip will always occur on the last minute of the working day. This is undesirable for both statistical and obvious practical reasons.

- f. Design the necessary forms which will be used during the study. These should be simple, clear, easy to read and use. There should be ample space available for special comments, remarks, etc., as well as for recording observations. The three basic forms used in a Work Sampling Study are:
  - i. Observation Sheet. This is the worksheet used for recording observations made during the trips. It can be varied to suit specific purposes but a sample of a universal type of observation sheet is shown in Figure 5.11.
  - ii. Summary Sheet. This sheet summarizes all daily results and should also be capable of enabling weekly results to be entered. A sample summary sheet is shown in Figure 5.12.
  - iii. Cumulative Graph. Each category or work element observed during the course of the study, after being summarized daily, should have the result plotted on a cumulative graph. This method of illustrating results can be of great value in determining the consistency of the data collected and deciding when sufficient samples have been taken. An illustration of a typical cumulative graph is shown in Figure 5.13.
- g. Select the person or persons who are going to carry out the Work Sampling Study. Brief them thoroughly on the nature of the work being observed, the purpose of the study and the limitations within which they are to operate. Make sure that they understand the importance of the randomness of their observations. The following few simple rules will assist the individual when making observations.
  - i. Select a spot from which the observations will be made before setting out on the trip.
  - ii. Vary the location of this selected point of observation often, preferably each day and always before the trips are made.
  - iii. Do not anticipate machine or operator activities when making observations. Record exactly what is happening at the instant of observation only. Nothing else. Do not slow down or hasten the approach to the selected point of observation to "catch" a particular activity or the randomness of the observation will be lost.
  - iv. Vary the approach to the observation point in order to prevent a quickening or change of activity by the individual being observed. This will prevent bias in results.

- v. Enter the area where observations are to be made using a different route each day or, if possible, each trip.
- h. Before the observations are commenced all personnel who are to be involved in the Work Sampling Study should be informed of what is about to occur, introduced to the person who will be making the study, and told how it will be carried out. Most important, let everyone know why it is being done and how it will affect them. Too many people are prone to view any type of study as a "head hunting" technique. Employees who have been fully informed by an enlightened management will always co-operate in any Work Study which will aid the company's growth and hence ensure the security of their jobs.
- i. Make the observations following the principles outlined in the previous sections. The observation sheet should be securely mounted on a clip-board and the observer should endeavour to keep these sheets in good condition.
- j. At the end of each day summarise all the daily observations and enter results on the summary sheet and cumulative graph. This should not take more than 15 to 30 minutes per day. Discuss the results obtained to date and make alteration in procedure or method as indicated. This daily "summing up" of activities is most important.
- k. At the completion of the Work Sampling Study prepare and present a report of the work done to management. This report should outline the Purpose and Scope of the Work Sampling Study, a summary of conclusions, recommendations and estimated savings arising from the recommendations. The body of the report should contain details of the method of implementation of the recommendations and all the necessary back-up data needed to verify the conclusions made.
- l. When management authorizes implementation of the recommendations arising from the study, close supervision of the changes involved should be maintained, preferably by the personnel who conducted the original study. After implementation, a regular check-up should be carried out every three months to ensure that changes installed are producing the savings anticipated.

#### How to Calculate the Number of Observations Required

The mathematics involved in work sampling are quite simple. The following formulae will give the total number of observations to be made in the complete study to obtain the desired accuracy for any one of the categories contained in it.

$$N = \frac{P (100 - P)}{L^2}$$

where L = the standard error. The standard error (L) is the degree of accuracy as a percentage of total time, e.g. ± 2 percent, that is desired. P = the

percentage of the total time occupied by the activity.  $N$  = the total number of observations.

As it stands, this equation will give the number of observations required to give a 68 percent probability that the calculated time ( $P$ ) for a given operation is within the specified error, e.g.  $\pm 2$  percent. This low probability is normally unacceptable in practice and the number of samples must be increased.

If the equation is changed to:

$$N = \frac{4P(100 - P)}{L^2}$$

(in statistical phraseology, 2 standard errors), then the chance that the calculated time ( $P$ ) has the desired degree of accuracy is increased to 95 percent. Similarly use of the equation (three standard errors):

$$N = \frac{9P(100 - P)}{L^2}$$

will provide 99.7 percent assurance. Obviously more observations must be taken to increase the probability of the result being within the desired range of accuracy. It is usually sufficient in most situations to calculate the number of observations which are required to maintain desired accuracy within the range of two standard errors (95 percent).

#### Example

In an operation where a Work Sampling Study is to be made the time required for one of the categories is estimated (usually by some person with experience of the operation). Suppose it is estimated that this category occupies 20 percent of the total time and that the accuracy desired has to be within  $\pm 2$  percent of the total time at the 95% confidence level. Then using the formula for two standard errors

$$N = \frac{4P(100 - P)}{L^2} = \frac{4 \times 20 \times 80}{2^2} = 1600$$

Therefore a total of 1600 observations should be made. If, however, after a few days it becomes apparent that the original estimate of 20 percent is not holding true and actual results are signifying that this work element is only occupying an average of 12 percent of the total time, the total number of samples will have to be recalculated. Assuming the error of  $\pm 2$  percent of the total time is still acceptable then

$$N = \frac{4 \times 12 \times 88}{2^2} = 1056$$

Therefore a total of 1056 observations should be capable of giving the desired accuracy. It should be noted that the  $\pm 2$  percent indicated is an error related to the total time for all categories and in this case would be  $100/12 \times 2$  percent or  $\pm 16\frac{2}{3}$  percent of the particular element being measured. Should greater accuracy be required, say within  $\pm 5$  percent of the time for the particular work element, then the standard error would be reduced proportionately.

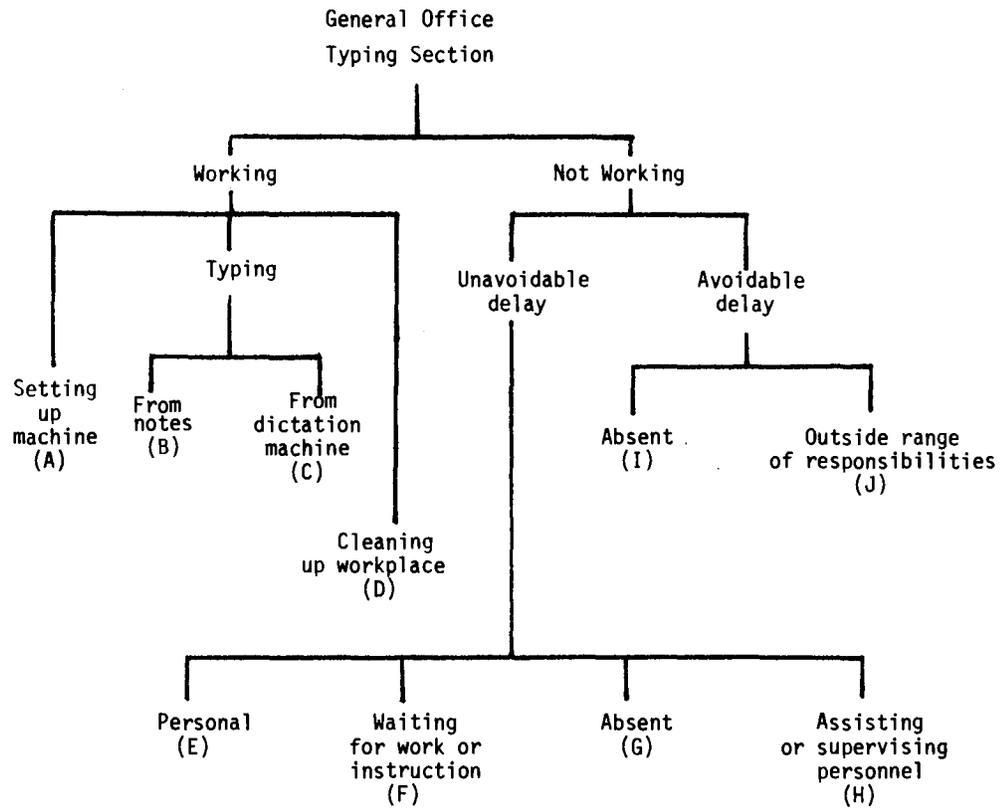
$$\begin{aligned} \pm 5 \text{ percent of the element time} &= \pm 5 \text{ percent of } 12 \text{ percent of total time} \\ &= 0.60 \text{ percent of total time} \end{aligned}$$

$$\begin{aligned} \text{then} \quad N &= \frac{4P(100 - P)}{L^2} \\ &= \frac{4 \times 12 \times 88}{0.6^3} \\ &= 11,733 \end{aligned}$$

Therefore to obtain an accuracy of  $\pm 5$  percent of the element time (12 percent) it is necessary to make a total of 11,733 observations.

In most practical situations the maintenance of a cumulative graph (Figure 5.13) will indicate when a sufficient number of samples have been taken. From the graph (Figure 5.13) which plots the activity "A" for a period of 17 days (July 3 to 25 inclusive) it is obvious that unless an extremely prolonged, radical change occurs in environment or in the work being studied it can be safely assumed that the value will remain within the boundaries of 22.5 percent and 24.0 percent. If the desired accuracy of activity "A" is  $\pm 1$  percent then a mathematical calculation would indicate that a total of 6,400 observations must be made (based on an estimate of  $P = 20$  percent) in order to fulfill this requirement. However, after 17 days (at 150 observations per day) it is indicated that the observations made to this point show activity "A" well within the desired accuracy of  $\pm 1$  percent. Continuing observations of this activity under similar conditions will serve only to further confirm the accuracy already indicated, although the total number of observations to this point is well below the calculated requirement ( $150 \times 17 = 2550 = 40$  percent of 6400 calculated). Therefore, it would be safe to discontinue the study at this point and assume the desired accuracy has been obtained, provided, as mentioned earlier, no prolonged, radical change in environment and in the work being studied is anticipated.

Work Sampling is a simple, easily learnt and applied technique based on sound mathematical principles. It shows how working time is utilized and is but one more extremely useful tool which has been made available to management in recent years.



Activities (A) to (J) inclusive can be used as headings under which all observations in a work sampling study of a general office typing section may be classified.

Figure 5.9 Breakdown of categories to be studied

DATE .....

DAY NO.....

STARTING TIME: 8.30 a.m. FINISHING TIME: 5.00 p.m.

PEAKS: 12.00 a.m. to 1.00 p.m. (1 hour - lunch)  
 10.00 a.m. to 10.15 a.m. (15 min. - coffee)  
 3.00 p.m. to 3.15 p.m. (15 min. - coffee)

TOTAL TRIPS REQUIRED = 15TOTAL MINS/DAY WORKED = 510 - 90 = 420

<u>RANDOM NUMBERS</u> (e.g. from telephone book)	<u>CONVERSION TO MINUTES USING MULTIPLIER</u>	<u>MINUTES</u>	<u>CONVERT TO DAILY TRIP TIMES</u> (mins)	<u>ACTUAL TRIP TIMES</u>
36 x .420 =		15.2	8.30 a.m. + 15.2	= 8.45 a.m. - 1st trip
39 x .420 =		16.4	8.45 a.m. + 16.4	= 9.02 a.m. - 2nd trip
84 x .420 =		35.2	9.02 a.m. + 35.2	= 9.37 a.m. - 3rd trip
64 x .420 =		26.9	9.37 a.m. + 26.9 + 15.0 (coffee)	= 10.19 a.m. - 4th trip
45 x .420 =		18.9	10.19 a.m. + 18.9	= 10.38 a.m. - 5th trip
72 x .420 =		30.1	10.38 a.m. + 30.1	= 11.08 a.m. - 6th trip
18 x .420 =		7.6	11.08 a.m. + 7.6	= 11.15 a.m. - 7th trip
94 x .420 =		39.5	11.15 a.m. + 39.5	= 11.54 a.m. - 8th trip
75 x .420 =		31.4	11.54 a.m. + 31.4 + 60.0 (lunch)	= 1.25 p.m. - 9th trip
70 x .420 =		29.4	1.25 p.m. + 29.4	= 1.55 p.m. - 10th trip
51 x .420 =		21.4	1.55 p.m. + 21.4	= 2.16 p.m. - 11th trip
92 x .420 =		38.6	2.16 p.m. + 38.6	= 2.55 p.m. - 12th trip
60 x .420 =		25.2	2.55 p.m. + 25.2 + 15 (coffee)	= 3.35 p.m. - 13th trip
31 x .420 =		13.0	3.55 p.m. + 13.0	= 3.48 p.m. - 14th trip
74 x .420 =		31.1	3.48 p.m. + 31.1	= 4.20 p.m. - 15th trip
<u>96</u> x .420 =		<u>40.1</u>	4.20 p.m. + 40.1	= 5.00 p.m. (Close check)
<u>TOTAL 1001</u>		<u>TOTAL 420.0</u>		

$$\text{MULTIPLIER} = \frac{\text{TOTAL MINS/DAY WORKED}}{\text{TOTAL OF RANDOM NUMBERS}} = \frac{420}{1001} = 0.420$$

Figure 5.10 Daily Trip Calculation Sheet

SAMPLE No. 1 BY J. Dee TIME 8.45 a.m. ACTIVITY	OPERATOR										DEPT: Steno pool	DATE: July 3
	1	2	3	4	5	6	7	8	9	10	TOTAL	
A		✓	✓								2	
B	✓									✓	2	
C							✓	✓			2	
D				✓							1	
E											0	
F											0	
G											0	
H					✓						1	
I						✓			✓		2	
J											0	
TOTAL	1	1	1	1	1	1	1	1	1	1	10	

Figure 5.11 A Sample Style of Observation Sheet

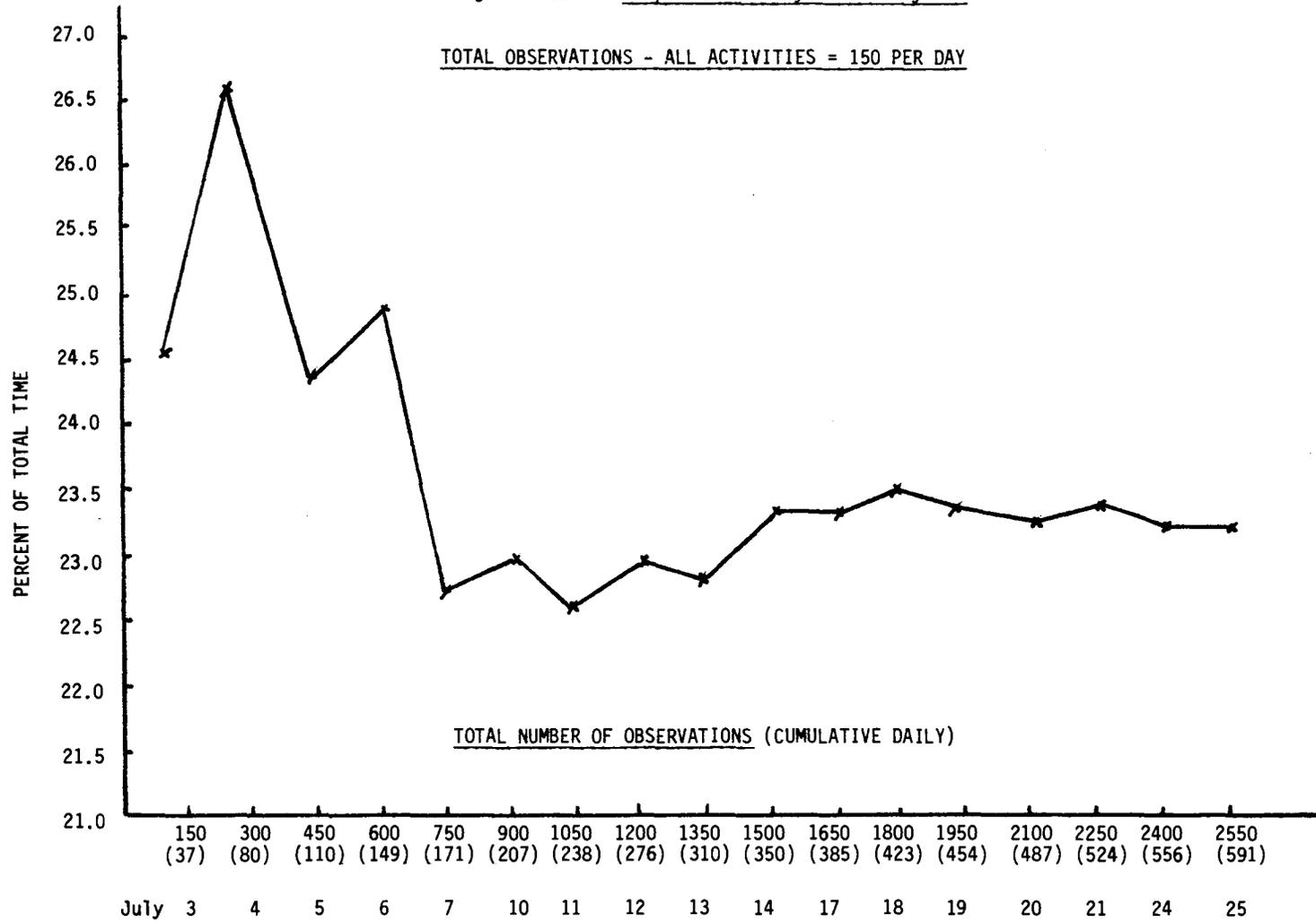
A check (✓) is made in the appropriate square to indicate the activity observed for each operator. This style of sheet is good for one trip only.

<u>WORK SAMPLING STUDY SUMMARY</u>																	
										<u>STUDY No.</u> 1							
<u>DEPT.</u> General Office																	
<u>OPERATION</u> Typing												<u>SHEET</u> 1		<u>OF</u> 2			
										<u>BY</u> J.D.		<u>APPR</u> D.J.					
ACTIVITY	DATE	ACTIVITY ÷ TOTAL OBSERVATIONS PER DAY x $\frac{100}{1}$															PERCENT TOTAL
		JUL 3	4	5	6	7	10	11	12	13	14	17	18	19	20	21	
A (+ 1%)		24.6	26.6	24.5	24.7	22.8	23.0	22.7	23.0	22.9	23.3	23.3	23.5	23.2	23.2	23.3	23%
B																	
C																	
D																	
E																	
F																	
G																	
H																	
I																	
J																	
TOTAL																	100%

Figure 5.12 A Sample Style of Work Sampling Summary Sheet

N.B. The reverse side of this sheet is used for remarks

Figure 5.13 Graphical Summary - Activity "A"



## 5.6 Method Study - Recording (Introduction)

### 5.6.1 Introduction

The Second step of the basic procedure for Method Study is the collection and recording of all the relevant facts about the processes under review. None of the steps of the basic procedure, however, can be regarded in complete isolation. In the case of RECORD, there is a considerable overlap since some of the information will be needed at the SELECT stage, while other facts need not be recorded until later in the study. In this and succeeding sections, the objectives and techniques of recording are described in detail, together with some comments on the stage at which they are most usefully employed.

### 5.6.2 Objectives

The principal aims of recording are:

- (a) To obtain adequate and accurate information.
- (b) To present the facts in a concise and comprehensible form for analysis.
- (c) To submit proposals to management in a way which is easily understood.
- (d) To provide, eventually, detailed operating instructions for the use of supervisors and operators.

### 5.6.3 The relevant facts

The information which will be required falls generally into four categories:

- (a) The Background - the history, future prospects, available resources, etc., of the situation under review.
- (b) The Process - an account of the activities involved in each of the jobs being done.
- (c) The Methods - an account of the various ways, manual or mechanical, in which the activities are carried out.
- (d) The Movements - a measure of the nature and amount of movement involved.

### 5.6.4 Scale

The amount of information required will vary considerably from one job to another. If, for example, a radical alteration is made to the process (which should always be examined first) then it is evident that very little information on the existing methods of work will be needed, since new methods will be devised to suit the new process. The pursuit of information and the degree of detail in which it is recorded will be determined by the economics of the job and the anticipated requirements of the subsequent analysis.

### 5.6.5 Recording Techniques

The most usual way of recording facts is to write them down, but writing has a

number of disadvantages. In complicated processes, it becomes virtually impossible to describe in writing the facts of the situation so that they can be seen in perspective. It is for this reason that facts are so often presented as figures in tabular or graphic form, rather than in writing. Figures do not solve all the problems of presenting processes in a manner in which they can be easily visualized, however, and other techniques for recording have been devised. These additional techniques involve the use of charts and diagrams.

(a) Background information can generally be recorded in tabular or graphic form. The number of operators, machines, components, etc., can be entered in tables; fluctuations in output, quality, marketing requirements, etc., can be plotted on graphs over a suitable period. In each case the aim is the presentation of the facts in such a way that their significance can be quickly grasped.

(b) For recording the Process, Frank Gilbreth devised a technique called PROCESS CHARTING, which is also used for recording methods. There are five varieties of Process Chart, two of which - the Outline Process Chart and the Flow Process Chart (Material) - are intended for recording the Process; another two - the Flow Process Chart (Man) and the Two-Handed Process Chart - present a record of the method. The remaining one - the Operation Process Chart - is used for recording the activities involved in indirect, non-productive work, such as maintenance and cleaning; and it can also be used for Process recording in the case of long or complex processes.

(c) The Methods can be recorded in several ways, depending on the amount of detail required. For a broad record of methods, the Flow Process Chart (Man) is used. More detail is provided by the Two-Handed Process Chart. A different type of chart, called the Multiple Activity Chart, enables the activities of several operators or machines to be recorded in relation to each other against a common time scale. A Memo-Motion Chart, recorded from a film of the job, gives a similar picture in greater detail. Finally, if very fine detail is required, the methods can be followed on a Simo-Chart, which is also recorded from film.

(d) Movements are recorded in diagrammatic form. A scale drawing of the working area is made, showing the location of the various activities. The movement between the different locations can be drawn in a line to make a Flow Diagram. Where the presence of so many lines would fail to make the picture clear, the locations can be marked with pins and string or thread is then wound along the path of the activities recorded. The result is called a String Diagram. A very highly detailed diagram of short movements can be made by photographing the track of an intermittent light attached to the moving object. The photographic record is called a Chronocyclegraph.

## 5.7 Method Study - Recording (Charting - conventions)

1. Introduction
2. Objectives
3. Process Chart Symbols
4. Process Chart Conventions
5. Multiple Activity Chart Conventions
6. Chart Identification

### 5.7.1 Introduction

Charting is the technique used to record the nature and sequence of the activities involved in a process. Normally only one job, or process, is recorded on any one chart, although many activities may be necessary for its completion.

### 5.7.2 Objectives

There are four principal aims in charting:

- (a) To enable the process to be clearly visualised
- (b) To present the existing facts for analysis
- (c) To submit proposals to management in a form which is easily understood
- (d) To act as detailed operating instructions for the use of operators and supervision

To achieve these objectives, it is necessary to be fully familiar with the jobs before making the chart.

### 5.7.3 Process Chart Symbols

A Process Chart is a pictorial representation of the activities of a process in which symbols are used to represent standard activities. These symbols are so designed as to be easily distinguishable and to represent an activity which would otherwise need many lines of writing.

Five standard symbols are used in making Process Charts:

SYMBOL	ACTIVITY	PREDOMINANT RESULT
(a) 	Operation	Produces, accomplishes, changes, furthers the process, etc.
(b) 	Inspection	Verifies Quantity and/or Quality.
(c) 	Transport	Moves or carries.
(d) 	Delay	Interferes or delays.
(e) 	Storage	Holds, keeps or retains.

The two principal activities in any process are Operations  and Inspections . The other three symbols portray the type of non-productive activities which can occur between operations and/or inspections.

- (a) An Operation  occurs whenever an object or material is changed in any of its properties or characteristics, physical or chemical, or when it is made ready for, or put away after, another activity.

Typical activities which can be described by the use of the operation symbol include:

- (i) Altering the shape, size or state of an object.
- (ii) A chemical reaction.
- (iii) Arranging, assembling, or dismantling parts.

- (b) An Inspection  occurs when any of the properties or characteristics of an object are checked:

- (i) Quantity characteristics may be verified by measuring, counting or weighing.
- (ii) Quality characteristics may be checked by testing to a standard or by grading.

It is important to recognise activities which on the surface bear some resemblance to inspection but which in reality are operations. When an inspection occurs, the condition of the material is checked against a standard and this check will be followed, in the case of failure, by rejection or some form of reprocessing. For example, when a bag is being filled to a predetermined weight on a weighing machine, an operation is carried out. If that filled bag is then reweighed to test the accuracy of the filling operation, an inspection is carried out.

- (c) A Transport  occurs whenever there is movement from the immediate area of the preceding activity.

Transports may be performed by various agencies, human or mechanical.

Typical examples include:

- (i) Material being carried by lift, truck, lorry or hand.
- (ii) Material flowing through a pipeline.
- (iii) Man walking.

- (d) A Delay  occurs when conditions do not permit the immediate performance of the next activity. This symbol is used to depict the various delays and interruptions which arise in the normal course of work. Typical examples include:

- (i) Material held up during the process.
- (ii) A letter on a desk awaiting signature.
- (iii) A man waiting for a lift.

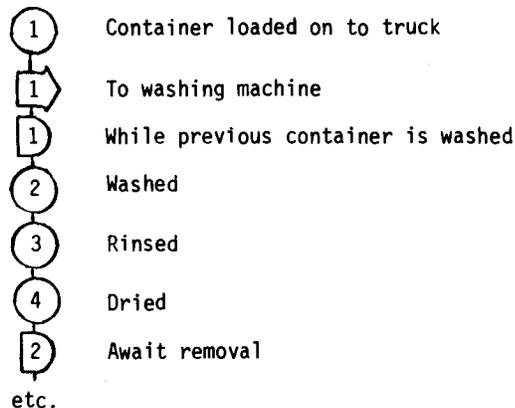
- (e) A Storage  $\nabla$  occurs when there is an authorised retention in a specified area. Typical examples include:
- (i) Documents filed in a cabinet.
  - (ii) Buffer stocks within a process.
  - (iii) Goods in warehouse awaiting despatch.

All five symbols can be used to represent a very wide range of activities, from the operation  $\bigcirc$  'build ship', on the very broad scale, down to the operation  $\bigcirc$  'fit washer to bolt' in fine scale recording.

In some cases, a change in emphasis will show certain activities in a different light altogether, as, for example, when the recording of transport work as such involves considering the transfer of goods from one point to another, not as a transport but as an operation.

#### 5.7.4 Process Chart Conventions

Process Chart symbols are placed vertically, one below the other in sequence, and joined to each other by a vertical line. To the right of each symbol, the activity is described concisely. Symbols are numbered to facilitate reference and comparison. Like symbols are numbered serially from the beginning of the chart.



Process charts are a means to an end - a visual aid to comprehension and analysis. They can, therefore, be adapted by the individual to suit his purpose. A certain recognisable uniformity is, however, desirable and the following conventions are generally observed:

#### (a) Combined Symbols

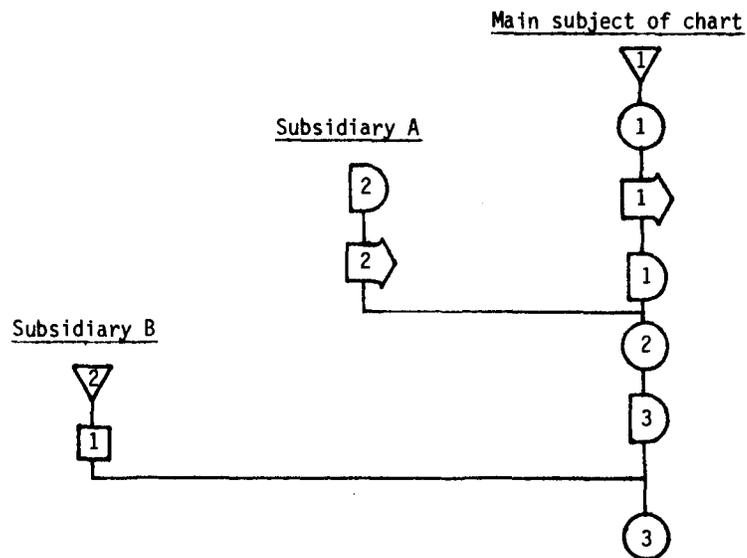
The simultaneous occurrence of two different activities is shown by the use of combined symbols. One symbol is superimposed upon the other. Where it is possible to distinguish the relative importance of the two, the outer symbol will represent the major activity. For example:

**1-5** This combination indicates that a minor operation is taking place simultaneously with a more important inspection. The number of the outer (more important) symbol is placed first, separated by a hyphen from the number of the other symbol.

(b) Introduction of Materials

Where a number of materials or sub-assemblies is involved, a chart may contain more than one vertical line of symbols. In all cases the main line of the process is placed to the right of any other line, while materials and parts are introduced from the left. The introduction is made by a horizontal line with a brief description of the material.

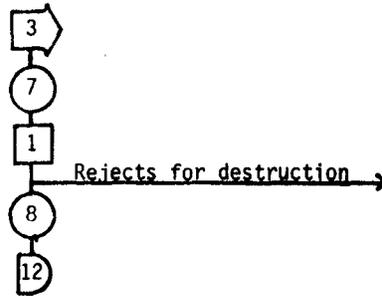
Numbering also proceeds first down the right-hand side and then in sequence towards the left.



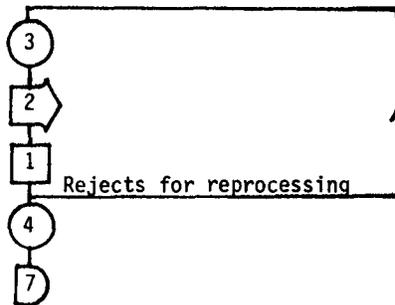
(c) Rejects and Reprocessing

Materials and components may be discarded during the process, either for destruction or reprocessing as rejects, or to enter another process not being charted.

The exit of materials is indicated to the right of the line from which they are discarded.

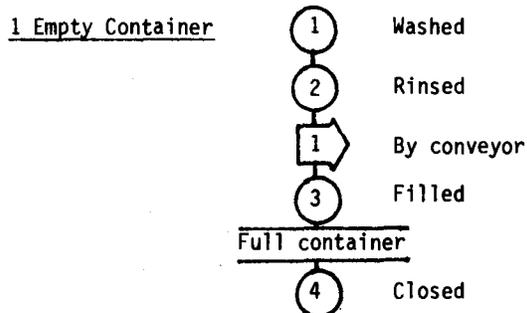


If the material is returned to an earlier stage in the process for further treatment, the transfer can be shown thus:



(d) Change of State

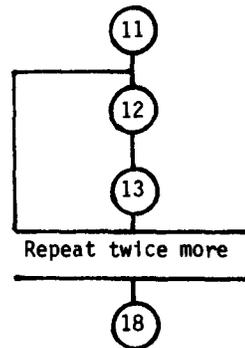
When the material charted undergoes a significant alteration as a result of some operation, so that its handling properties from that stage on are changed, this is indicated on the chart in the following manner:



Since a change of state is likely to occur after nearly every main operation, this convention is only used when it is thought desirable to draw attention to the change.

## (c) Repetition

One or more activities may be repeated a number of times before the process continues. Here again, the chart line is broken at the appropriate point by two parallel lines. The upper line is joined to a bracket which encloses the activities repeated.



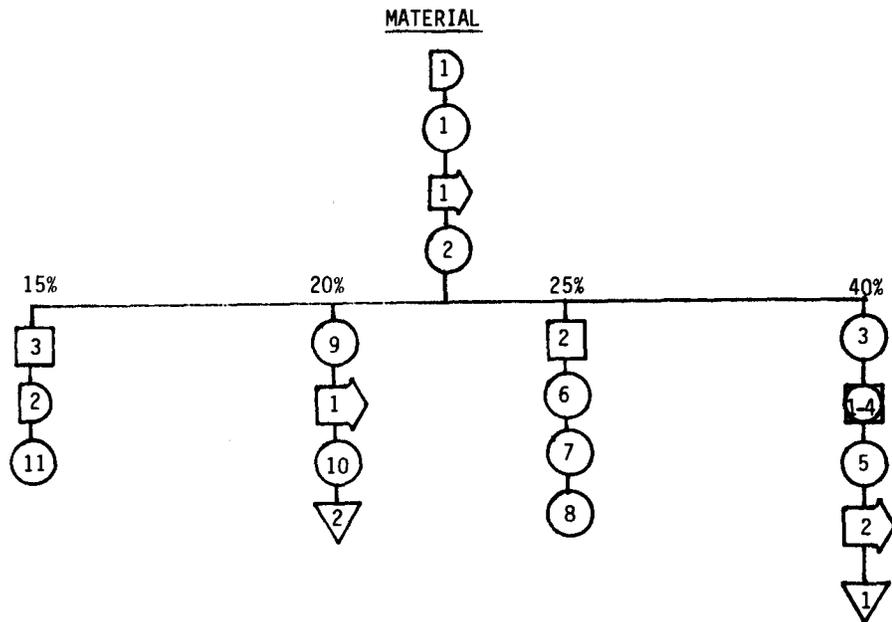
This convention must only be applied to a sequence which is truly repetitive. Sometimes the first and last repetitions differ slightly from the others. In this case, these will be charted in the normal way and the convention will be applied only to the intervening identical repetitions.

Special care must be taken to note the correct number of recurrences, so that the proper continuity of numbering is preserved.

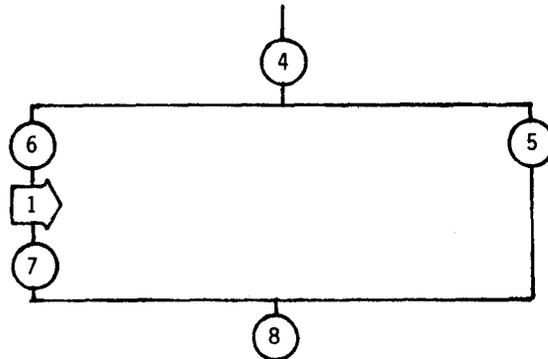
## (f) Alternative Routes

At certain stages, a process may diverge along alternative routes. For example, as a result of an operation, material may be divided into several portions each of which receives separate treatment.

In such a case, the main trunk of the chart is divided into the appropriate number of branches, with the major flow on the right-hand side. Other flow lines are drawn successively to the left in order of importance.



When materials may proceed along alternative routes for a while before resuming the same path, the chart can be split into two or more paths as shown. This convention can also be used to record activities of different parts of the same material, where they are subdivided.



(g) Adding Further Data

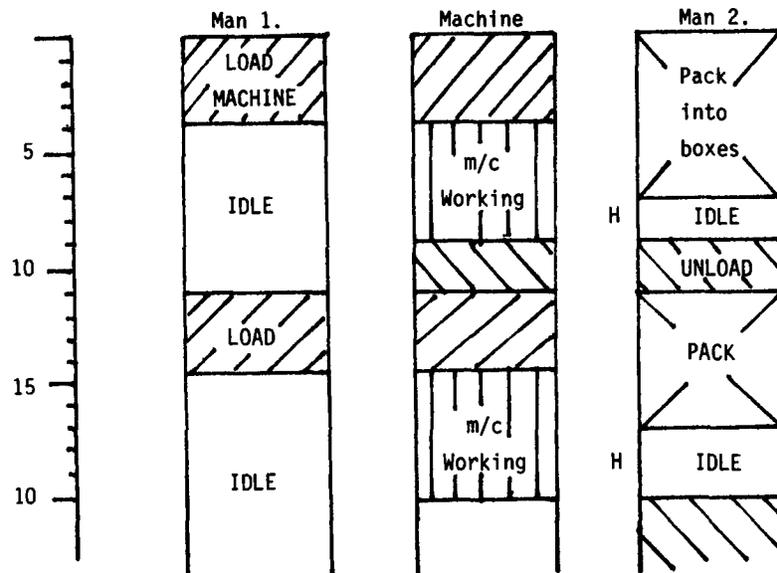
Any quantitative data can be added to the chart. When process, waiting and other times or costs are known, for example, they are sometimes entered alongside the chart, to the left of the appropriate symbol. Distances also can be entered to the left of the appropriate transport symbol.

### 5.7.5 Multiple Activity Chart Conventions

As its name implies, this chart permits the recording of several subjects at the same time. The activities of a number of operators and/or machines can be recorded against a common time scale. No symbols are employed.

Since this chart presents a chronological record of several activities which occur more or less simultaneously, the correct sequence and duration of each must be known.

A vertical bar, usually about half an inch wide, is allocated to each operator and machine recorded. The vertical time scale is shown where convenient, but near enough to the bars to make accurate reading possible. The duration of each activity is marked off across the appropriate bar beginning at the top of the chart. Colouring, hatching and similar devices are often used to distinguish one activity from another.



This type of chart may begin at the bottom, or be arranged horizontally. The conventions described are, however, the most frequently employed.

### 5.7.6 Chart Identification

Before beginning to construct a chart, it is necessary to provide, as a heading, some descriptive information about the chart. Only the essentials need be written; but if these are neglected the chart may become, after the passage of time, almost unrecognisable and perhaps meaningless.

The following information is usually given:

- (a) Type of chart - whether Outline Process, Flow Process (Material), etc.
- (b) Nature of Job or Process being charted.
- (c) Version of Job - whether existing (Present Method) or Proposed.
- (d) Subject of Chart.
- (e) A clear statement of where the chart begins and ends.

The date of construction, together with the name or initials of the author, should be added; and the use of any symbols, conventions or devices other than those normally employed should be explained in an accompanying legend.

#### 5.8 Method Study - Recording (Outline Process Chart)

This chart must give a schematic diagram of the interrelationship between the parts of the process which are approximately equal in relative importance. The detail should be decided by the person doing the study. The outline process chart is a useful tool in explaining processes and situations to groups and third party decision makers. It is a vital stage in defining problems.

1. Introduction
2. Description of the Outline Process Chart
3. Using the Outline Process Chart

##### 5.8.1 Introduction

At the initial recording stage, only an overall view of the process is required. This will help to indicate how detailed further records need be. Such a 'bird's eye view' is provided by the Outline Process Chart, abbreviated to OPC.

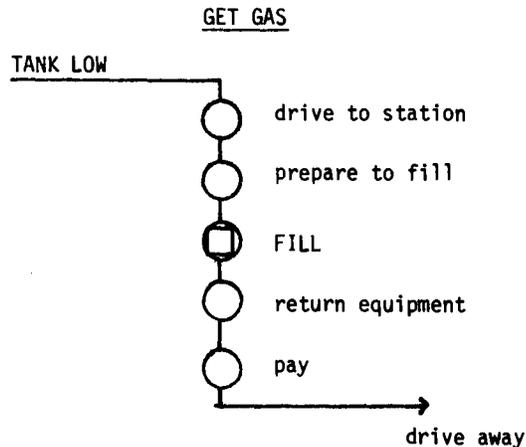
##### 5.8.2 Description of Outline Process Chart

The OPC is the simplest type of Process Chart. Like all process charts, it is a pictorial record of work using symbols to represent various activities.

By definition it is "a Process Chart giving an overall picture of a process by recording in sequence only the major 'Operations and Inspections'".

Thus, only two of the five Process Chart symbols are used in the construction of an OPC - the operation  and the inspection . The incidence of delays, transports and storages is not recorded.

For example, the job of getting gas at a self-serve station could be outlined in the following chart:



### 5.8.3 Using the Outline Process Chart

- (a) The OPC serves as the basis for Examination, without further recording.
- (b) The OPC is more often used as a skeleton around which the more detailed Flow Process Chart is built although the OPC gives a general picture of the operations which are completed, it does not record exactly what is involved in these activities; nor how they are accomplished.
- (c) An alternative to amplifying the entire OPC is to select one or more of the Operations and Inspections which are sufficiently complex to require clarification. These are then made the subject of further Outline or Flow Process Charts.
- (d) When a very simple job is being studied, an OPC is generally of little value. In this case, the facts would be recorded on a Flow Process Chart.
- (e) After examination and the early stages of development, the OPC is used again to provide a skeleton summary of the proposed new method. This will incorporate the broad modifications to the process, which will later be amplified in the Flow Process Chart.

### 5.9 Method Study - Recording (Charting - application)

The application of charting techniques can help to:

- Reduce number of steps
- Arrange steps in best order
- Make steps as economical as possible
- Reduce handlings
- Combine steps if economical
- Shorten moves

Provide most economical means for moving  
 Cut in process inventory to worktable minimum  
 Use minimum number of control points at most advantageous places.

Simple questions which result from charting include:

Can any step be eliminated?

- a. as unnecessary (Ask: Why is it done?)
- b. by new equipment (Ask: Why is present equipment used?)
- c. by changing the place where it is done or kept (Ask: Why is it done there?)
- d. by changing the order of work (Ask: Why is it done in this present order?)
- e. by changing the product design (Ask: Why is it done as it is?)
- f. by changing the specifications of the incoming supply (Ask: Why is it ordered in its present form or used at all?)

Can any step be combined with another?

Are there any possible changes that would make this feasible in

- a. workplace
- b. equipment
- c. order of steps
- d. product design
- e. specification of supply or any raw material

Can the steps be rearranged so as to make any shorter or easier?

Can any step be made easier?

## 5.10 Method Study - Selection of the key operation

### 5.10.1 Key operations

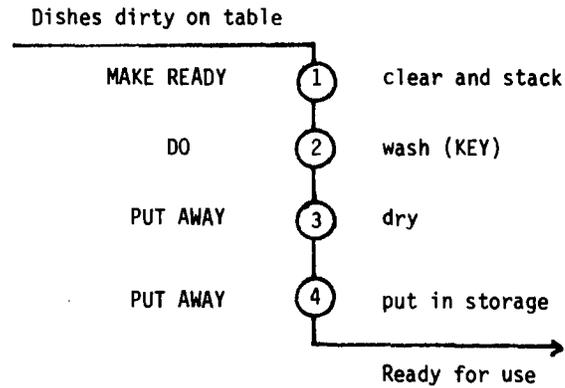
In every process there are operations which control all, or a major portion, of the whole. These are called Key Operations and may be defined as: "Those operations which, if eliminated, will eliminate all, or a major portion, of the whole process".

The definition of any problem can be considered complete and ready for analysis when the controlling or "key" operation has been stated in a simple phrase. It is important, therefore, that the action of choosing this "key" operation to the process under study be clearly understood so that definition can be achieved.

As previously stated in the sections on Purpose, Scope and Outline Process Chart, the key operation is that operation which, if it is altered or eliminated alters or eliminates the process itself. It is truly the action which controls the end result of the process.

### Further Examples of Key Operations

#### 1. Wash Dishes



#### 2. Prepare and eat a meal



### 5.10.2 Statement of Achievement/End Result

The simple phrase which describes the END RESULT of the Key operation is called the Statement of Achievement. This statement is not a description of what is done during the operation but is a clear picture of what has been achieved by taking this action.

Using the washing of dishes as an example:

Key operation - "wash"

The action taken on how you carry out the Key Operation is to place the dishes in soapy water and rub clean. This is not the requirement that must be met but merely How it is met.

The requirement is to remove all food particles from the dishes so that they will be clean and ready for the next meal. There are obviously other ways to do this but the way that has been chosen is soapy water.

The End Result, therefore, (or achievement) is the cleansing of the dishes. To make the phrase simple and usable it should consist, where possible, of simply a subject and verb and the verb should always be in the passive voice.

e.g. "Dishes are cleaned"  
(the answer to the question - What is achieved?)

### 5.11 Deciding on process improvement alternatives

The Key Operations in any process represent the "Doing" or "Action" stages. Although improvements to a process can be made through modifying the "make ready" or "put away" operations these will seldom make as great a contribution to total process improvement as a modification to a key operation.

Identification of the Key Operation(s) of a process should lead to list of potential modifications to these operations. For example, in the dish washing example the key operation of cleaning the dishes could be achieved by:

Washing under running water  
Soaking in soapy water  
Soaking in hot non-soapy water  
Spraying with steam  
etc.

The list of alternatives to achievement of the key operation can go on. In fact, it is this "idea generation" or "brainstorming" for process alternatives which forms one of the most important steps in process improvement. All ideas should be listed. No idea should be rejected at first sight - the most ridiculous

idea may lead to the most revolutionary and successful process improvement.

When the list of alternative methods for achieving the key operation is complete they should be compared on the basis of their potential for improving the process. A number of criteria are defined as being important to process improvement within the company, for example, increasing capacity, improvement in product quality, reduction in operating costs, lowering capital costs. The alternatives are rated on each of these criteria. The total scores indicate the processing alternative with the greatest potential for improvement.

Table 5.1 shows an example of the application of this simple screening technique to the dish washing process. Although steam cleaning the dishes offers more rapid throughput and greater efficiency it is very expensive in terms of both capital and operating cost. It would be better to stay with the tried and tested method of soaking in hot, soapy water.

Table 5.1 Screening of Process Alternatives

Criterion	Process alternatives			
	Running cold water	Soapy water	Hot non-soapy water	Steam
Throughput (30) <sup>1</sup>	15	25	19	28
Efficiency (25)	5	20	15	22
Operating cost (20)	20	14	12	6
Capital cost (20)	20	15	15	5
<b>Total</b>	<b>60</b>	<b>74</b>	<b>61</b>	<b>61</b>

<sup>1</sup> Maximum possible, i.e., most beneficial, scores shown in parentheses.

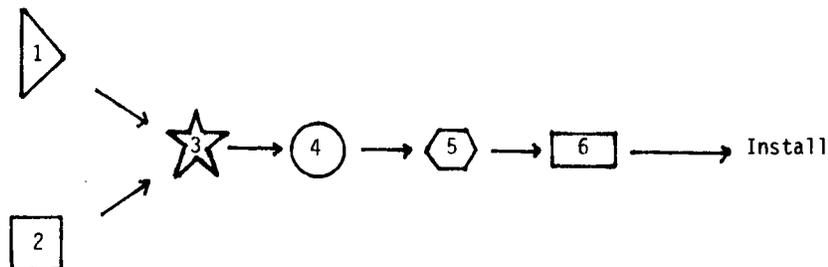
### 5.12 Plant layout

Simplified Systematic Layout Planning is a set of six procedures to follow when laying out an area<sup>(1)</sup>. These procedures are a simplification of Systematic Layout Planning (SLP), a technique developed for layout planners and widely used by facilities planners and industrial engineers.

Simplified SLP is best suited to small manufacturing plant and office areas up to about 5,000 square feet (450 m<sup>2</sup>). It can also be used in auxiliary, laboratory and support areas up to 7,000 square feet (650 m<sup>2</sup>). Larger areas and those having multiple floors or other complications should be planned with the full SLP procedure<sup>(2)</sup>.

For departmental, branch or small office areas, Simplified SLP can be of great value: saving time, encouraging participation and permitting effective delegation of layout planning responsibility.

The pattern of Simplified Systematic Layout Planning can be shown schematically as follows:



(1) The booklet, Simplified Systematic Layout Planning by Richard Muther & J.D. Wheeler, is available from Management and Industrial Research Publications, P.O. Box 7133, Kansas City, MO 64113.

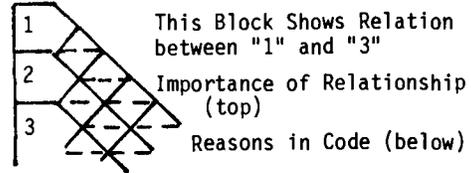
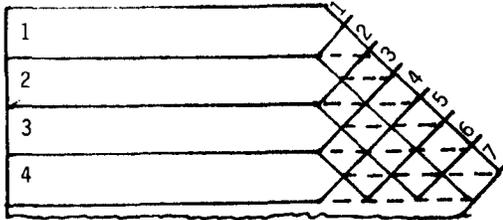
(2) The full SLP procedure is explained in detail in the book, Systematic Layout Planning (SLP) by Richard Muther, available from Cahners Books International, Inc., 221 Columbus Avenue, Boston, MA 02116.

▷	<b>CHART THE RELATIONSHIPS</b> a. Identify the activities, functions, of building features. b. List activities on a Relationship Chart. c. Assign "closeness" values to each pair of activities and code "reasons" therefor.	○	<b>ARRANGE SPACE FOR EACH ACTIVITY</b> a. Join the space required for each activity with the relationship diagram. b. Adjust and rearrange to integrate all modifying considerations.
□	<b>ESTABLISH SPACE REQUIREMENTS</b> a. Prepare an Activities Area and Features Sheet. b. Determine the area required for each activity. c. Mark physical features and configuration requirements.	◡	<b>EVALUTE ALTERNATIVE LAYOUTS</b> a. Visualize the most likely arrangements. b. Establish specific objectives of the layout. c. Weigh the various factors. d. Rate each alternative arrangement. e. Select the most suitable arrangement.
★	<b>DIAGRAM THE ACTIVITIES ARRANGEMENT</b> a. Diagram pairs of activities on the basis of relationship ratings. b. Re-arrange activities into final Activity Relationship diagram. c. Indicate required floor space on the diagram.	□	<b>DETAIL THE SELECTED LAYOUT PLAN</b> a. Show detail of each piece of equipment and major utilities.

**STEP 1: CHART THE RELATIONSHIPS**

**Step 1 - Chart the Relationships.** Basically, every layout planning project - large or small - rests on three fundamentals: Relationships among various functions or activity-areas; Space for each activity-area, in amount, kind, and shape; and Adjustment of these into a layout plan.

Establishing the relationships involves relating each function, activity-area, or major building feature of the particular contemplated layout to every other activity-area by a closeness-desired rating. Determining and recording these relationships is a basic first step in Simplified SLP.



In charting relationships, each activity-area is listed on a relationship chart (above). Each activity-area line slopes away at 45 degrees - down and up. Where down-sloping line 1 intersects up-sloping line 3, record the desired (or required) relation between Activity 1 and Activity 3.

A vowel-letter rating scale is used to record the closeness desired between each pair of activity-areas - using the upper half of the particular intersected box (or square).

The lower half of the box is used to record the reason(s) for the closeness. Each reason is given a number and the various reasons support each closeness-desired decision by one or more reason-code numbers.

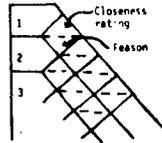
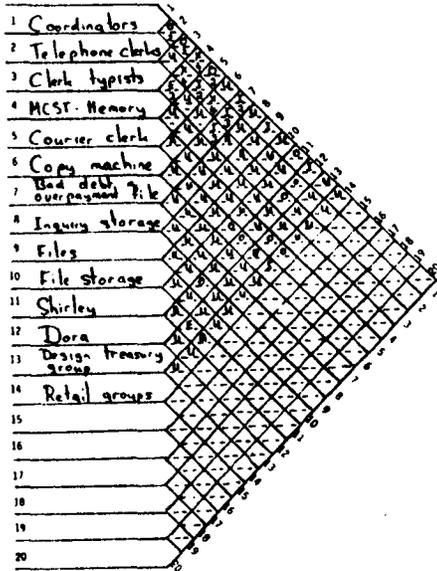
Value	CLOSENESS	No. of Ratings
"Closeness Value"	A Absolutely Necessary	
	Especially Important	
	Important	
	Ordinary Closeness OK	
	Unimportant	
	Not desirable	

Code	REASON
1	
2	
3	
4	
5	
6	
7	
8	
9	

Reasons behind the "Closeness" Value

RELATIONS-IP CHART

Plant Company: Big 'A' Project: Change.  
 Chartered by: Planning Dept. with  
 Date: May 1982 Sheet: 1 of 1  
 Reference:



Value	CLOSENESS	No. of Ratings
A	Absolutely necessary	6
E	Especially important	4
I	Important	6
O	Ordinary closeness o.k.	11
U	Unimportant	61
X	Not desirable	3
Total		91

Code	REASON
1	Personal contact
2	Convenience
3	Ease of supervision
4	Noise level
5	Control of work

The relationship chart is a simple and effective device to help organize a host of decisions into usable form.

In the office layout example above, there are 91 separate decisions recording how each activity relates to the others. The relationship chart relieves you of having to keep in mind all these decisions and the reasons for them.

1. Complete the heading on the working form.
2. Identify all activities involved and list them on a relationship chart, one on each line.
3. Determine and record in the upper half of the appropriate diamond-shaped block a closeness rating for each activity relative to every other activity. For example: Coordinators (Activity 1) relates to Files (Activity 9) in the block where down-sloping line 1 intersects up-sloping line 9.
4. Record a reason-code number in the lower half of each block in which a rating other than U is recorded.
5. Explain each reason code used with appropriate entry in the reason box.

The relationships can be established in several ways: a) by the layout planner

- if he or she is really familiar with the desired workings of the areas(s) involved;
- b) by group discussion between the planner and one-to-three key supervisors;
- c) by face-to-face questioning of each person involved in the area(s) being laid out;
- or d) by questionnaire to be filled out by all or selected individuals.

The relationship chart serves also as a convenient check sheet that helps you avoid overlooking any relationship that should be included. One of its less obvious advantages is the opportunity it provides to involve people in planning the layout of the areas in which they will be working. It helps them understand that any office layout is a best combination of many interacting relationships.

**STEP 2: Establish Space Requirements**

SUMMARY OFFICE LAYOUT REQUIREMENTS DATA																
Project: <u>SO PROJECTION</u>				Company: <u>Lambert Press</u>				Bldg: <u>Main</u> Floor: <u>2</u> Page: <u>1</u>								
Project: <u>SO PROJECTION</u>				Sq. Ft. now Assigned: <u>          </u>				Estimate received (Fill in Quantity, Size & Description as per 4.)								
Room or Dept. Number	Identification	JOB TITLE or Description	Type of Space	Regular Equipment*						Other Equipment		Special Utilities or Requirements (Describe)				
				Machine	Desk	Chair	Locker	Legal File	Telephone	Vertical Light	Other		Quantity	Description		
1	COORDINATOR	SENIOR	100	125	100	2	30x40	10								
2	TELEPHONE CLERK	SENIOR	30	30	30	3	30x40	10								
3	CLERK TYPIST	SENIOR	10	70	15	4	30x40	10								
4	MGMT - MEMORANDUM	SENIOR	10	70												
5	COMBINE CLERK	SENIOR	10	40												
6	COPY MACHINE			20												
7	ADD. COPY 2			20												
8	INVENTORY FILE			20												
9	INVENTORY STORAGE			20												
10	FILE CLERK			20												
11	SHOULDER	SENIOR	10	35												
12	DESK	SENIOR	10	100												
13	OFFICE TRUNK GROUP	SENIOR	30	245												
14	WIRETRAY GROUP	SENIOR	10	340												
Totals				100	1225		100	100								

\* Type of Space: P-Person; E-Semi-Private; R-Release; O-Open or Semi-Open; S-Service or Special Areas (For special areas furnish amount and dimensions)  
 \*\* Filled in by layout engineer (or office layout analyst)

Reference Note: SEE BACK-UP SHEETS FOR CATALOG NUMBERS AND SPECIFICATIONS

Date Recorded by: PLANNING GROUP Date: MAY 1976

**Step 2 - Establish Space Requirements.** Next, we list the same activities as in Step 1. Then we calculate and record the amount of space and the furniture and equipment required to support each activity (Figure above).

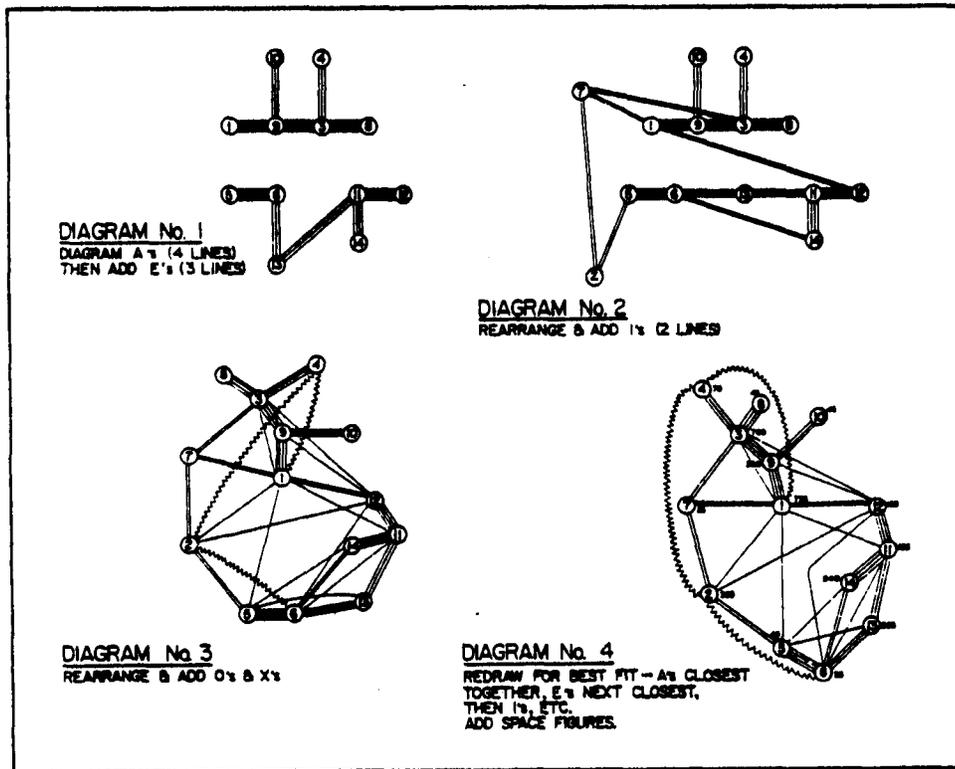
Requirements can be established in several ways. One is to determine the space now used for each activity; then apply a factor for effectiveness of present utilization, and another factor for any projected change(s) in the level of

operations to be supported.

Another way is to develop space, furniture and equipment standards for typical work stations, groups of positions, or job categories. Recognize that the type of furniture used can influence the space required. Panel-mounted furniture systems, for example, often take less floor space but provide less work surface than other types of furniture.

In some instances, space is set by measuring each piece of equipment, allowing for operator's work area, access and maintenance areas. Then calculate the total area required to house the equipment. If the shape or overall dimensions of an area are critical, then a rough layout may be useful to establish proper requirements. Measuring and rough layout are most useful when establishing space for canteens, computer rooms, reproduction centers and the like, where relatively major equipment and installation costs are involved.

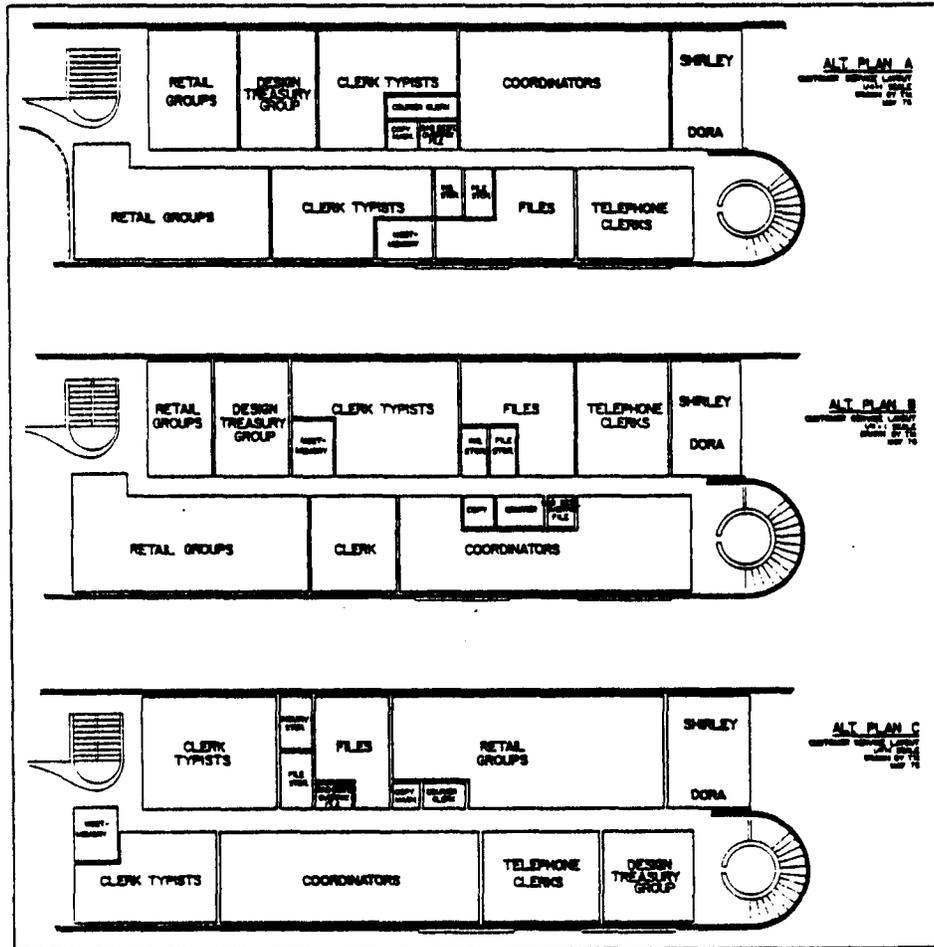
STEP 3:      DIAGRAM ACTIVITY RELATIONSHIPS



Step 3 - Diagram Activity Relationships. So far, we have merely recorded and tabulated data. We will now use these data to develop an arrangement of activities. We do this by preparing an activity relationship diagram (Figure for Step 3). Numbered circles are used to represent the activities. Circles are connected to one another by parallel lines corresponding to the closeness rating values recorded in Step 1 on the relationship chart.

The highest rated relationships (A's) are represented by four connecting lines; the next highest (E's) by three lines; and so on, through the O's with one line. Unimportant (U) relationships are not diagrammed. A zig-zag line is used to show X relationships. For comparison, think of elastic bands pulling the activities together and a compressed spring pushing activities away.

The goal is to place the activity pairs with higher closeness ratings nearest each other, and those with lower closeness-ratings progressively further away. The resulting diagram is the basis for subsequent steps and must be carefully constructed. Several diagrams - each a redrawing of the activities already diagrammed with the next "level" of closeness-desired ratings added - are customarily required to develop the final best-fit diagram. Once you have it, mark the space requirements from Step 2 beside each circle.

STEP 4: DRAW SPACE RELATIONSHIP LAYOUTS

Step 4 - Draw Space Relationship Layouts. The temptation in office layout planning is to jump prematurely into placing furniture and equipment. But no matter how well you arrange these details, you cannot get maximum operating effectiveness if overall work-group of departmental positions are improperly located with respect to each other.

Concentrate on making good overall or block layouts (as in the Figure above) using the diagram from Step 3 as a direct guide. Several workable layouts will become apparent, each adjusted in a different way to accommodate utilities, building features, personnel matters, aesthetics and the like.

Don't stop with one layout. You cannot tell how well or how poorly it will perform without comparing it to other alternatives. Three of four alternative



### Step 5 - Evaluate Alternative Arrangements

Objective evaluation can help you identify the best layout alternative and smooth the inevitable ruffled feathers of those whose desires could not be completely satisfied.

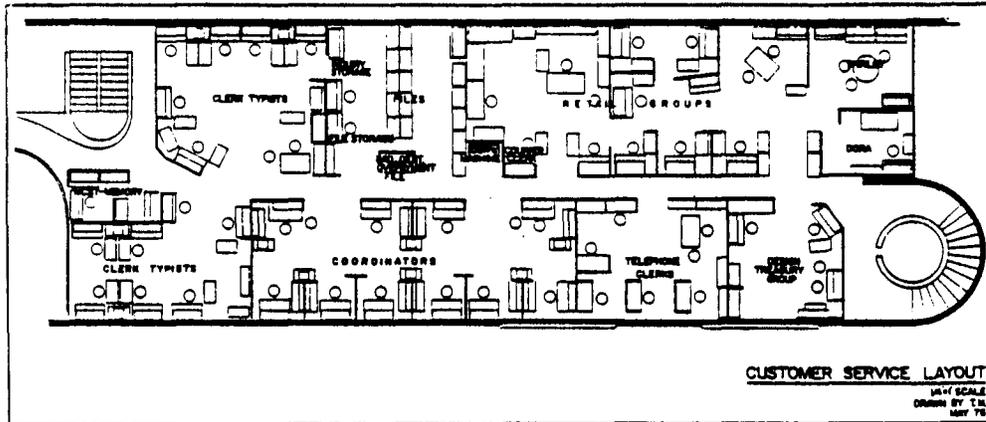
A simple listing of pros and cons usually does not dig deep enough and gives little recognition to the differing importance of various factors. Cost comparisons often result in a stand-off. SLP uses a weighted-factor approach which makes objectives explicit. It allows those who are affected to participate in selecting the basic layout plan.

First, enter the data at the top of the form. Then, identify each plan. Next, list the objectives to be achieved or the factors or considerations on which the plans will be compared. Assign weight values to the relative importance of each factor or consideration - starting with 10 for the most important. The weights should be set by managers and supervisors in the areas involved.

Next, rate the effectiveness of each alternative layout on each factor, or consideration, again using the vowel-letter ratings, A, E, I, O and U in descending order. Here, the workers in the areas involved can themselves actually participate in the ratings.

After all plans have been rated on all factors or considerations, convert the vowel-letter ratings to numerical values (A=4, E=3, I=2, O=1, and U=0). Multiply numerical values by the appropriate weight and down-total the extended weighted ratings for each alternative layout. The highest total should indicate the best layout.

If two plans score almost the same, you can re-evaluate with more factors, other people, or after revisions to the plans themselves that may eliminate some weak points.

STEP 6: DETAIL THE SELECTED LAYOUT PLAN

Step 6 - Detail the Selected Layout Plan. In this final step, all the previous work pays off. Specific pieces of furniture and equipment can now be laid out with complete assurance that the overall arrangement will be effective.

In big layouts, in order to show the details, the scale of the planning sheet changes at this step. These details can be drawn on tracing paper or arranged as two dimensional templates on a grid-backed sheet. Three dimensional models are seldom justified for small office layout planning.

As a practical matter, some adjustment from the selected block plan will be necessary to accommodate final positions of furnishings and utilities. Once completed, the detailed plan can be reproduced and used to guide architects, decorators, contractors, maintenance crews and others involved in the non-operating and installation activities.

Simplified SLP - Six Simple Steps to Small Office Layouts

In Steps 1 and 2, we identified the necessary activities, rated their relationships to each other, and determined the amount and kind of space each required.

In Steps 3 and 4, we transformed this into a best-fit diagram, added the space amounts to the diagram, and determined a number of alternate layout solutions.

In Step 5, we evaluated the alternative layouts considered most workable.

Then in Step 6, we detailed the selected plan into a working drawing that showed all equipment and furniture in place.

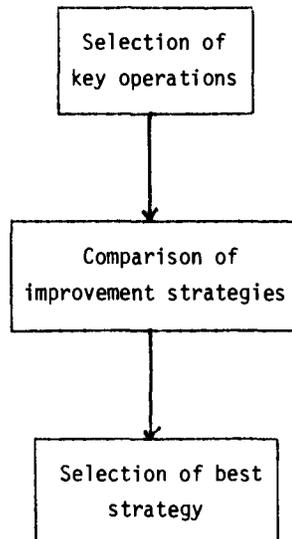
This completes the Simplified S.L.P. procedure. Now we will be able to turn our plans over to the installers and/or movers to physically place the actual equipment, or to others who may need to do more work to dress-up the space or adjust other details to our layout plan.

## 6. OPERATIONS RESEARCH AND SYSTEMS ANALYSIS (OR/SA) by G.K. Rand

The production management techniques discussed in Section 5 lead to the selection of specific key process operations.

Each of these key operations may present a number of potential process improvement strategies. Management now requires methods for evaluating these alternative strategies.

Although operations research can have wider applications it is presented in this manual as a set of problem solving tools to assist management in the comparison of alternative process improvement strategies. A selection of OR/SA techniques is presented in this section.



### 6.1 The nature of Operational Research and Systems Analysis

The suggestion that it is worth considering the contribution that Operational Research and System Analysis may make to small food firms indicates that these firms can be regarded as consisting of various operations, which can be researched, and various systems, which can be analysed.

Operational Research, as defined by the Operational Research Society, is the application of the methods of science to complex problems arising in the direction and management of large systems of men, machines, materials and money in industry, business, government and defence. The distinctive approach is to develop a

scientific model of the system, incorporating measurements of factors such as chance and risk, with which to predict and compare the outcomes of alternative decisions, strategies or controls. The purpose is to help management determine its policy and actions scientifically.

At face value this definition would seem to exclude the possibility of using Operational Research in small food firms. It talks about 'complex problems' arising in 'large systems'. It is true, too, that the majority of OR applications have been in large private firms, in nationalised industries or for local/national government. However, simply stated problems can be exceedingly large and complex. Consider, for instance, a small engineering shop which is required to sequence ten jobs over two machines, and all jobs must go through the machine in the same order. The best sequence is one of over 3,600,000 possible sequences. When, as in this example, there are many possible courses of action, OR can be used.

As can be seen from this definition OR has its roots in the scientific method: it is science applied to the function of management. Indeed, a synonym is Management Science. OR therefore, relies heavily on the language of science, mathematics, in order to express problems in an abstract form and so more easily find a solution. The OR worker will thus be familiar with a collection of mathematical techniques, such as linear programming, some of which are discussed in Section 6.4. As a result many, including, unfortunately, some OR workers, think that OR is just applied mathematics. This is not true. OR is an approach to problems, in which their essential form is discovered, in order that help is given to the decision maker. For an OR worker it is the problem that matters, and the techniques are simply a means to an end: namely, the evaluation of different courses of action, so that informed decisions can be taken.

When one begins to consider the different functions of a firm it soon becomes clear that they cannot be isolated from each other. For example, from a sales point of view it may be desirable to introduce a new variation of a particular product. However, the production manager may argue that the new variety is difficult and expensive to produce and causes inconvenience because machinery has to be stopped in order to change from one variety to another. The accountant, too, may be concerned at the increase in stocks that may be necessary to support the sales of the new product. This is the focus of systems analysis: the recognition that each system which may be considered is merely a sub-system of a larger system, and will interact with other sub-systems. Therefore, to evaluate any problems in an organisation, it is necessary to identify all the significant interactions and evaluate their combined impact on the organisation as a whole, and not merely determine the effect on the area of the firm in which the problem originally appeared.

## 6.2 Significant features and problems of small firms

A small firm is something notoriously difficult to define. There are, for instance, a number of different ways of measuring size (by output, in physical or monetary terms, by number of employees etc). The environment makes a difference: a food factory that seems large in Botswana may seem small in Britain. The nature of the product would also affect a classification: an enterprise employing 200 people would be very large in terms of the distributive trades, but exceedingly small in terms of automobile manufacture. For our purposes, though, a food firm is unlikely to be thought small if more than 200 workers are employed.

A more helpful way of defining small firms, however, in that it reveals some of their particular problems, is to consider their characteristics. The Bolton Report on Small Firms characterises them in three ways: 'Firstly, in economic terms, a small firm is one that has a relatively small share of its market. Secondly, an essential characteristic of a small firm is that it is managed by its owners or part-owners in a personalised way, and not through the medium of a formalised management structure. Thirdly, it is also independent in the sense that it does not form part of a large enterprise and that the owner-managers should be free from outside control in taking their principal decisions'. The first characteristic is ambiguous because it depends on the absolute size of the market and how narrowly the market is defined. A firm may, for instance, be the sole producer of an exotic food, and in one sense have a 100% market share, but in terms of the whole food industry in the country may have a very small market share indeed.

Staley and Morse, in a book particularly relevant to the consideration of small firms in developing countries, propose four characteristics that justify separate analysis of the role of small industry in development.

1. Relatively little specialization in management
2. Close personal contacts
3. Handicaps in obtaining capital and credit
4. Sheer number of small industry units

Mackness also suggests that a small firm is characterised by four features:

1. A lack of specialist services to advise management.
2. The necessity for senior people to get involved in all aspects of running the business.
3. Usually only one or two people are involved in significant decision taking.
4. The lack of time for the senior men to think about the development of the firm.

All these are essentially aspects of the first characteristic of Staley and Morse.

What sets a small firm apart from large firms is the fact of one-, or perhaps two-, man management. The manager, and perhaps a few assistants, look after production, finance, purchases, personnel, sales, etc. It is this characteristic that results in an obvious lack of specialization, and lack of time to think about the future of the firm, and which gives a small firm need for advice and aid from outside, which a large firm will probably be able to find from within its own resources.

Another problem is also identified. Small firms cannot raise capital as easily as large firms, and often find difficulty in obtaining loans from banks or other financing institutions. This characteristic also suggests the need for aid from outside.

One major advantage of a small firm results from the small management base. The managers are not only in personal touch with their employees, giving the opportunity for good relationships within the firm, but also know both suppliers and customers, which provides the opportunity for flexibility in daily operations, such as meeting a customer's urgent requirement. This may, indeed, give a competitive advantage over larger industry.

### 6.3 Problem areas in a food company

#### 6.3.1 Production

It is clear that in a manufacturing company a major source of problems will be in the production function itself. Management of this function will involve both design and planning and operation and control. The tasks that might be considered in the category of design and planning include the design and specification of the products and production system, the determination of the location and layout of the production plant, the determination of capacity, the design of jobs and the determination of the payment system and the appropriate work standards. The operation and control of a production system includes such activities as the planning and scheduling of production and inventories, the control of quality, the scheduling of maintenance and the replacement of equipment, and the measurement of production efficiency. Whilst all these areas are potential trouble spots, it is worth identifying some of them more closely as they have a particular significance for a food company.

#### Capacity planning

In order to operate effectively a food company manager must plan capacity carefully. Excess capacity inevitably results in low productivity, whilst inadequate capacity leads to poor customer service and loss of potential profit. The objective of capacity management is therefore to match the production rate to demand, and this is made difficult by uncertainty of demand, both in terms of average demand and in

terms of fluctuations about an average level. There are four basic options for the management of capacity:

1. Maintain 'excess' capacity
2. Accept loss of customers
3. Require customer waiting (not very likely with food products)
4. Provide output stocks

Only the last two options allow temporary demand reduction without the risk of decreasing production efficiency.

#### Production planning

The production planning problem in a company is to determine when to produce the various products in order to meet expected demand. If the capacity planning problem has a medium- to long-term timescale, then the production planning problem is a short- to medium-term one. For many food firms this problem is particularly difficult because of the seasonal nature of the products.

Some products, such as fruit and vegetables, may have a very short harvesting season, although they may be sold throughout the year. Other products, such as drinks may have peak selling periods, although they can be produced throughout the year. In the second case, if the firm decided to plan production to follow the demand pattern it may be necessary to add extra production shifts during the peak demand period. On the other hand, a decision to have a constant production rate throughout the year would lead to increased stocks during the periods of low sale. Frequently a production plan is a compromise between these two extremes.

#### Equipment layout

A manufacturer must arrange his facilities, and the adequacy of the layout will affect the efficiency of subsequent operations. Although this is a fundamental problem, it is an extremely complex one because objectives will vary from one company to another and because there is no single acceptable and rigorous procedure by which the objectives, however they may be specified, can be achieved. The nature of the layout will determine the extent of the movement and handling of the products and, in some sense, the layout must be arranged to enable the products to be provided at minimum total costs.

#### Quality control

A production plant will not be capable of operating continually in a specified fashion without variation in the quality of the goods produced. It is, therefore, vital, and no more so than in a food firm, for procedures to be established to ensure that unacceptable products are not passed on to the consumer, and, equally

importantly, to help to prevent unacceptable products being produced.

### 6.3.2 Inventory

Inventory management, or stock control, is an important concern of all manufacturers. Stocks of finished product are very costly, yet enable good service to be given to the customer, so a balance must be struck between the benefits obtained from stocks and their costs. This problem is exacerbated for many food firms by the seasonal nature of the products or raw materials (See production planning above).

### 6.3.3 Distribution

Once products have been produced it is necessary to provide a means by which customers can obtain them. Larger firms may well set up a system of deliveries via regional distribution centres, and so will need to decide where these centres should be located. A smaller firm may only be concerned with customers within a relatively small distance of the production plant. In this case the problem of location may not be present, but, in common with the large firms some method for organizing the deliveries will need to be devised. The problem of distribution is often an important one for food firms because products may be perishable and need to be delivered as quickly as possible, and because of the high cost of a distribution system.

## 6.4 Potentially useful techniques

### 6.4.1 Systems analysis

Strictly speaking, systems analysis is not a technique. It is an approach to problem solving which requires many techniques for a successful outcome. However, for our purpose, it is convenient to treat it here as a diagnostic technique for unravelling the particular problem of a small firm.

The word 'system' has been defined in many ways, but a basic definition is that a 'system' is a set of parts coordinated to accomplish a set of goals. More fully, a system according to Mackness:

1. has an objective
2. has a measure of performance
3. has sub-components which are themselves systems
4. has sub-components which themselves interact and which show a degree of connectivity such that effects and actions can be transmitted through the system
5. exists in wider systems with which it interacts
6. has resources
7. has a decision-taker and a decision-taking process
8. has some guarantee of continuity and ability to recover stability after disturbance.

The aim of systems analysis is to understand the relationship between the structure of the existing situation (i.e. the physical layout, organisation hierarchy, communication patterns, etc.) and the process with which it is concerned (i.e. the activities concerned with planning and controlling etc.). Specifically the aim is to discover who uses what resources in what operational processes under what planning procedures within what structure in what environments and wider systems, and how the resource usage is monitored and controlled.

In Mackness's work a simple model of a manufacturing business was used as an aid in structuring the investigation into what was going on in a firm. The model is shown in Figure 6.1. As an investigation proceeds in a firm various apparent disagreements or differences of emphasis will arise. In order to resolve these conflicts it is necessary to collect factual information. For instance, if the production department claims that scheduling is inefficient because all orders are accepted, then the sort of information required will be the size distribution of orders, down time on machines and claims by unsatisfied customers. Mackness supplies in an appendix a checklist of useful questions which may be used to guide analysis of the key areas of a firm.

From all this information it is possible to begin to analyse the strengths and weaknesses of a firm. It is then usually possible to collect together many of the points made in the weaknesses section to discover the key problem of the firm.

For instance, in one company Mackness discovered the following weaknesses:

1. Raw material stocks were high
2. Many small orders were accepted
3. The costing system could not show which products were profitable
4. Product priorities were not established
5. There was a lack of coordination in getting new business
6. The factory was untidy because of high Work-In-Progress stocks
7. Despatch costs were high
8. Staff morale was low.

His analysis of the key problem area in this company is given in Figure 6.2. As a result of analysing a number of firms in this way Mackness came to the conclusion that there is a series of standard problems which are often met in small firms and these can be analysed by a set of minimum activity models. He suggests two main reasons why this is possible in small firms. First, the problem situations in small firms do not have the complexity of large organisation problems and therefore it is easier to see in which direction possible solutions lie. Secondly, the solution is very dependent for its successful implementation on the people who are to operate the system. Usually a great level of technical or other detail is not required in recommending a change.

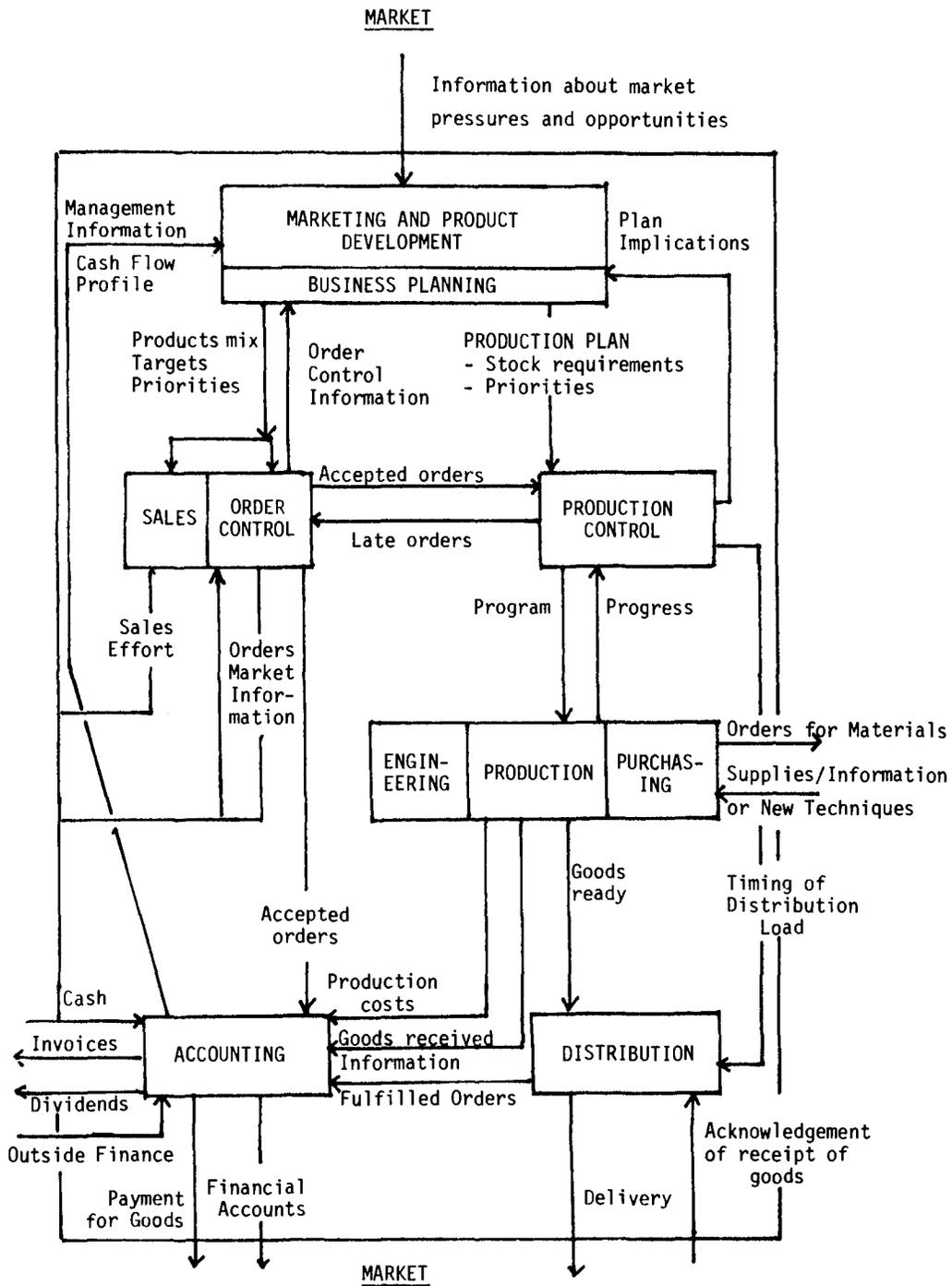


Figure 6.1 A Model of a Small Manufacturing Firm

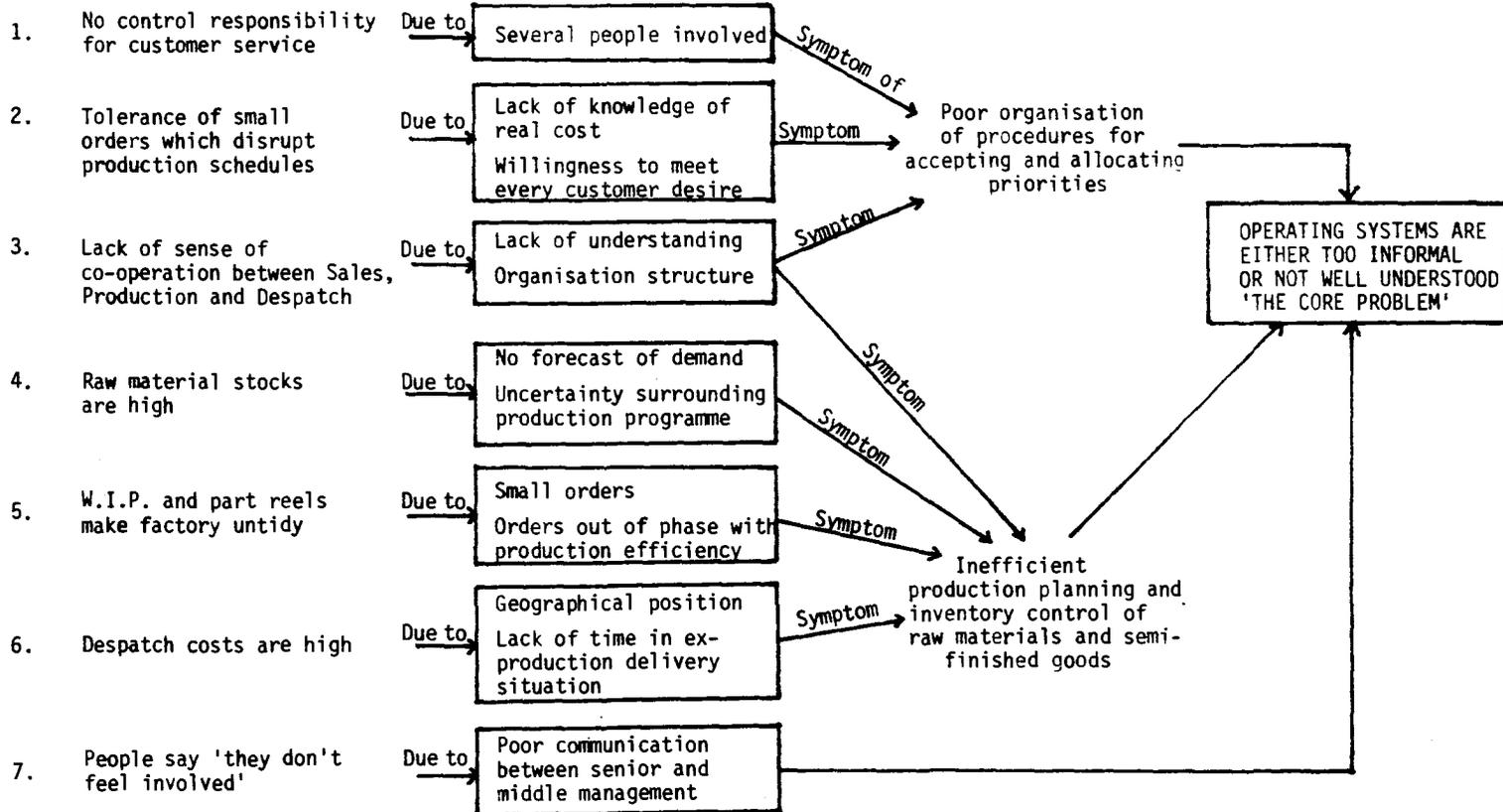


Figure 6.2 Example of the Derivation of the Core Problem

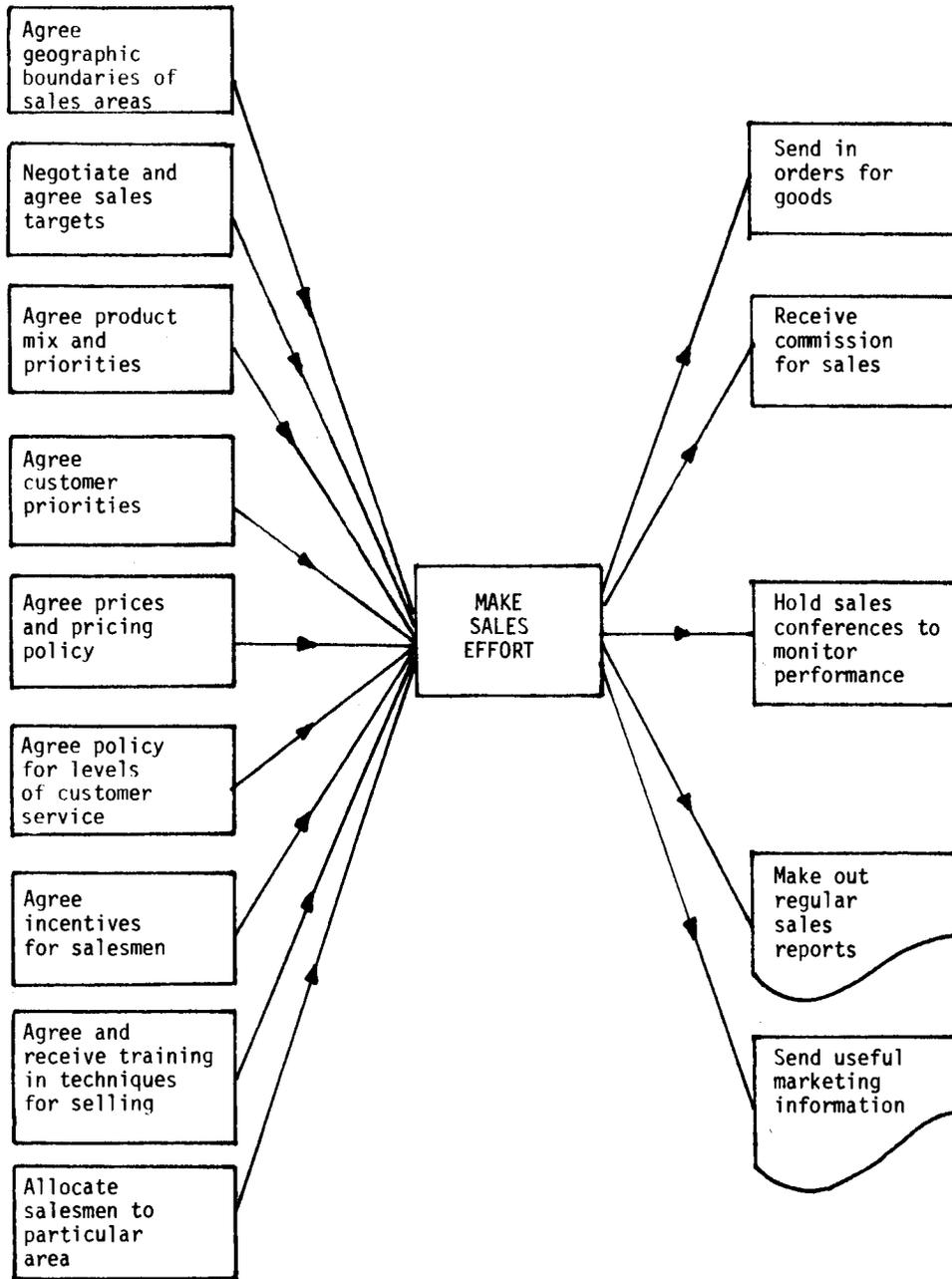


Figure 6.3 Sales activities in the firm

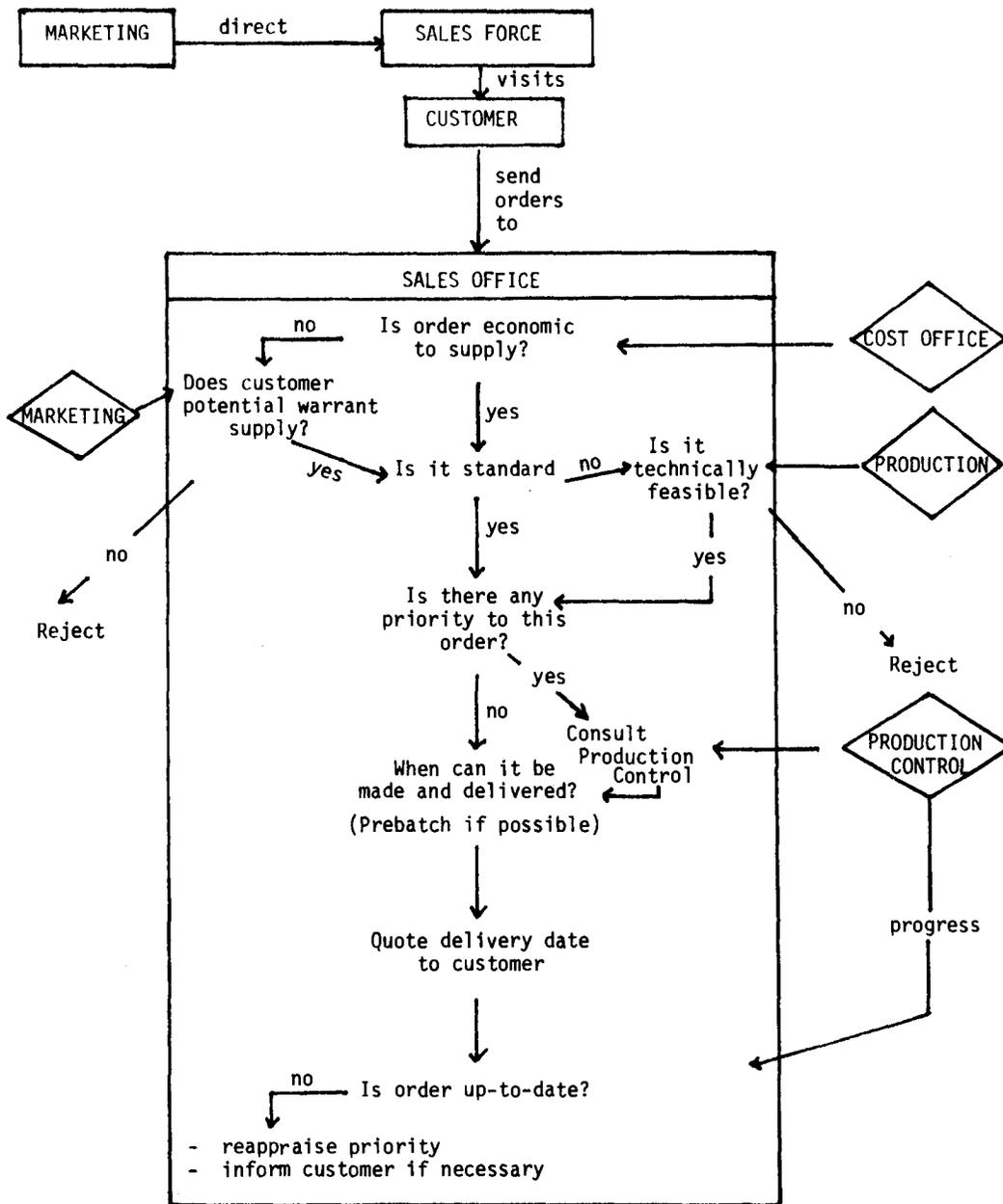


Figure 6.4 Minimum activities model for order processing

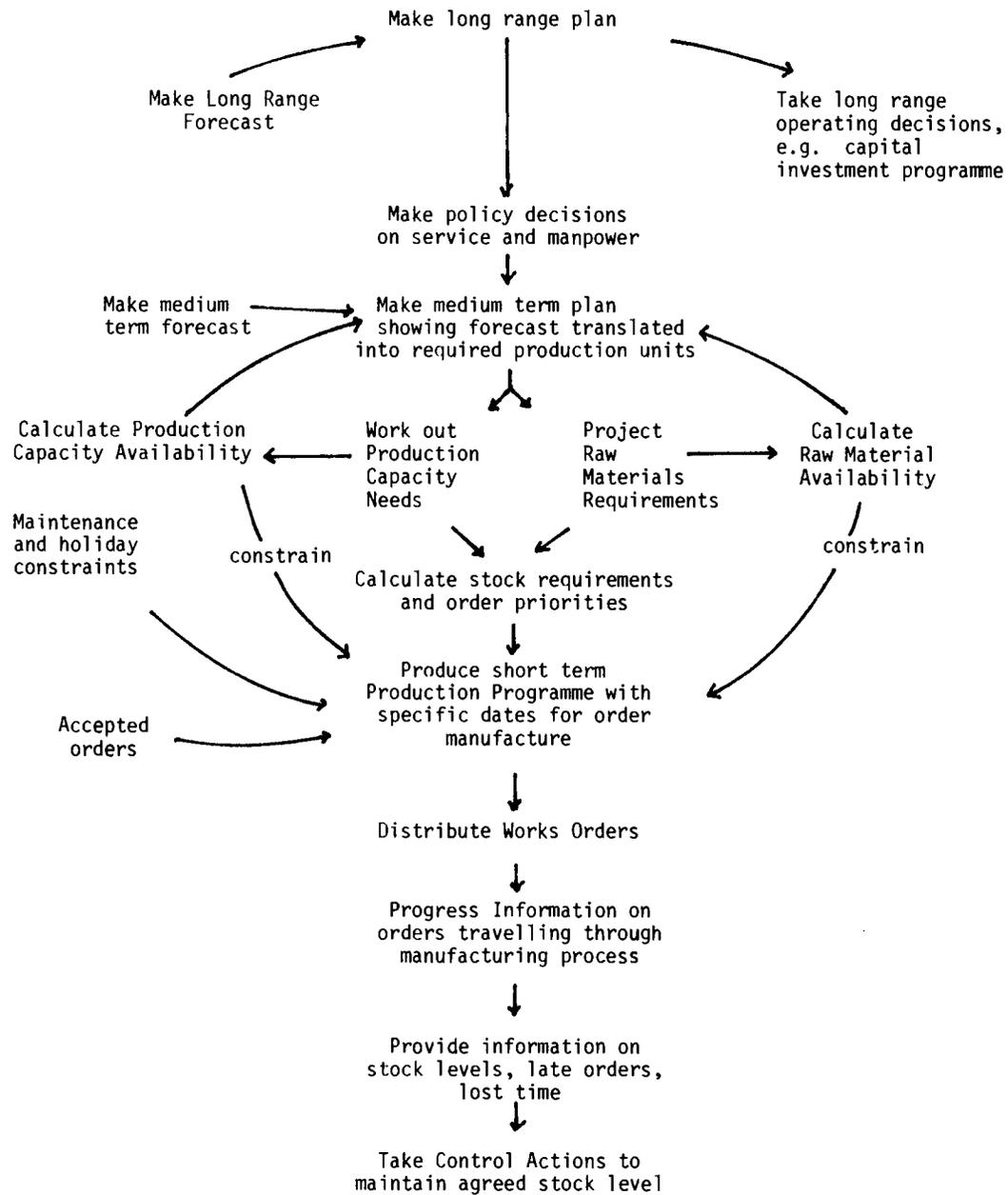


Figure 6.5 Minimum activities model for production planning

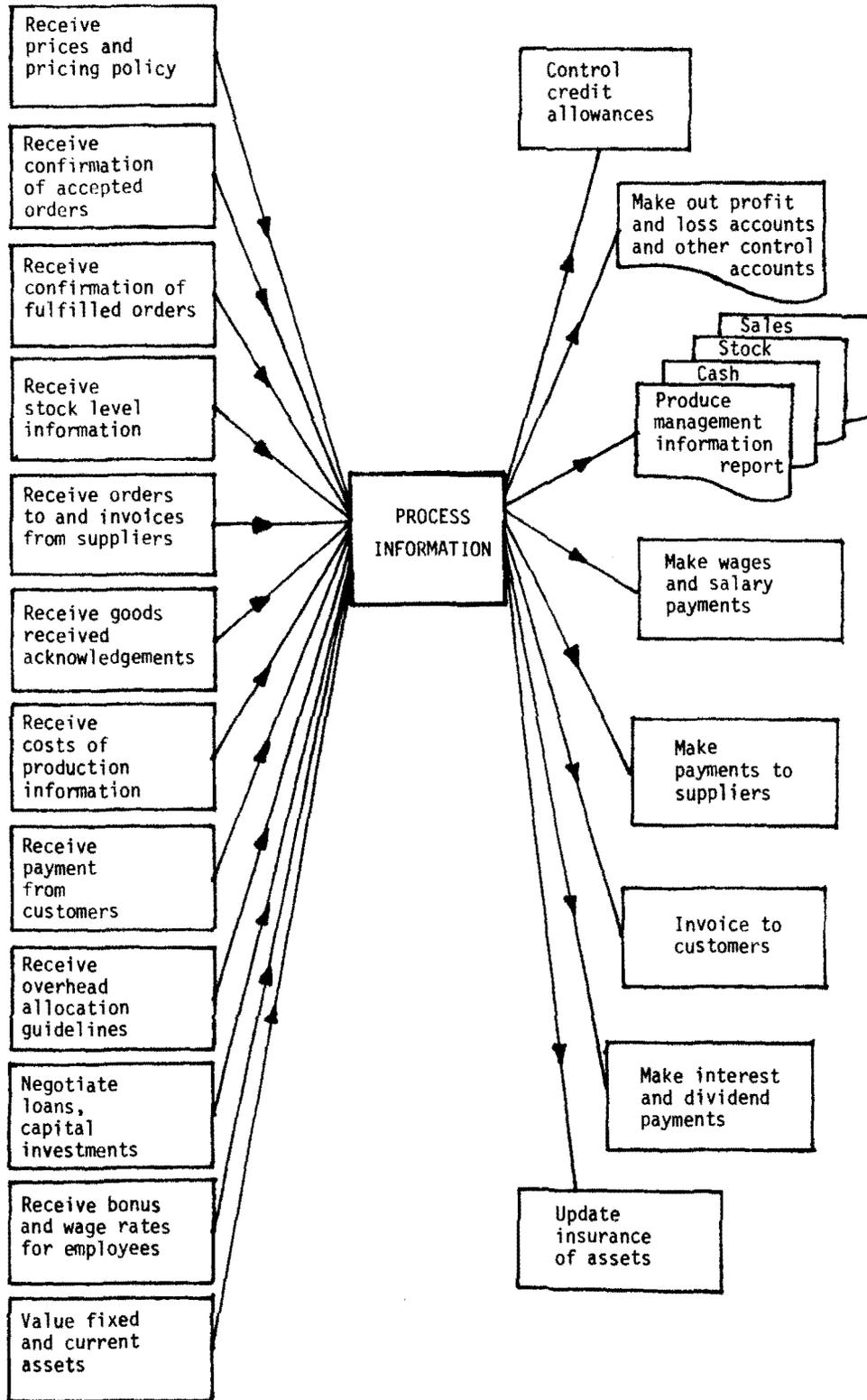


Figure 6.6 Administration and finance in the firm

- (1) Write down current strategy
- (2) Quantify financial objectives within this strategy
- (3) Forecast a scenario of sales and profits of products within main product areas, adopting current strategy
- (4) By comparison with target figures, quantify likely shortfalls in turnover and profit, thereby quantifying need for new products
- (5) Generate, gather in and investigate new product ideas
- (6) Evaluate them against the need for new products quantified in (4)
- (7) Select new product ideas for development
- (8) Prepare action programmes for development work
- (9) Budget for development costs for as far ahead as is reasonable (at least 12 months)
- (10) Monitor and control development work using agreed performance measures.

Figure 6.7 New product planning and development in the firm

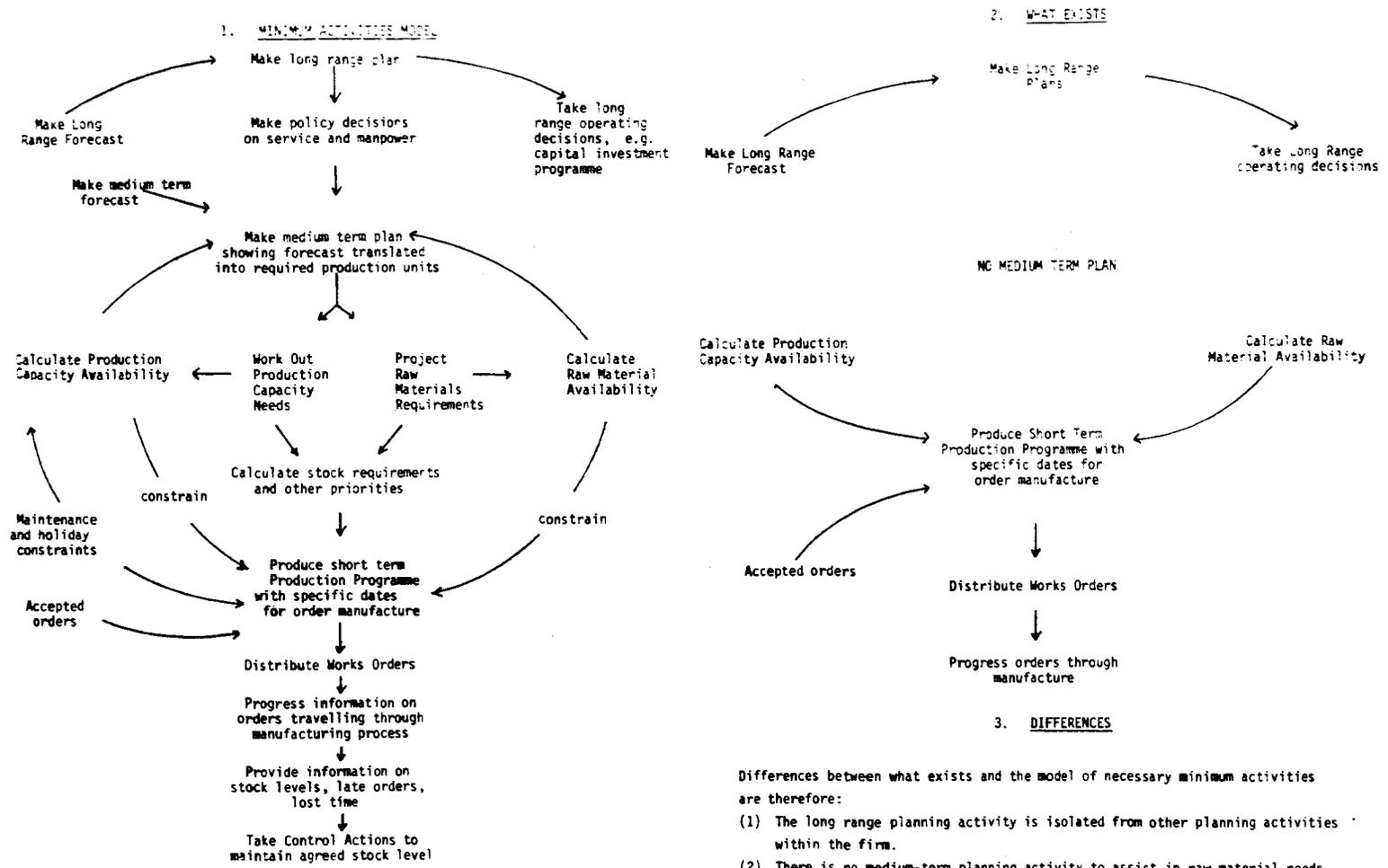


Figure 6.8 Comparison of minimum activities model with what exists

The minimum activity models which Mackness derived are given in Figures 6.3 - 6.7, and show the necessary activities which must be carried out if the various areas of the firm (sales, order processing, production planning, finance and administration and new product planning) are to function effectively. Figure 6.8 gives an example of how one of these models was used in a project. It concerned the production planning and inventory control system of the firm. The comparison of the actual system with the minimum activity model revealed the need for further investigation and formed the basis of recommendations for change.

#### 6.4.2 Linear programming

When a manager is concerned with an activity that has some measurable input of men, money, machines or materials and an equally measurable output, he may wish to do one of the following:

- a) minimize input to achieve a pre-assigned output
- b) maximize output from a specified input
- c) maximize some functions of input and output values  
such as profit or return on investment.

Such optimization problems can often be solved by programming techniques, the most widely used of which is linear programming, so-called because the constraints to which the input and output variables conform can be expressed linearly.

#### The assignment problem

The simplest LP problem is the assignment problem, in which the manager is concerned with the allocation of one item from each source and the assignment of one item to each demand. Consider the allocation of four men to four machines. The following matrix gives the inefficiency of each man on each machine, expressed as a percentage.

		Machine			
		1	2	3	4
Men	Mr A	10	5	9	18
	Mr B	13	19	6	12
	Mr C	3	2	4	4
	Mr D	18	9	12	17

In this case, the manager wishes to minimize the inefficiency caused by assigning the men to the machines. The procedure for solving this problem is

- a) Subtract the smallest number in each row of the matrix from all elements in that row.
- b) Subtract the smallest number in each column of the new matrix from all elements in that column.
- c) Determine the least number of vertical and/or horizontal lines required to cover all the zeros in the new matrix.

- d) If the number of lines is less than the number of columns or rows, proceed to steps e to h. Otherwise, proceed to step i.
- e) Identify the smallest uncovered number in the new matrix.
- f) Subtract this number from all uncovered elements in the new matrix.
- g) Add this number to those elements covered by two lines.
- h) Do not change those elements covered by one line and return to step c.
- i) The optimal assignment is obtained when the number of lines equals the number of columns or rows. The assignment of men to machine is given by the zeros in the matrix.

The application of these steps to the example gives the following results:

a)	1	2	3	4		b)	1	2	3	4	
	A	5	0	4	13		A	4	0	4	11
	B	7	13	0	6		B	6	13	0	4
	C	1	0	2	2		C	0	0	2	0
	D	9	0	3	8		D	8	0	3	6

The purpose of steps a and b can now be seen. There is a zero in each column and in each row. The manager cannot get an assignment just using these zeros because we would need to use A-2 and D-2. This is the purpose of step c, which shows that he must continue. The smallest uncovered element is 4.

c)	1	2	3	4		f) and g)	1	2	3	4	
	A	4	0	4	11		A	0	0	4	7
	B	6	13	0	4		B	2	13	0	0
	C	0	0	2	0		C	0	4	6	0
	D	8	0	3	6		D	4	0	3	2

On returning to step c the manager finds that he needs four lines to cover all the zeros. The assignment is given by A-1, B-3, C-4 and D-2 at a total loss of efficiency of 29%.

If the manager had wished to maximize (for instance, if the figures had been expressed as efficiencies) then the procedure is exactly the same as above except for an initial step of replacing all the elements in the cost matrix  $c_{ij}$  by  $M - c_{ij}$  where  $M$  is the largest figure in the cost matrix. In our example  $M$  is 19 and the maximum assignment is A-4, B-2, C-3, D-1, the total efficiency of which is 59%.

### The transportation algorithm

This is a special case of LP in which both requirements and resources are expressed in the same units. It can be used, for example, to minimize the total cost of distributing goods from  $m$  dispatch points to  $n$  receiving points, provided the following conditions are satisfied:

- a) The number of items to be dispatched from, and the number to be received at, each point is known.
- b) The cost of transportation between each pair of points is known.

Consider an example based on one used by Battersby. The Plankton Co. owns factories at three ports where its edible plankton is landed and processed: in Amsterdam, where the capacity is 50,000 tons per year, in Barcelona, where the capacity is 70,000 tons per year and in Copenhagen where the capacity is 60,000 tons per year. It also has three main centres for distribution to the European market: Milan with an estimated demand of 40,000 tons per year, Paris with an estimated demand of 70,000 tons per year and Rome, with an estimated demand of 70,000 tons per year. The company runs its own fleet of delivery vehicles, which have a round trip cost of 1DM per kilometre per ton. The Transport Manager has the problem of deciding how the factories and distribution centres should be linked so that the cost of distribution is as low as possible. He firstly compiles a table of distances.

	Milan	Paris	Rome
Amsterdam	1100	500	1700
Barcelona	1000	1100	1400
Copenhagen	1500	1200	2000

The costs of transportation between all these cities can now easily be calculated (in '00DM). All the information needed to solve this problem is displayed in the table below.

Factory \ Market Centre	Milan	Paris	Rome	Capacity 30,000 tons
	Amsterdam	11	<u>5</u>	17
Barcelona	<u>10</u>	<u>11</u>	<u>14</u>	7
Copenhagen	15	12	<u>20</u>	6
Demand '0000 tons	4	7	7	18

The first step is to obtain a feasible solution. There are many ways of doing this and it does not matter which one is used. The manager simply adopts a procedure whereby he uses as much of the cheapest route as possible. The cheapest route is Amsterdam - Paris, but he cannot put all the Paris demand of 70,000 tons on that route, because Amsterdam's capacity is only 50,000 tons. The next cheapest route is Barcelona - Milan. Although Barcelona can supply 70,000 tons, Milan only has a demand for 40,000 tons. Continuing in this way the following allocation is made, at a total cost of  $221 \times 10^6$  DM per year.

	M	P	R
A		5	
B	4	2	1
C			6

This solution is unlikely to be the optimal solution, so the manager now tries to improve upon it, by using the concept of dispatch and receiving costs. The dispatch cost plus the receiving cost is equal to the transportation cost for the route in question. For example, from the table on page 93, if the dispatch cost for Amsterdam is 0 then the receiving cost for Paris is 5 (at this stage only the routes that are used are considered.) Therefore, the dispatch cost for Barcelona must be 6 (11 minus 5) and the receiving costs for Milan and Rome must be 4 (10 - 6) and 8 (14 - 6) respectively. Thus the dispatch cost for Copenhagen is 12 (20 - 8).

Now consider the routes not used in the previous solution. The 'costs' for these routes are the sum of the appropriate dispatch and receiving costs. For example, the costs of the Amsterdam-Milan route is  $0 + 4 = 4$ . The difference between this cost and the actual cost (11) represents the saving which might be obtained by introducing this route into the solution (i.e. -7). The potential savings for each unused route are therefore:

	Calculated Cost	Actual Cost	Saving
Amsterdam - Milan	4	11	-7
Amsterdam - Rome	8	17	-9
Copenhagen - Milan	16	15	1
Copenhagen - Paris	17	12	5

The manager therefore wishes to use the Copenhagen - Paris route as much as is possible, because it gives the maximum saving. If he used this route, he will need to make some changes to the previous solution. He will, for instance, use the Barcelona - Paris route less, the Barcelona - Rome route more, and the Copenhagen - Rome route less. He can only reduce the Barcelona - Paris route by 20,000 tons, so that the new solution at a total cost of  $211 \times 10^6$  DM per year is:

	M	D	R
A		5	
B	4		3
C		2	4

Again he is not certain that this is the optimal solution, so again makes an attempt to improve it, by calculating dispatch and receiving costs, to determine if any of the other routes represent a cost saving. He discovers that the Copenhagen - Milan route still represents a cost saving of 100 DM per ton, and he produces the following new solution at a total cost of  $207 \times 10^6$  DM p.a.

	M	P	R
A		5	
B			7
C	4	2	

It can be shown that this is an optimal solution, but it introduces one of three complications that should be mentioned. It is possible to determine all dispatch and receiving costs only when at least  $m + n - 1$  routes are used. Otherwise the situation is degenerate, but this difficulty can be overcome by allocating a very small delivery ( $\epsilon$ ) to a route which is unused.

If we wish to maximise rather than minimise, improvements are sought from routes not in use by selecting the route with the largest negative value for the difference between calculated and actual cost.

The third complication arises if the demand does not balance the supply. If the total supply exceeds total demand an additional 'dummy', column must be added to the matrix to accommodate this excess supply. If the total demand exceeds total supply, a 'dummy' row must be introduced to satisfy this excess demand. In both cases all 'dummy' transportation costs are zero.

Consider, therefore a variation of this problem. The Amsterdam capacity increases to 70,000 tons per year, and the costs matrix becomes a profit matrix, so that the manager wishes to maximise the profit. A maximum profit of  $262 \times 10^6$  DM p.a. can be obtained by using the following allocation.

	M	P	R	Dummy
A			5	2
B		7		
C	4		2	

A most interesting example of the use of the transportation algorithm is in production planning problems. Each production possibility (regular time and overtime, or day shift and evening shift) in each time period may be considered a source of input or supply. Similarly each sales requirement in each time period may be considered a separate destination or output. The cost matrix is formed by combining the relevant production cost with the storage cost for the appropriate number of time periods. Many of the 'cell-routes' are infeasible if backlogging is not allowed because it is not possible to deliver in a period prior to manufacture. In this case a large 'penalty' cost is placed on the 'cell-route'. When more than one product is produced on a production line a large cost matrix will be created, even for a small problem. For instance, if 5 products are produced on a certain line and a schedule is being prepared for 6 periods with two different levels of production, the resulting matrix is of size 12 x 30. Generally, in these circumstances, when  $n$  products are involved in a plan for  $p$  periods the matrix size is  $2p \times np$ .

The Simplex Algorithm

Suppose that a firm has to decide upon a mixture of ingredients for a canned dog food. The ingredients have the composition and costs that are set out below. The goal is the cheapest blend of those ingredients that complies with certain nutritional standards. The standards are set out in the lower part of the table.

	Bean-meal	Meat-meal	Cereal
% Protein	50	50	0
% Fat	25	10	0
% Carbohydrate	15	0	90
% Indigestible fibre and ash	10	40	10
Cost (\$ per ton)	60	50	40

Protein must be not less than 25%	}	in the blend
Fat must be not less than 10%		
Indigestible matter must not exceed 20%		

Let  $b$ ,  $m$  and  $c$  represent the proportions in which the bean-meal, meat-meal and cereal are present in the blend. If we settle the values of two of these ( $b$  and  $m$ , say) the third one is fixed automatically because the three ingredients together make up the whole mixture, so

$$b + m + c = 1 \quad \text{or} \quad c = 1 - m - b.$$

The cost of 1 ton of the blend is itself a blend of the costs of the ingredients in the proportions  $\underline{b}$ ,  $\underline{m}$  and  $\underline{c}$ . If we call the cost  $C$ , then

$$C = 60b + 50m + 40c \quad \text{or} \quad C = 20b + 10m + 40 \quad \text{by substituting for } c.$$

What is required is to choose  $b$  and  $m$ , each of them a positive fraction, so as to make the cost per ton,  $C$ , as low as possible. However, the choice is not an entirely free one: it is constrained, firstly by the standards imposed in the table and secondly because  $c$  cannot be less than zero, so we can express this as:

$$b + m \leq 1.$$

The next condition arises from the specification of protein content. The amount of protein in one ton of the blend will be 50% of  $\underline{b}$  tons from the bean-meal, 50% of  $\underline{m}$  tons from the meat meal, and none from the cereal. This total amount of protein must be not less than 25% of one ton, so

$$50b + 50m \geq 25.$$

Similarly, the specification of fat content implies

$$25b + 10m \geq 10.$$

The requirement with regard to indigestible fibre and ash is a little more awkward to express in terms of  $\underline{b}$  and  $\underline{m}$ . In terms of  $\underline{b}$ ,  $\underline{m}$  and  $\underline{c}$  it is straight-forward:

$$10b + 40m + 10c \leq 20.$$

Substituting for  $\underline{c}$  we obtain

$$30m \leq 10$$

or

$$m \leq \frac{1}{3}.$$

The axes of the chart in Figure 6.9 are scales for  $\underline{b}$  and  $\underline{m}$ . Any point on the chart thus corresponds to a pair of values  $(\underline{b}, \underline{m})$ . For some points the constraints will be satisfied while for others they will not. The line corresponding to each constraint ( $b + m = 1$ ,  $b + m = \frac{1}{2}$ ,  $\frac{5}{2}b + m = 1$ ,  $m = \frac{1}{3}$ ) have been drawn on the graph.

Each of the conditions states that acceptable values of  $\underline{b}$  and  $\underline{m}$  must correspond to a point that lies on, or to one side of, the appropriate line. An easy way to check the consistency of the conditions is therefore to draw the line for each condition in turn and shade that area of the chart that the condition rejects. Any unshaded area left after this has been done for all the conditions contains points whose co-ordinates,  $\underline{b}$  and  $\underline{m}$ , satisfy all the conditions.

The area ABCDE contains all the points whose co-ordinates,  $\underline{b}$  and  $\underline{m}$ , comply with all the conditions of the problem. This area is called the region of feasible solutions. Had the conditions been incompatible no such unshaded region would have existed. The problem would then have been insoluble. The result for the dog

food manufacturer would have meant his seeking further ingredients. However, the problem does have feasible solutions and in the area ABCDE there is a wide range of choice. It is the extent of this choice that leaves room for the seeking of the optimal or best solution, which in this case means the cheapest.

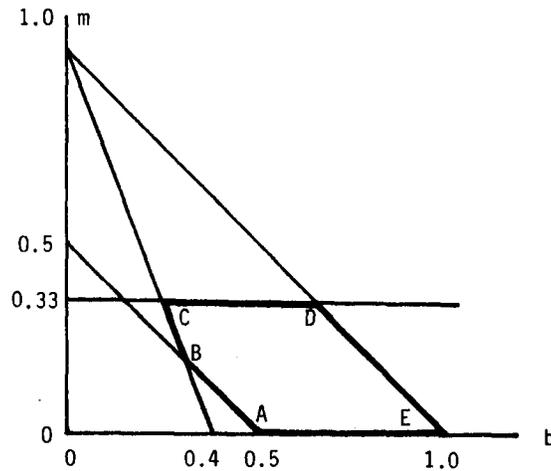


Figure 6.9 The region of feasible solutions for the blending problem

The chart of Figure 6.9 provides us with a very simple process for finding the cheapest mixture. The cost per ton of blended ingredients we found to be

$$C = 20b + 10m + 40$$

which we can rearrange as

$$m = -2b + C/10 - 4$$

If a particular cost is chosen, say \$50 per ton, we can put  $C = 50$  in the equation and find

$$m = -2b + 1.$$

This is the equation of a straight line. All the mixtures for which  $b$  and  $m$  satisfy this equation are represented by the points on this line, and all these mixtures are ones that would cost \$50 per ton. The line is shown as AP Figure 6.10. Repeating the process for a cost of \$45 per ton gives another line, also shown in the figure with the equation.

$$m = -2b + 0.5.$$

Any choice of  $C$  will give such a line, and every line of this kind will have the same slope, that is,  $-2$ . These lines are contours of cost in Figure 6.10.

You can see that the cost increases steadily as these contours get further and further from the origin. The cheapest possible blend given by the values of  $\underline{b}$  and  $\underline{m}$  for the point B in the feasible region because this is the first acceptable point that a line of slope -2 will strike as it slides away from the origin.

In our example, then, the optimal mixture is one-third bean-meal, one-sixth meat-meal and one-half cereal. Its cost is  $\$48\frac{1}{3}$  per ton. These results can be found by solving simultaneously the equations of the two lines AB and CB,  $b + m = \frac{1}{2}$  and  $\frac{5}{2}b + m = 1$ .

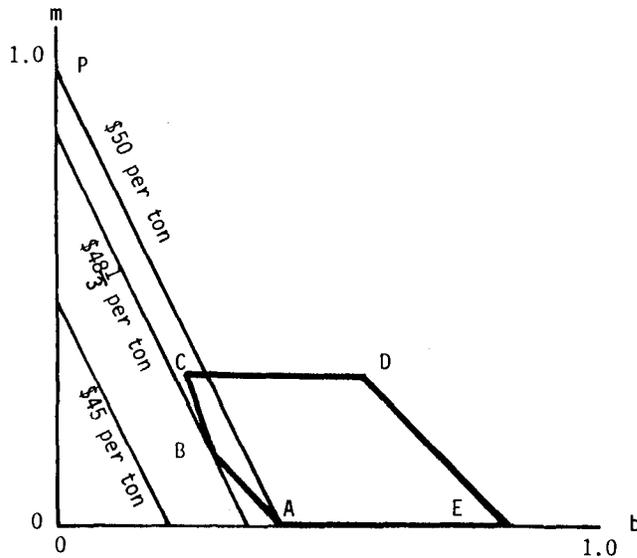


Figure 6.10 Cost contours and the feasible region for the blending problem

This form of algebraic problem turns out to be a symbolic model of a remarkably large variety of planning problems. The optimum sought may be a minimum, as it was in our example, or a maximum, as it might have been had the example been based on the manufacturer's profits rather than his costs. The quantity to be optimized is called the objective-function. When the objective function and the constraints take the form that they took in the example, they are called linear (all our drawing involved only straight lines) and the problem is called a problem in linear programming.

The example that we have looked at is not typical of linear programming problems. We were able to get the solution by a graphical method because there were only two variables,  $\underline{b}$  and  $\underline{m}$ , to be found. Had there been four ingredients to be mixed three of the proportions would have had to be determined in order to fix the fourth. Instead of a flat drawing we would have needed a solid model with three axes to represent the three variable proportions. In three dimensions the feasible region would look rather like a cut gemstone. The contours of the objective function

would be parallel plane surfaces. With five ingredients, and hence four independent variables, we cannot visualize a suitable geometrical model. However, the notion of the feasible region crossed by contours of the objective function can still be used as the basis for an algorithm, called the Simplex algorithm, applicable to any finite number of variables and constraints. In practice the limitation on the size of the problem - that is, on the numbers of variables and constraints - is set only by the size of computer that is available.

The installation of a planning system in a food factory using LP is described by Jones and Rope. The factory manufactured ten different food products by nine different processes from two highly perishable and seasonal raw materials. Two models were used for planning, one for six successive periods of a month, the other adding two further periods of three months each.

The constraints included those on production, maximum and minimum stock levels, availability of raw material and some contractual obligations. The objective, to maximise profit, had to be modified in various ways. Products which had forecast sales, therefore had a constant expected revenue from sales, and since the raw material cost was the principal variable element in their manufacture, the minimization of this cost was adequate. Other products were essentially users of residual raw materials, and their contributions were taken as expected gross profit margins. Stock holding costs were included, including the hiring of warehouse space if necessary.

#### An example of the transportation problem

This case study has been worked out together with R. Likwenanga, A.M. Ng'umba and J.M. Roki. One of them comes from Mtukwao village in Kilwa District, Lindi Region, which is famous for its coconuts. The coconuts are usually sold in Dar es Salaam, Kilwa Masoko or Lindi (see Figure 6.11).

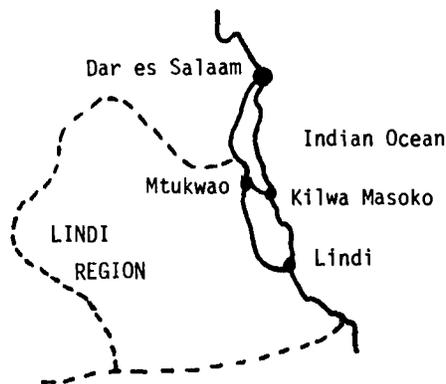


Figure 6.11 Map to illustrate the location of Mtukwao village

This season the village will sell 200 bags of coconuts. Each bag contains 120 coconuts and we may assume that the quality and the size of the coconuts are uniform. The selling prices of the coconuts are different in the various towns. In Dar es Salaam one coconut sells for sh.1/=, in Kilwa Masoko for 60 cts. and in Lindi for 80 cts.

(1)

The coconuts are transported by lorry and the transporters charge the village as follows:

13 Shillings per bag to Dar es Salaam

1 Shilling per bag to Kilwa Masoko

(2)

10 Shillings per bag to Lindi

Since the village needs money urgently for various projects, the financial committee of the village allows the villagers to spend only Shs. 1700/= for the transport of the coconuts and wants even to reduce this amount of money.

The problem to be considered here is where the village should sell their coconuts and if the decision of the financial committee is a good one.

Before we try to solve this problem with the aid of Linear Programming we will first give some general comments on the problem. The selling price of the coconuts is the highest in Dar es Salaam and also the selling price minus the transport costs per bag is the highest for Dar es Salaam. So it seems to be the best strategy to sell all the coconuts in Dar es Salaam. The total transport costs would then be  $200 \times 13 = 2,600$  Shillings. This is, however, more than there is available, so some of the coconuts will have to be sold in another town. This seems not to be an ideal solution, since we get considerably more money in Dar es Salaam, but it cannot be avoided as long as there is a restriction on the available money for transport. To study this problem in more detail and to solve it we shall set up a mathematical formulation.

We want to know how many bags of coconuts should be brought to Dar es Salaam, to Kilwa Masoko and to Lindi. Well, call these numbers of bags  $x_1$ ,  $x_2$  and  $x_3$  respectively. Since the village is going to sell 200 bags it follows that

$$x_1 + x_2 + x_3 = 200 \quad (3)$$

The total costs of transportation - see (2) - are  $13x_1 + x_2 + 10x_3$ . Since the village may spend only 1700 Shillings, we have

$$13x_1 + x_2 + 10x_3 \leq 1700 \quad (4)$$

It is obvious that

$$x_1 \geq 0, \quad x_2 \geq 0, \quad x_3 \geq 0 \quad (5)$$

The village is urgently in need of money, so it wants, of course, to get as much as possible from the coconuts. The revenue obtained from the sale is given by  $120(1.0x_1 + 0.6x_2 + 0.8x_3)$  - see (1) - and the net revenue, i.e. revenue minus

transportation costs, is:

$$\begin{aligned} & 120x_1 + 72x_2 + 96x_3 - 13x_1 - x_2 - 10x_3 \\ = & 107x_1 + 71x_2 + 86x_3 \end{aligned} \quad (6)$$

Our problem is now translated into a Linear Programming problem where we have to find those values of the variables  $x_1$ ,  $x_2$  and  $x_3$  where (6) takes its maximum value and the constraints (3) - (5) are satisfied.

We can simplify this Linear Programming problem because we may eliminate from (3) one of the variables, for instance

$$x_3 = 200 - x_1 - x_2. \quad (7)$$

Substituting this expression for  $x_3$  in (4) - (6) we arrive at the following Linear Programming problem in two variables  $x_1$  and  $x_2$ :

$$\text{Maximize } 17,200 + 21x_1 - 15x_2 \quad (8)$$

where  $x_1$  and  $x_2$  are subject to:

$$-3x_1 + 9x_2 \geq 300 \quad (9)$$

$$x_1 + x_2 \leq 200 \quad (10)$$

$$x_1 \geq 0, x_2 \geq 0 \quad (11)$$

Verify this. Note especially that (10) follows from  $x_3 \geq 0$ .

The Linear Programming Problem (8) - (11) will now be solved graphically. All points  $(x_1, x_2)$  which satisfy (9) lie above and on the line  $-3x_1 + 9x_2 = 300$ . See Fig. 6.12. Check in the same way where the points  $(x_1, x_2)$  lie which satisfy (10) and (11). The points satisfying all constraints form the feasible region. The points belonging to the feasible region are called feasible points or feasible solutions. For this example, the feasible region is illustrated in Figure 6.12.

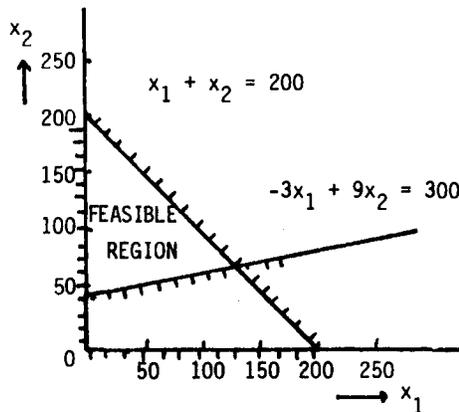


Figure 6.12 The feasible region for L.P. case study

We are looking for that point on the feasible region where the function  $17,200 + 21x_1 - 15x_2$  takes its maximal value. This point can easily be found if we draw the parallel lines  $17,200 + 21x_1 - 15x_2 = k$  for some different values of  $k$ . Two of these lines are illustrated in Figure 6.13. The parallel line through Point A corresponds to a value of  $k = 17,200 - 15 \times 200 = 14,200$ . B lies on the line  $x_1 + x_2 = 200$  and  $-3x_1 + 9x_2 = 300$  and its coordinates can be found by solving these two equations resulting in  $x_1 = 125$  and  $x_2 = 75$ . So the corresponding value of  $k$  is equal to  $17,200 + 21 \times 125 - 15 \times 75 = 18,700$ . From the discussions at the beginning of this chapter follows that for parallel lines between the two drawn lines the corresponding values of  $k$  are all less than 18,700. Do you see why? So  $k = 18,700$  is the maximum value of  $k$  which can be obtained in the feasible region. It equals the maximal value of the objective function and B is the solution point. Note that a parallel line corresponding to a maximum value of  $k$  necessarily passes a corner point of the feasible region.

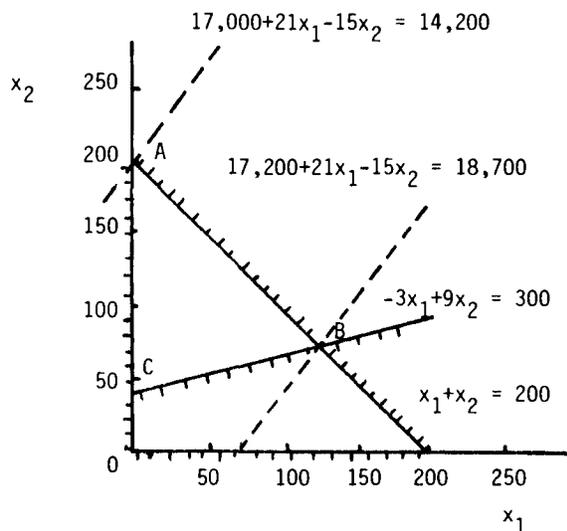


Figure 6.13 Graphical solution of the Linear Programming problem of Case Study

So it has been found that 125 bags of coconuts have to be transported to Dar es Salaam and 75 bags of Kilwa Masoko. Since the solution point B lies on the line  $x_1 + x_2 = 200$  it follows - see (7) - that  $x_3 = 0$ . So no coconuts are sold in Lindi. Since B lies also on the line  $-3x_1 + 9x_2 = 300$  it follows - see (4), (7) and (9) - that all the 1700 Shillings allowed for transport is indeed spent. Point B implies making of  $x_1$  as large as possible (within the feasible region), i.e., selling as many coconuts as possible in Dar es Salaam. To what situation does corner point A correspond where the objective function takes its minimal value? Can you reason why the origin 0 does not belong to the feasible region?

If there is more money available for the transport, the boundary of the feasible

region through B and C moves parallel to BC downwards. Do you see why? Point B moves along the line  $x_1 + x_2 = 200$  to the point  $x_1 = 200, x_2 = 0$  where all the coconuts are sold in Dar es Salaam and the maximum revenue is obtained, if we had - see (4) -  $13 \times 200 = 2600$  Shillings available for transport. We would obtain then 21,400 Shillings; which is 2,700 Shillings more than the maximum revenue of 18,700 if we have only 1700 Shillings available for transport! By investing 900 Shillings more in transport the village earns an extra 2,700 Shillings! So if these 900 Shillings can be made available, which especially depends on the time when the transporter has to be paid, the financial committee's advice would certainly not be a good one.

The corner points A, B and C of the feasible region of Figure 6.13 are called extreme points. It can be shown that, if a solution of a Linear Programming problem exists, this solution can be found at one of the extreme points. So, instead of drawing parallel lines in Figure 6.13 we could also have computed the values of the objective function at all the corner points and checked where the maximum value is found.

In this example, there is only one solution point. If the parallel lines of Figure 6.12 are also parallel to one of the boundaries of the feasible region, then all the points of this boundary belonging to the feasible region are solution points. It can be verified that if the selling price at Kilwa Masoko was 90 cents, one of the parallel lines coincides with BA. In that situation it would make no difference if we sell at Dar es Salaam or at Kilwa Masoko. It is noted that it is also possible to eliminate one of the other variables instead of  $x_3$ . This results in different feasible regions but, of course, in the same solution.

#### 6.4.3 Network Analysis

The management team of a small firm may frequently be involved in projects, or schemes to use resources in order to reach a defined objective. A project may be the installation of a new accounting system, the overhaul of plant or the marketing of a new product. Such a project can be subdivided into the individual jobs which contribute to its achievement, and an analysis of their logical sequence can prove immensely valuable to the project manager.

The basic steps in project planning by network analysis are

- a) construct a diagram to represent the project that indicates the sequence and interdependence of all necessary jobs or activities in the project;
- b) determine how long each of the jobs will last;
- c) calculate the overall duration of the project and the criticality of the various jobs;
- d) if the project completion date is later than required,

consider modifying either the network and/or the individual job durations in order that the project may be completed within the required time.

Three steps are required in the construction of the network diagram. First a list of all the activities needs to be produced. Secondly, the sequence in which the activities are to be performed and the inter-relationships between them can be determined by asking, for each activity

1. Which activities must precede it
2. Which activities cannot start until it is complete
3. Which activities can proceed at the same time.

Thirdly, the network needs to be drawn so that these relationships, and only these, are implied. The network is drawn so that there is only one initial event and one terminal event. (Events identify the beginning and end of activities that occur between them and are represented by 0 on the diagram. Activities are represented by an arrow.)

The activity list for a simple project, namely the fabrication and assembly of a simple storage cabinet, is as follows:

Order materials for framework  
 Await delivery of materials  
 Set up tool to fabricate frame  
 Fabricate frame  
 Test frame for strength  
 Obtain pre-cut cladding panels from store  
 Fix panels on frame  
 Decorate complete assembly

Which activities precede each activity?

<u>Activity</u>		<u>Preceding activities</u>
Order materials for framework	:	None
Await delivery of materials	:	Order materials
Set up tool to fabricate frame	:	None
Fabricate frame	:	Await delivery, Set up tool
Test frame for strength	:	Fabricate frame
Obtain pre-cut cladding panels from store	:	None
Fix panels on frame	:	Test frame, Obtain panels
Decorate complete assembly	:	Fix panels

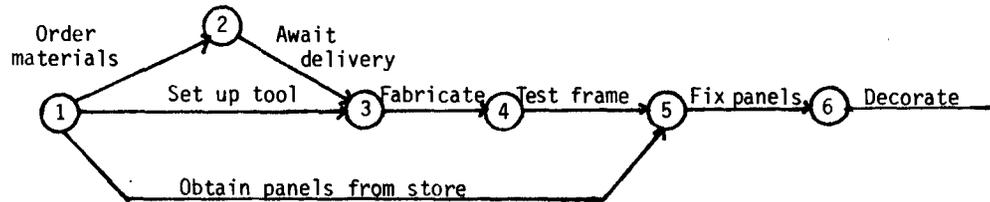
Which activities succeed each activity?

<u>Activity</u>		<u>Succeeding activities</u>
Order materials for framework	:	Await delivery
Await delivery of materials	:	Fabricate frame
Set up tool to fabricate frame	:	Fabricate frame
Fabricate frame	:	Test frame
Test frame for strength	:	Fix panels
Obtain pre-cut cladding panels from store	:	Fix panels
Fix panels on frame	:	Decorate
Decorate complete assembly	:	None

Which activities can proceed at the same time?

- Obtaining the pre-cut cladding panels from store can be done at the same time as all the activities preceding it on the activity list.
- The tool to fabricate the frame can be set up at the same time as the materials are ordered and while delivery is being awaited.

The network



It is then necessary to analyse the network, once the duration of each activity has been determined. The purpose of the analysis is to determine the critical path, i.e. those activities for which any delay in their completion would cause a corresponding delay in the completion of the project. The analysis first determines the earliest possible time that an activity can begin, by summing the durations of all activities on the longest path leading to the event that identifies the beginning of the activity. Then the latest time that an activity can start and still remain on schedule are calculated, on the basis of a 'reverse pass' through the network. The difference between these two times is the total float of the activity, and represents the maximum time that an activity can be delayed beyond its earliest start without delaying the project completion time. Thus if a date for completion has not been specified the float for all activities on the critical path will be zero. The analysis of our example is given below.

Example

Activity	Duration	ES	EF	LS	LF	Total float
Order materials	1	0	1	3	4	3
Await delivery	2	1	3	4	6	3
Set up tool	4	0	4	2	6	2
Fabricate	3	4	7	6	9	2
Test frame	1	7	8	9	10	2
Obtain panels	10	0	10	0	10	0
Fix panels	2	10	12	10	12	0
Decorate	1	12	13	12	13	0

The minimum project duration time is 13.

The critical path consists of three activities

- Obtain panels
- Fix panels
- Decorate

#### 6.4.4 Calculus

The straightforward use of the mathematical technique of differential calculus allows the optimal solution for a non-linear objective function to be found. This technique forms the basis of statistical inventory control models.

The simplest situation occurs when the objective is a continuous function of one variable. Consider a product costing \$4 whose demand is 500 items per quarter. The usage rate is uniform, so that orders can be placed to arrive at the moment when the stock runs out. The cost of an order is \$1 and the stockholding rate is 10% per annum. The buyer has to determine the frequency with which orders are placed. Let the time interval between orders be  $T$  quarters, so that the order quantity will be  $500T$  items. Therefore the average stock will be  $250T$  items, because the stock level decreases at a constant rate from  $500T$  to zero. The annual stockholding cost will thus be 10% of the capital tied up in stocks, which is  $\$1000T$ . The number of orders per year is  $4/T$ , giving an annual ordering cost of  $\$4/T$ . The total annual cost is therefore

$$100T + 4/T$$

When this expression is differentiated with respect to  $T$  (N.B. if  $y = ax^b$  is differentiated with respect to  $x$ , the result is  $abx^{b-1}$ ), we find that the minimum annual cost occurs when

$$100 - 4/T^2 = 0$$

so that  $T = 1/5$  and there should be 5 orders per quarter. The order quantity will be 100 items worth \$400, and the annual cost of purchasing and holding the stock is \$40.

In general, if the order cost is \$ $A$ , the annual demand  $D$ , the product cost \$ $C$ , and the stock holding rate  $i\%$  p.a. and the order size is  $Q$ , then the annual ordering cost is  $AD/Q$  and the annual stockholding cost is  $QiC/2$ . The optimal order quantity is then

$$Q = \sqrt{\frac{2AD}{iC}}$$

A complication occurs when the objective function is discontinuous, because it is then necessary to examine the minimum or maximum, obtained by differentiation within each continuous range, and the values of the function at the discontinuities. For instance, the product we have just examined may be subject to the following quantity discount

- \$4 each for orders of 100 or less
- \$3.40 each for orders of more than 100 but less than 200
- \$3 each for orders of more than 200.

Again the buyer wishes to know how frequently the orders should be placed. We know that, when the price is \$4, the optimal order size is 100, which is within the range for which the price is \$4. The annual cost of the product is \$8000, making a total cost of \$8040.

When the price is \$3.40 each the optimal order size is 108.5 items, which is within the range for the price to be \$3.40. In this case the total annual cost is only \$6837. Suppose finally that the price is \$3 each. The optimal order size is 115.5 items, which is not within the range for a price of \$3. Therefore, the optimal policy for a price of \$3 will be to order in quantities of 201, for which the annual total cost will be \$6040, which is clearly the best policy in this particular situation.

Another complication occurs when the objective is a constrained function of two variables. Whilst it may be continuous and therefore differentiable, the apparent optimum may be invalid because the values of the variables at the optimum are not consistent with one or more constraints. If the constraints are differentiable, then a valid optimum may be obtained by using the method of Lagrange multipliers. This technique involves differentiating a linear function of the objective function and the constraints, equated to zero, to obtain the constrained maximum or minimum. Suppose that the buyer in fact buys two products for which there is limited warehouse space. One product we have already considered. The second costs \$10, the demand is 256 items per quarter, and the order costs are \$2. The products are of the same physical size, and the warehouse space is such that the total number of items of the two products must never exceed 120 units, so it will be assumed that the total maximum stock level,  $Q_1 + Q_2$ , must be less than or equal to 120. We know that the optimal order quantity for the first product is 100. Similarly, for the second product the optimal order quantity is 64. Thus the constraint on the available warehouse space is exceeded, so that values of  $Q_1$  and  $Q_2$  must be found to minimise the total annual cost of both products.

$$TC = \frac{Q_1}{5} + \frac{2000}{Q_1} + \frac{Q_2}{2} + \frac{2048}{Q_2}$$

consistent with  $Q_1 + Q_2 = 120$ .

The method of Lagrange multipliers consists of differentiating

$$TC + \lambda (Q_1 + Q_2 - 120)$$

with respect to  $Q_1$ ,  $Q_2$  and  $\lambda$  and setting the differentials equal to zero (N.B. we need to use partial differentiation in this case because we have more than one variable. When we differentiate with respect to one variable, all other variables are treated as constants).

Hence  $Q_1$ ,  $Q_2$  and  $\lambda$  are the solutions of the three equations

$$\frac{1}{5} + \frac{2000}{Q_1^2} + \lambda = 0$$

$$\frac{1}{2} + \frac{2048}{Q_2^2} + \lambda = 0$$

$$Q_1 + Q_2 = 120$$

$$\text{So } Q_1 = \sqrt{\frac{2000}{0.2+\lambda}} \quad , \quad Q_2 = \sqrt{\frac{2048}{0.5+\lambda}}$$

$$\text{and } \sqrt{\frac{2000}{0.2+\lambda}} + \sqrt{\frac{2048}{0.5+\lambda}} = 120$$

The solution of this equation, found by trial and error, is  $\lambda = 0.24$ , so that  $Q_1 = 67.4$  and  $Q_2 = 52.6$ , which would be rounded to 67 and 52. Hence the frequency of placing orders is 30 and 20 for products one and two respectively.

#### 6.4.5 Quality Control

Quality control in its broad sense means the total activities of a company in carrying out its quality objectives. More particularly, there has grown up a vast literature on statistical techniques for quality control, including acceptance sampling schemes, control charts, continuous sampling plans, cusum charts, etc. The aim of these techniques is to

1. detect defects as they occur and exclude defective materials from production and sale
2. diagnose the reasons for the defects
3. take appropriate action to prevent further similar defects.

Suppose that a manufacturer receives supplies of a particular component in batches of size  $N$ , say 10,000 and that there is one attribute of prime interest, (i.e. the component is good or bad).

What do we mean when we say that a batch must be of satisfactory quality? Do we mean that all 10,000 items must pass our attribute test? Obviously not because this is costly. We would be content with a small percentage of defectives to specify this is our first task. Call this % the Lot Tolerance Percentage Defective (LTPD).

A sampling scheme aims to detect (and exclude) all incoming batches with a percentage of defectives higher than the specified LTPD, and to accept all other batches.

A single sampling scheme consists of drawing a sample of size  $n$  from a batch, testing the relevant attribute on each and applying the following rule:

- if the number of defectives is less than or equal to an acceptance number  $d$ , accept the batch
- if the number of defectives is more than  $d$  reject the batch.

Assume,

1. The probability of drawing a defective item does not vary materially between the first and last item of a sample (i.e.  $n$  is small compared to  $N$ ).
2. Immaterial whether we sample with or without replacement ( $n$  is small compared to  $Np$ ,  $p$  is the proportion defective).

So the number of defectives in a sample follows the binomial distribution, such that the probability of a defective is

$${}_n C_r p^r q^{n-r} .$$

This expression does not include  $N$ . so we can cease reference to it, although we have assumed it to be large enough compared to  $n$  for our assumptions to hold.

Suppose now we institute a sample scheme with  $n = 10$ ,  $d = 1$  (we can set out LTPD at 15).

We can construct an operating characteristic curve which shows us what effect this scheme has in practice (Figure 6.14).

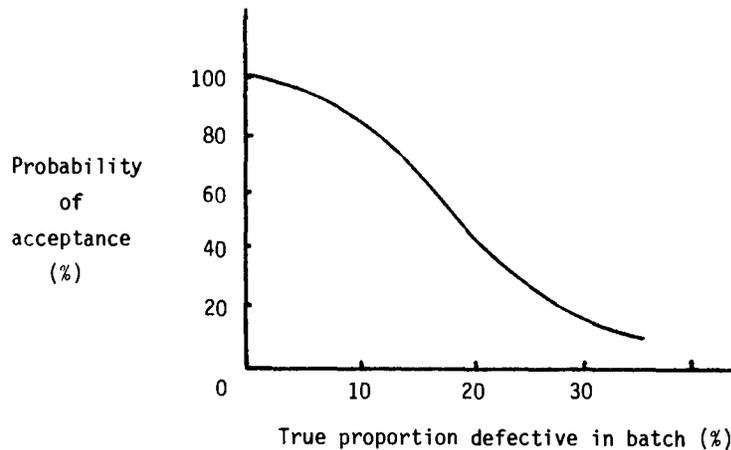


Figure 6.14 Operating Characteristics Curve

We have seen that it is not enough to specify an LTPD but we must also specify what probability  $p$  we are prepared to countenance of a lot with a higher percentage defective getting through the net. This figure is called the consumer's risk - it represents the risk that a consumer will accept a batch that is borderline quality.

In practice, we make LTPD a genuine limit in the sense that it is considered quite uneconomic to operate the process with more defectives than this. Then  $p$  can be quite small (10% or less).

The supplier must give supplies with less than LTPD on average, otherwise a large proportion of his supplies will be rejected. So he produces at a process average and we can specify the producer's risk - the probability that a batch with a proportion of defectives equal only to the process average will be rejected. It is the risk that a producer or supplier on his planned average behaviour will get a raw deal. This is usually set lower than the consumer's risk (5% say).

The binomial distribution for sample size  $n$  and probability  $p$  is approximated by the normal distribution with mean  $np$  and standard deviation  $\sqrt{npq}$ . For most combinations of  $n$  and  $p$  this is a good approximation. It is not very accurate when  $n$  and  $p$  are both small, say  $n < 100$  and  $p < 0.10$ .

To determine  $\underline{n}$  and  $\underline{d}$ , start by considering the consumer's risk. Suppose we have set an LTPD of  $p_1$  and a consumer's risk of  $C$ . Then if we choose a sample size  $n$  we can approximate to the (binomial) distribution of  $X$ , the number of defectives in the sample, under the hypothesis that the proportion defective in the batch is equal to the LTPD by a normal distribution with mean  $np_1$  and variance  $np_1q_1$ . (Notice that we are assuming in advance, by use of the normal approximation, that  $n$  will turn out to be large).

We must set  $d$  at  $k_1$  s.d. below the mean where  $k_1$  is such that

$$P(X < \mu - k_1\sigma) = C$$

So 
$$d = \mu - k_1\sigma = np_1 - k_1\sqrt{np_1q_1}$$

We can find  $k_1$  from tables of the standard normal distribution.

Now consider the producer's risk. Suppose the PA is  $p_2$  and the producer's risk is set at  $D$ . Then we can approximate to the distribution of  $X$ , under the assumption that the proportion defective is equal to PA, by a normal distribution; here, we have

$$\mu = np_2 \text{ and } \sigma^2 = np_2q_2$$

To ensure that only  $D\%$  of the samples with the PA produce an  $x$  greater than acceptance number  $\underline{d}$  we must set  $\underline{d}$  at  $k_2$  standard deviations above the mean where

$$P(X > \mu + k_2\sigma) = D$$

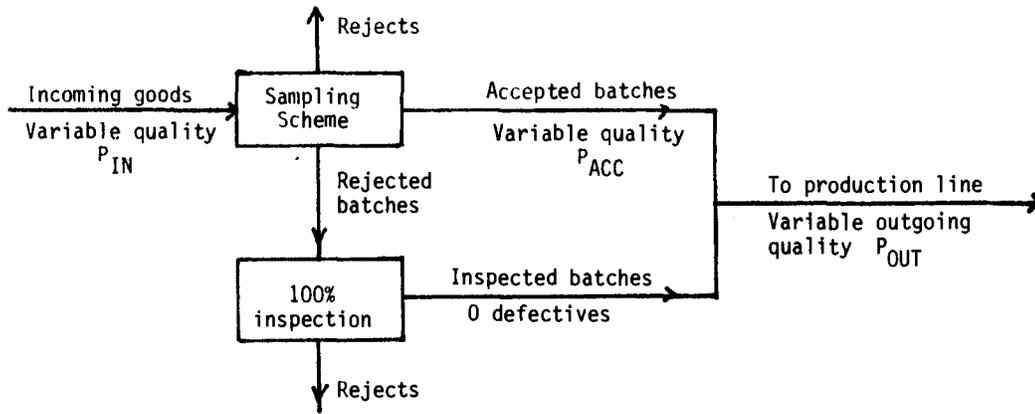
We can find  $k_2$  from tables of the standard normal distribution

$$d = \mu + k_2\sigma = np_2 + k_2\sqrt{np_2q_2}$$

The two equations in  $d$  can be solved simultaneously to give

$$n = \frac{(k_1\sqrt{p_1q_1} + k_2\sqrt{p_2q_2})^2}{(p_1 - p_2)^2}$$

Sampling schemes involving 100% inspection of rejected batches change the average quality of the goods passing through



Suppose a batch is of size  $N$  and contains a proportion  $P_{IN}$  of defectives to start with, i.e.  $N P_{IN}$ . The probability of accepted a batch of quality  $P_{IN}$ , denoted by  $P(P_{IN})$  can be obtained from the operating characteristic.

So a proportion  $P(P_{IN})$  will be accepted and each on average will carry forward  $(N-n)P_{IN}$  defectives. The remaining  $1-P(P_{IN})$  proportion of batches will fail and be subjected to 100% inspection. These will therefore carry forward 0 defectives. Hence the average number of defectives over all outgoing batches will be

$$\begin{aligned} NP_{OUT} &= P(P_{IN})(N-n)P_{IN} + 1 - P(P_{IN}) \cdot 0 \\ &= P(P_{IN})(N-n)P_{IN} \end{aligned}$$

So 
$$P_{OUT} = P(P_{IN})\left(\frac{N-n}{N}\right)P_{IN}$$

(We have assumed that the number of defects rejected is small compared to  $N$ , i.e. outgoing batches are of size  $N$ ). This is the Average Outgoing Quality for batches submitted of quality  $P_{IN}$ .

We can make a statement like:

"We believe that the proportion of defectives in batches submitted is, on average, somewhere near the  $P_A$ . However it may wander from that. We therefore specify an AOQL. We choose that sampling scheme which meets this AOQL and which gives the minimum cost if the quality submitted is at the process average."

All the appropriate schemes are tabulated and it is necessary only to know the AOQL and the PA to look up the answer.

A commonly used type of sampling scheme involves double sampling so that those batches which are obviously good (or for that matter obviously bad) could be settled quickly and cheaply in a relatively short first stage and those which are in borderline regions of good and bad would be looked at more closely in a second stage.

A typical usual procedure is:

1. Take a sample of size  $n$ , and count the defectives  $x_1$ .
2. Let  $d_1, d_2$  be two acceptance numbers specified in the scheme. If  $x_1 \leq d_1$  accept the batch,  $x_1 > d_2$  reject the batch.
3. If  $d_1 < x_1 \leq d_2$  take a second sample of size  $n_2$  and count the defectives  $x_2$ .
4. If  $x_1 + x_2 \leq d_2$  accept the batch  
 $> d_2$  reject the batch.

e.g. instead of  $n = 100$   $d = 6$   
 $n_1 = 60$   $d_1 = 2$   
 $n_2 = 90$   $d_2 = 10$

#### 6.4.6 Forecasting

Business planning and decision making are inseparable from forecasting. The prediction of sales, earnings, costs, production, inventories and purchases is the basic foundation of corporate planning and control. Management is increasingly turning to formal statistical methods for assistance in the difficult task of predicting the future. A widely applied set of procedures is time series analysis. A time series is a set of statistical observations arranged in chronological order. In particular, we are concerned with series of observations in which the value of one observation is not independent of the value of preceding observations, such as, for example, the monthly cost-of-living index.

Classical time series analysis is essentially a descriptive method which attempts to break down an economic time series into distinct components. These components are:

1. Secular trend
2. Cyclical fluctuations
3. Seasonal variations
4. Irregular movements.

Secular trend refers to the smooth upward or downward movement which characterises a time series over a long period of time. Cyclical movements are recurrent

oscillations around secular trend levels which have a duration of, typically, 2-15 years. An important example is the so-called business cycle representing intervals of prosperity, recession, depression and recovery. Seasonal variations are the identical, or almost identical, patterns which a time series seems to follow during corresponding months of successive years. Finally irregular movements are fluctuations in time series which are erratic in nature, and follow no regularly recurrent or other discernible pattern. These movements are sometimes referred to as residual variations, since by definition they represent what is left over in a time series after trend, cyclical and seasonal elements have been accounted for.

Moving averages are some of the simplest forecasting methods available. The basic assumption in applying them is that a slight trend upwards or downwards may exist but it is negligibly small over the period covered by the forecast when compared with the random errors.

Given a series of numbers  $Y_1, Y_2, Y_3 \dots$  we define a moving average of order  $N$  to be given by the sequence of arithmetic means

$$\frac{Y_1 + Y_2 + \dots + Y_N}{N}, \quad \frac{Y_2 + Y_3 + \dots + Y_{N+1}}{N}, \quad \frac{Y_3 + Y_4 + \dots + Y_{N+2}}{N} \dots$$

If data are given annually or monthly, a moving average of order  $N$  is called respectively an  $N$ -year moving average or  $N$ -month moving average.

Let us illustrate the calculation from sales data collected every quarter for four years, by taking a 4-point moving average.

		Year			
		1	2	3	4
Quarter	1	1	1	1	2
	2	2	3	3	2
	3	5	6	6	8
	4	2	2	4	4

The calculation is given below.

<u>Period</u>	<u>Sales</u>	<u>4 point moving total</u>	<u>4 point moving average</u>
1	1		
2	2		
3	5	10	2.5
4	2	10	2.5
5	1	11	2.75
6	3	12	3.0
7	6	12	3.0
8	2	12	3.0
9	1	12	3.0
10	3	12	3.0
11	6	14	3.5
12	4	15	3.75
13	2	14	3.5
14	2	16	4.0
15	8	16	4.0
16	4		

Exponentially weighted moving average is a form of weighted moving average in which the weights differ by a constant ratio; i.e. for example, the weight for period 4 is half that for period 5, and so on. At first sight we might reject exponential weighting on the grounds that it is too cumbersome to calculate. However, it turns out to be even easier to calculate than an ordinary moving average.

Let us look at an example in which the constant ratio is one half. Consider the first four columns of the table below. We calculate the EWMA and find it to be 74.2. Then the sales for period 11 arrive, 64, and we expect to have to do the calculation

<u>Period</u>	<u>Sales</u>	<u>Weight</u>	<u>Weight x Sales</u>	<u>New Weight</u>	<u>Weight x Sales</u>
1	73	.001	0.1		
2	75	.002	0.2	.001	0.1
3	59	.004	0.2	.002	0.1
4	58	.008	0.5	.004	0.2
5	69	.016	1.1	.008	0.6
6	78	.031	2.4	.016	1.2
7	62	.063	3.8	.031	1.9
8	57	.125	7.1	.063	3.6
9	71	.250	17.8	.125	8.9
10	82	.500	41.0	.250	20.5
11	64	-	-	.500	32.0
		<u>1.000</u>	<u>74.2</u>	<u>1.000</u>	<u>69.1</u>

contained in the last two columns. But, lo and behold, we don't have to do this, because all the sales figures now have their weight halved and we can get the same result by simply bringing forward half their total, i.e.

$$\begin{aligned} \text{New EWMA} &= \frac{1}{2} \text{ New Sales Figure} + \frac{1}{2} \text{ Old EWMA} \\ &= 0.5 \times 64 + 0.5 \times 74.2 = 69.1 \end{aligned}$$

We have used a common ratio of 0.5 because it is easy to see what is happening. It shows, for instance, the 'dying-away' effect of exponential weighting, i.e. one has only to go about ten periods into the past to find all previous sales figures contributing virtually nothing to the average. Such rapid decay is not always desirable.

Generalising the rule we have:

$$\text{New EWMA} = a \times \text{New Sales Figure} + b \times \text{Old EWMA}$$

where  $b$  is equal to the common ratio and  $a + b = 1$ . If the time series is well established (sales of a well known product, for example) then  $b$  is usually chosen to be about 0.9. If the time series is not so well established (a new product's sales, for example) then it will be correspondingly lower.

The difference between two successive moving averages gives an estimate of the long term trend. Now, because of the way a moving average is calculated, a time lag

has been introduced, e.g. when calculating a 5-month moving average for month 3 we use the information from month 5. In other words we can only calculate the moving average for month 3 in month 5 and so a two-month time lag has been introduced. In general, when calculating an N-period moving average the

$$\text{Time Lag} = \frac{1}{2}(N-1) \text{ periods.}$$

The estimate of the long term trend can be used to correct for this time lag. Taking again the example of a 5-month moving average, if we wish to forecast the value of the series for the next period, we must apply a trend correction corresponding to three periods. If the estimate of the trend is T then the forecast is the correct value of the moving average plus 3T.

As an example consider forecasting an Insurance Company's turnover for 1975. The calculation (using a 3-year moving average) is:

<u>Year</u>	<u>Turnover</u> <u>(\$ million)</u>	<u>3-year MT</u>	<u>3-year MA</u>	<u>Trend</u>	<u>Forecast</u> <u>MA + 2T</u>	<u>Error</u> <u>(Forecast</u> <u>- Actual)</u>
1969	57,944					
1970	65,123	193,590	64,530			
1971	70,524	212,521	70,840	6,310		
1972	76,874	229,598	76,533	5,693		
1973	82,200	243,741	81,247	5,714	83,460	+1,260
1974	85,667				87,919	+2,252
1975					92,675	

The trend column is simply the difference between the last two moving averages. The forecast, in this case, is MA+2T, because the time lag for a 3-year MA is only 1 year. So the forecast for 1973 is the MA for 1971 + 2T.

One component of a time series, mentioned previously, is that of seasonal variation when regular patterns are followed during corresponding periods of successive years. The first time series used as an example, clearly exhibits this sort of behaviour. In each year the lowest sales are in Quarter 1 and the highest sales are in Quarter 3. The question that now arises is 'How do we forecast this sort of seasonal pattern?' Many methods have been devised, of course, to answer this question, but we shall consider just one.

#### The Average Percentage Method

The first step in using this method is to forecast the total sales in the next year, using one of the methods described previously. For the data used in the first example, the yearly totals are 10, 12, 14 and 16 respectively so that it is not difficult to imagine that the total sales in the next year (Year 5) might be estimated as 18! It is now necessary to express, for each quarter, the actual sales as a percentage of the total sales in the year. The calculation is shown below.

	Year			
	1	2	3	4
Quarter 1	1/10 = 10%	1/12 = 8.33%	1/14 = 7.2%	2/16 = 12.5%
Quarter 2	2/10 = 20%	3/12 = 25%	3/14 = 21.4%	2/16 = 12.5%
Quarter 3	5/10 = 50%	6/12 = 50%	6/14 = 42.8%	8/16 = 50%
Quarter 4	2/10 = 20%	2/12 = 16.67%	4/14 = 28.6%	4/16 = 25%
Total	100%	100%	100%	100%

The seasonal factors are then calculated by taking the average percentage for each quarter, i.e.

	<u>Total percentage</u>	<u>Average percentage</u>
Quarter 1	38.03	9.5
Quarter 2	78.9	19.7
Quarter 3	192.8	48.2
Quarter 4	90.27	22.6

The final stage is to apply these seasonal factors to the forecast sales for year 5, i.e. 18.

<u>Forecast for year 5</u>	
1	18 x 0.095 = 1.71
2	18 x 0.197 = 3.55
3	18 x 0.482 = 8.69
4	18 x 0.226 = 4.05
	<u>18.00</u>

#### 6.4.7 Simulation

The other techniques that have been described are analytical techniques. To use them we must decide which variables are relevant and develop relationships between them in order to form a model of the situation. This is not always possible, because we cannot with certainty state which variables are important, or because the relationships are too complex to solve analytically. For such problems, simulation offers a very powerful approach to developing a solution. When using simulation the aim is to produce a system which has identical behaviour to the real situation, or as near identical behaviour as possible.

There are four major ways of simulating management problems. In system dynamics a computer is used to simulate situations in which there is feedback of information as a result of decisions, which affects future decisions. In financial and corporate modelling a computer programme is written to represent the financial structure of the business, and allow various policies to be examined and the most suitable chosen. Operational gaming is typified by competitive business games, where the aim is to set up an accurate model of the situation and allow people to

operate it so as to learn without the expense of mistakes.

The original form of simulation, and the one on which we will concentrate is sometimes called the Monte Carlo method because early applications used roulette wheels to simulate the chance events inherent in its approach. Consider a small company which operates a bank of power presses which stamp out shallow metal containers. (This example is due to my colleague, Michael Pidd, and is included in his contribution to Littlechild's book). One of their presses, has two identical dies, A and B, which must be periodically replaced. The replacement dies cost \$40 each and the act of replacement (i.e. dismantling, reassembly and lost production) costs \$100. This latter cost is the same whether one or both dies are replaced. Consequently, it may be cheaper to replace both dies when one fails than to replace only the die which fails. The Company wish to determine which of these two replacement policies will minimise their total costs.

The works engineer has collected historical data on the life of the dies, as shown in the first two columns below. Thus, there is a 10% chance that a die will fail in its first week, a 15% chance that it will fail in its second week, and so on. The maximum life of a die is six weeks. For simplicity, it will be assumed that the die fails only at the end of a week.

<u>Life (weeks)</u>	<u>Probability</u>	<u>Associated range of random numbers</u>
1	0.10	00 - 09
2	0.15	10 - 24
3	0.20	25 - 44
4	0.35	45 - 79
5	0.15	80 - 94
6	0.05	95 - 99
	<u>1.00</u>	

The first step is to generate a series of lives for the two dies, which is consistent with the previous known data, and to see which of the two alternative policies performs best in this hypothetical situation. The Monte Carlo method involves taking a series of random numbers, one for each die, and associating with each random number a life (in weeks) for that die. In order that the resulting life distribution be consistent with previous experience, the number of random numbers associated with a particular life must be proportional to the probability of that life occurring, as given in the table above.

We shall use a table of random numbers, as given below. These random numbers range between 00 and 99, and any number in that range has an equal probability of occurring in any position. The obvious ways of associating these random numbers to the die lives is to let the first 10 numbers of the range (i.e. 00 to 09) be associated with a life of one week, the next 15 numbers (10 to 24) with a life of two weeks, and so on, as shown in the third column above.

The next step is to write down a stream of random numbers and find the corresponding lives. For die A we shall start in the top left-hand corner of the table and work across the first block row by row. Thus, the first number 29 (indicated by \*) lies in the range 25-44 and represents a life of three weeks. For die B we shall work similarly from the second block of numbers, beginning with 00 (indicated by +). The results are shown below.

*29	94	98	94	24	14	90	56	86	07
64	49	69	10	82	39	80	82	77	32
53	75	91	93	30	06	28	89	80	83
34	25	20	57	27	86	50	75	84	01
40	48	73	51	92	87	51	76	49	69
+00	39	68	29	61	17	46	85	09	50
66	37	32	20	30	17	72	70	80	15
77	84	57	03	29	77	40	27	72	14
10	45	65	04	26	66	25	22	91	48
11	04	96	67	24	14	22	56	85	14

Die No.	Die A		Die B	
	Random numbers	Life	Random numbers	Life
1	29*	3	00+	1
2	94	5	39	3
3	98	6	68	4
4	94	5	29	3
5	24	2	61	4
6	64	4	66	4
7	49	4	37	3
8	69	4	32	3
9	10	2	20	2
10	82	5	30	3
11	53	4	77	4
12	75	4	84	5
13	91	5	57	4
14	93	5	03	1
15	30	3	29	3
16	34	3	10	2
17	25	3	45	4

This table may be used to evaluate the two policies over a simulated time period of 50 weeks, as shown below:

Separate replacement policy				Joint replacement policy		
Die A No.	Cumulative life	Die B No.	Cumulative life	Dies No.	Minimum joint life	Cumulative joint life
1	3	1	1	1	1	1
2	8	2	4	2	3	4
3	14	3	8	3	4	8
4	19	4	11	4	3	11
5	21	5	15	5	2	13
6	25	6	19	6	4	17
7	29	7	22	7	3	20
8	33	8	25	8	3	23
9	35	9	27	9	2	25
10	40	10	30	10	3	38
11	44	11	34	11	4	32
12	48	12	39	12	4	36
(13)	(53)	13	43	13	4	40
		14	44	14	1	41
		15	47	15	3	44
		16	49	16	2	46
				17	3	49

- a) Separate replacement policy. Examination of the table shows that die A is replaced a total of 12 times in the 50 weeks. Die B is replaced a total of 16 times but four of these occur at the same time as replacement for die A. Hence, the total cost of this policy is:

$$\begin{array}{rcl}
 \text{Cost of dies} & = & \$40 \times (12 + 16) = \$1,120 \\
 \text{Replacement cost} & = & \$100 \times (12 + 16 - 4) = \underline{\$2,400} \\
 \text{Total cost} & & \underline{\underline{\$3,520}}
 \end{array}$$

- b) Joint replacement policy. The table also shows the joint cumulative life time of the two dies using the shorter of the two lives as the joint life. This shows that replacing both dies when one fails leads to a total of 17 joint replacements over the 50 weeks. Hence the total cost of this policy is:

$$\begin{array}{rcl}
 \text{Cost of dies} & = & \$40 \times 34 = \$1,360 \\
 \text{Replacement cost} & = & \$100 \times 17 = \underline{\$1,700} \\
 \text{Total cost} & & \underline{\underline{\$3,060}}
 \end{array}$$

It would seem at first sight that the results of this replacement problem are straightforward. They seem to indicate that joint replacement is cheaper than single replacement by \$460 over 50-week period. However, this does not necessarily mean that the difference in costs between the two policies will be exactly \$460 in practice. If, instead of starting at the points indicated by \* and + in the

random number table we had started elsewhere, this would mean that we would have drawn a different random sample from the life distribution of the dies. This would have produced results slightly different from those shown. For instance, if we had used the second block of numbers instead of the first block, the separate policy would have cost \$3660, and the joint policy \$3240, indicating that joint replacement is cheaper than single replacement by \$420 over a 50 week period.

It is usual, therefore, to make several simulation runs each with a distinct random sampling pattern. Techniques are available for deciding how many runs are required in a given situation. The golden rule in examining the results produced by a simulation is the one which underlies all classical statistics: caution allied to rational argument. No simulation study should be completed on the basis of a single finished computer run. If the results are that obvious and clear cut, the simulation was probably superfluous anyway.

We have now seen that the Monte Carlo method is a way of taking random samples from probability distributions. In our example, we had three such probability distributions: one for the life of each die and one for their joint life. We took samples from these to produce a synthetic history of the two replacement policies which were under consideration. The order and rate at which these samples are taken is determined by the dynamic logic of the situation. Hence we may simulate the dynamic behaviour of the system under investigation.

#### 6.5 Implementation of OR/SA

The aim of all OR/SA work is implementation. There is no real point in attempting to help managers in the decision-making process if the recommendations are not implemented. Yet, all too often, little thought is given to this stage of a project, with the result that recommendations are either not implemented, or badly implemented.

Before discussing some of the factors which research and experience **have shown** lead to a greater likelihood of implementation, it is worth considering some of the possibilities that exist regarding who should carry out the implementation of a project's recommendations and how the implementation might be done. There are three main possibilities as regards who should implement. First, and by far the most common, is implementation by management. Often this arises as a result of little, or no, thought being given to this stage of the project. Recommendations are presented to the appropriate management by the OR/SA team, who then leave the management to carry them out. A second possibility is that the OR/SA team, themselves, implement their own recommendations. This happens quite frequently, in particular when the management is short of resources, but also when it is felt that it would be best if the OR/SA team retain their involvement. Not infrequently, this approach leads to one of the team leaving his specialism and joining the

management. When the implementation is complete and the new system is working properly, control is handed back to the management. A third possibility, which usually occurs on large projects, is a planned joint implementation of the team's recommendations.

There are also three principal methods for implementation. First, parallel running, in which a new system is run alongside the old, until it is clear that it is working correctly. This method is most frequently used for the installation of new decision rules, for instance in stock control or purchasing. Obviously it is impossible for physical changes to equipment. An alternative method is that of the pilot project, where the system is introduced to part of the organisation in order that any 'bugs' can be removed, before it is implemented right through the organisation. A danger with this method is that the part, in which the system is introduced, may not be representative of the whole. A third, and obvious alternative is immediate and full scale implementation. This is very frequently the choice that is made by management, often ignoring the counsel of the OR/SA team, and it does leave the organisation potentially open to disaster. Mackness has argued that the comparative ease of implementation in a small firm, because the system and decision-taking procedures are less complex than in a large firm, gives rise to potential danger. A manager is more likely to proceed with implementation more quickly than is advisable, and the OR/SA team must be aware of this, and make clear the dangers involved.

It is clear that one of the factors that increases the probability of a successful implementation arises from the nature of the project initiation. Lonnstedt carried out some research on 107 OR projects proposed for implementation prior to the summer of 1970 in 12 Swedish firms. Of these projects, 29 were reported as not implemented by the user. All but one of the 23 projects initiated by top management were implemented. Of 43 projects initiated by the user, 32 were implemented, but only 8 out of 20 projects initiated by the OR groups were implemented. (There were 21 projects in which no information was obtained as to the initiator's identity). This piece of research indicates what one would expect: if a project is foisted on to a company, or if the management or users do not really see the need for it, the results are less likely to be implemented.

Ackoff and Sasieni suggest that 'it is always desirable to have those managers for whom the research is being done pay for it .... Although it may seem that a manager should welcome research for which he does not have to pay, this is seldom the case. Only if he pays for it, can he be sure that the research is serving his, rather than someone else's best interests. Therefore, whenever possible, he should at least share in the cost of the research'. They write in a large company context, in which a central administration function may well pay for research done on divisional operations, but the point is well made for other situations.

Furthermore, participation of the management is more likely if they have been charged for the research, and participation is a vital ingredient for successful implementation. In Lonnstedt's study the implementation rate more than doubled, from 40% to over 80%, when the user was actively involved in the project work. Ackoff and Sasieni say that 'the OR team should begin to make the solution to the problem acceptable to managers before it is obtained .... Hence their participation in the research is not only desirable but practically essential'. This means that all managers concerned with the study should frequently be met individually for consultation and discussion, and, in addition, there should be regular project meetings with the entire group of relevant managers. Such a continuous review of the work by the management will assure them that all the significant aspects of the problem have been allowed for, and it enables them to appreciate the methods and techniques that are being used. Working papers can be issued at appropriate intervals during the course of the study so that the assumptions on which the work is based can be questioned by the management. This practice may mean that a long final report is not necessary, but if it is it should be one that, essentially, has been agreed with the management before it is presented. It certainly should not be modelled on the short stories of Roald Dahl, which have recently appeared on British Television under the title 'Tales of the Unexpected'!

#### 6.6 Implementation of OR/SA in developing countries

In recent years a small, but significant, literature has appeared on the implementation of OR/SA in developing countries. Experience in such countries as Peru, Botswana, India, Kenya, Egypt, Columbia, Paraguay and Indonesia has been reported. Not all the work described has direct relevance to small food firms, though it is worth commenting on three projects in some detail. More important, however, is the extraction from this experience of principles to be followed in considering the introduction of OR/SA to small food firms in developing countries.

##### Project 1 Study of the distribution system of a dairy firm in Peru.

The managing director of the largest dairy firm in Lima commissioned two young professionals, whom he knew from his previous responsibility for two consulting groups, to study the distribution system because distribution costs accounted for more than one-half of the unit costs per milk bottle and the company was running into deep financial trouble. Approximately 52 trucks and 180 assistants were needed to deliver the milk, which took place twice daily, with the first delivery accounting for more than 80% of total sales. The trucks were crewed by a driver and two assistants, and incentive schemes meant that the driver got a small amount on every bottle sold by his assistants and a larger amount on the bottles that he sold himself. The allocation of areas to trucks had been made some time previously and adapted as demand had increased.

The study involved a series of logical analyses to determine the most efficient

way of distributing milk in Lima. The suggestions made included enlarging a second depot in another location, changing the distribution areas to eliminate overlaps and unnecessary long trips, changing the incentive structure for the driver and his assistants, increasing the number of assistants per truck and reducing the number of trucks by one-half. Even though the OR/SA men demonstrated that except for the 26 men who would lose their jobs, no average salary would be reduced, these radical changes faced strong opposition from the union. However, the managing director was able to convince the workers that the reforms were needed and that he had complete confidence in the recommendations of the OR/SA team. His interest and participation in all stages of the project and the confidence he had in the OR/SA team were key factors in making this the most successful application of OR/SA in Peru during the 60's.

Immediately after implementation, there were some days of confusion during which sales dropped to 60% below daily averages, but they soon rose and after one month previous averages were exceeded. Distribution costs were cut by 25%, which represented considerable savings. In a short time demand almost doubled, with the result that a co-operative was formed and the distribution of the additional demand was, in part, sub-contracted to it, using the trucks and drivers that were not needed by the original company.

Project 2 Production planning for a soft drinks manufacturer in Peru.

As a result of seasonal variations the firm had serious production problems; in summer they worked at full capacity and ran out of stock frequently, while in winter they had excess capacity and greatly increased stock levels. Three industrial engineering Masters students constructed a production smoothing model using linear programming, which gave the minimum cost production schedule for a whole year and showed the value of building additional storage capacity and expanding certain production facilities. When the model was ready for implementation, the firm refused to provide actual demand data on the grounds that this was confidential. Furthermore, nobody in the firm had confidence in the model and so it was not implemented. This project illustrates the dangers of trying to impose OR/SA on an unwilling or uncertain management.

Project 3 Processing and distribution of meat products in Paraguay.

International Product Corporation of Paraguay was the largest Paraguayan company engaged in the processing and distribution of meat products. Indeed, it accounted for 25% of Paraguay's annual export revenues. It was acquired by Ogden Corporation, a large American firm, in July 1966, and provided a real opportunity to apply OR/SA to a Latin American country. A linear programming model was built in order to allocate resources, such as labour and various types of machines and materials, at the ranch, and a series of experiments was planned to test the effect of four controllable factors (cattle breed, grass type, mineral supplement and cattle

weaning age) on the output (meat shipped). At the packing plant another linear programming model was built to determine the optimal use of the available resources in the various possible products, and a production smoothing model was developed to find optimal inventories. Several other projects were investigated, but at the time of the report none had been implemented. The reason for this was twofold. First, the lack of qualified personnel and secondly, the lack of computing facilities.

These, and the other, projects described in the literature together with the informed comments of the authors enable a number of principles to be delineated which should be followed when considering the introduction of OR/SA to small food firms in developing countries.

It is clear, first, that all the participants in the exercise need to be educated. 'Experts' visiting the developing country need to become informed about the political and social context in which OR/SA is to be introduced. Full attention must be paid to the current management environment before any technical transfer. Indeed OR cannot be transferred from the developed to the industrialising world without such reference to a host nation's current technology levels, styles, institutions and policies (Clayson). Indeed Luck would go further. 'I want to make the point that in a developing country the history as well as the current political and economic situation have an important effect on the possibilities for developing ORSA'. One example of the difference that the political environment makes is in the problem of unemployment. Okita says 'because of the baby boom experienced in many of the developing countries during the post-war years, there has been a very sharp increase in labour supply in many of the developing countries and the Governments are under pressure to provide employment opportunities for increasing numbers of young labour force'. In Kenya, for instance, the Government instructed all Kenyan firms to increase employment by 10%. As a result, industries are terribly overstaffed by American or European standards but it is not possible to 'solve' this problem by using approaches such as substitution of capital or even simply better scheduling.

Secondly, it is vitally important that the managers of firms into which OR/SA is to be introduced should be made aware of what is involved and have some appreciation of what OR/SA can do for them. Sagasti (1974) has as his first principle 'The OR/MS professional should not begin work on the project unless he is convinced that the client knows well what results to expect, what demands the project will place on him and understands the general principles of the process by which the analyst will generate his advice'. For these managers a 2-3 day appreciation course, concentrating on the application of OR through case studies and not on mathematical techniques is needed.

Thirdly, it is clearly necessary for nationals of the developing countries to be

trained to do OR/SA. Luck recommends that such education should start with real problems because the OR/SA approach is learnt through facing real problems in the field: 'Real problem solving becomes the main thrust of the programme supported by classroom teaching, rather than the other way round'. Equally it is important that university courses in the practice of OR/SA should be encouraged. In order to do this, Morse and Brown point out that at least three sorts of people must be committed to the effort: 'Someone in the administration of the university must be convinced that the venture deserves support. At least one faculty member must be convinced that he will find students, and that the time he spends in preparing the course will be repaid in some way. And at least a few students must be convinced that the time they spend on the course will also be repaid in some way'. Sagasti (1972), however, sounds a note of warning. Tradition, he says, 'has kept Peruvian and many other Latin American universities away from any kind of institutional participation in applied work, and also because the constraints imposed by law on university activities, particularly in state universities, make it almost impossible to organize groups that could apply OR directly through university channels'.

The issue of University courses raises a second important question. Not only must participants be educated, but they must also be provided with an institutional base. Sagasti (1972) suggests that one reason for the poor rate of implementation in Peru during the 1960's was the lack of institutions involved in OR work. He proposes four institutional modes for organizing OR activities of particular relevance to underdeveloped countries, viz:

- a) OR groups established within government organisations
- b) 'Research-Application' institutions which undertake research on some generic problem, or group of problems, but at the same time seek to apply their research
- c) Consulting House which would provide services on a consulting basis
- d) Cooperative Research Organization in which several private enterprises and/or government departments join efforts and, instead of each having a small OR group, set up a larger institution capable of providing services to all of them.

For reasons stated earlier Sagasti does not include universities in his list. However, in other countries tradition and legal constraints may not be such as to rule out this fifth possibility.

Morse and Brown suggest that one of the best ways for a country to begin to create its own OR/SA practitioners 'is to begin in a small way with the setting up of a working OR group. The group does not need to be large, at the outset; three or four people might be enough, or perhaps as many as six. If the work they do is good, and if the projects they are working on are worthwhile, the idea will spread

and the group itself will grow in size and will probably split off parts of itself to work in other areas .... Two elements have to be brought together for the process to be started: an administrator who wants to use OR and a capable, or potentially capable, OR director who wants to develop a group'.

The third area in which some principles can be specified concerns the OR/SA approach itself. In this area there are conflicts between authors. Consider first the question of whether simple or complex approaches are needed. Sagasti (1972) observes that 'any efforts to simplify OR approaches and techniques with the intention of putting them within reach of personnel with little knowledge about OR are not likely to produce models and results commensurate with the problems they attempt to solve'. McCarthy takes an opposite point of view: 'There is no place for the use of complicated standard techniques and volumes of data in order to arrive at optimal solutions to mathematical models of a problem'. He adduces three reasons for this position. He argues, first, that most standard techniques are justified by the achievements of marginal improvements in situations where total cash involved is large enough for the marginal benefit to outweigh the considerable research cost involved, and that these situations do not generally arise in developing countries. However, in developing countries the techniques are likely to make more than marginal improvements.

His other reasons are more cogent. 'Data necessary for detailed studies are not available ... Furthermore, the rapid growth of the economy and its continual structural change would make historical data, even if it were available, a poor indicator to the future'. A number of authors have raised this objection, and it does create a problem. However, it is a problem that must be overcome. Experience suggests that adequate data bases do not develop unless there is an effective demand for more detailed data. McCarthy's third reason against the use of complex models is that 'there is rarely time to undertake a detailed mathematical study of a problem before a decision has to be made'. This is a cry frequently heard in the more developed countries, and too often solutions from complex models are not implemented because they arrive too late.

The answer to this apparent dilemma is that the appropriate model must be built for each particular situation. In certain circumstances a complex model will be appropriate. For instance when decisions are to be taken about the location of an expensive new plant it is important to take all aspects thoroughly into consideration. On the other hand, if the purpose of the project is to provide an on-going planning tool, to be used by someone who is not familiar with some of the more complex OR techniques, then it would be important to make it as simple as possible in order to increase the likelihood of continued implementation. As a general rule, the complexity of the model to be used is limited by the available computers. Whilst this is identified as a problem by Elshafei who argues that 'this has forced OR analysts to resort to simple models to accommodate

their programme within the storage of available computers', the age of the mini computer should enable OR/SA workers to be more adventurous in building models and planning aids, particularly for small firms in developing countries.

#### 6.7 Some recommendations

One of the dangers inherent in OR/SA work is that the analyst, or indeed the management, may arrive at a conclusion as to what should be done before the problem has been fully defined. In making some recommendations for the introduction of OR/SA to small food firms in developing countries before the workshop one is breaking all the rules that are designed to avoid such danger. However, in spite of the risk, it is worth having some ideas presented as a base point from which discussion might begin.

Some countries which may be classified as developing countries already have some OR/SA activity. We have seen that OR was introduced into such countries as Peru and Paraguay over 20 years ago, and other countries such as Singapore, Chile and Egypt have their own OR societies which are affiliated to IFORS. It may well be helpful in such countries to seek the co-operation of these established agencies when seeking to introduce OR/SA to small food firms. In other countries, where there is little or no OR/SA activity it will be necessary to identify a sympathetic senior administrator to coordinate such a development.

The next stage would be to seek an experienced OR/SA person, who will probably come from a developed country and who will be willing to devote a substantial amount of time, over a period of 2 years or so, in order to help educate prospective analysts and management and to give advice on the project work. They would encourage the development of an environment in which the OR/SA work could develop and allow the OR/SA experience to be absorbed as required by the needs of the problems to be analysed. Collcutt reported at the close of the recent EURO IV Conference in Cambridge that IFORS is 'considering setting up an IFORS Foundation to seek funds specifically to provide this 'catalytic' support to sympathetic countries with as yet no tradition of OR'. It is possible that financial support for the developments envisaged by this workshop may be provided by IFORS, but whether or not that proves to be the case, IFORS certainly would be able to help to find appropriate personnel. Furthermore, Collcutt also reported that IFORS are proposing to the International Bureau for Informatics to have an invitational conference in Rome in 1981 at which senior administrators and scientists from specific African states could discuss with IFORS how OR could be developed to help them'. These initiatives from IFORS are a direct result of the Morse and Brown paper presented at the IFORS Conference in Japan in 1975.

The coordinator and the experienced OR/SA visitor should then appoint a project team of, perhaps, 4 people. It is not necessary for them all to have been

trained in OR/SA, but they should be scientists or technologists willing to analyse the problem of small food firms. Initially their salaries would probably be met by an outside agency, but later would be met substantially from payments for project work.

There would then follow an introductory familiarisation course given by the OR/SA visitor, with the project team, to 10-15 invited managers. The course would probably cover some of the material presented earlier, but would concentrate on case studies, not on the mathematical techniques, seeking to show the potential benefits of OR/SA to the managers. During the course interested managers can discuss with the OR/SA team and begin to form ideas of suitable projects. Following the course the team could visit each interested firm, perhaps one day at each firm, to discuss potential projects. Finally, 4-6 suitable projects with which to start the activity, would be selected. The course itself would probably be sponsored by an outside agency, but the project work should be paid for by the firms, although not necessarily at a full economic rate.

## 6.8 References

### Section 6.1

- 1.1 ACKOFF R.L. and M.W. SASIENI (1968) Fundamentals of Operations Research. Wiley, New York.
- 1.2 CHURCHMAN C.W. (1968) The Systems Approach. Delacorte Press, New York.
- 1.3 MISER H.J. (1980) Operations Research and Systems Analysis Science 209, 139-146.
- 1.4 RIVETT P and R.L. ACKOFF (1963) A Manager's Guide to Operational Research. Wiley, London.

### Section 6.2

- 2.1 BOLTON J.E. Chairman (1971) Small Firms HMSO, London.
- 2.2 MACKNESS J.R. (1974) The Application of Systems Engineering Principles to Operations of Small Companies. Unpublished PhD Thesis, University of Lancaster.
- 2.3 STALEY E and R. MORSE (1965) Modern Small Industry for Developing Countries. McGraw-Hill, New York.

### Section 6.3

- 3.1 MERCER A, M.F. CANTLEY and G.K. RAND (1978) Operational Distribution Research: Innovative Case Studies. Taylor and Francis, London.
- 3.2 WILD R. (1977) Concepts for Operations Management. Wiley, Chichester.
- 3.3 WILD R. (1979) Production and Operations Management: Principles and Techniques. Holt, Rinehart and Winston, London.

## Section 6.4

References 1.1, 1.2, 2.2 and 3.3.

- 4.1 BATTERSBY A. (1966) Mathematics in Management. Penguin, London.
- 4.2 CHIU W.K. and G.B. WETHERILL (1975) Quality Control Practices. Int. Journal of Production Research 13, 175-182.
- 4.3 JONES W.G. and R.M. ROPE (1964) Linear Programming Applied to Production Planning - A Case Study. ORQ 15, 293-302.
- 4.4 LITTLECHILD S.C. ed. (1977) Operational Research for Managers. Philip Allan, Oxford.
- 4.5 OPEN UNIVERSITY (1972) Technology Foundation Course Unit 18 - Modelling II.
- 4.6 RAND G.K. (1974) A Manual Production Scheduling Algorithm ORQ 25, 541-551.

## Section 6.5

- 5.1 ACKOFF R.L. and M.W. SASIENI (1968) Fundamentals of Operations Research. Wiley, New York.
- 5.2 LONNSTEDT L. (1975) Factors related to the implementation of Operations Research solutions. Interfaces 5, 23-30.
- 5.3 MACKNESS J. (1975) The Application of Systems Engineering Principles to Operations of Small Companies. University of Lancaster Unpublished PhD Thesis.

## Section 6.6

- 6.1 BANDYOPADHYAY R. and S.D. VARDE (1980) OR Education and development economies with special reference to India JORS 31, 675-687.
- 6.2 BANDYOPADHYAY R. (1980) OR applications in industry and problems of industrialisation of a developing economy with special reference to India. JORS 31, 769-780.
- 6.3 CLAYSON J.E. (1980) How relevant is Operational Research to development? The case of Kenyan industry. JORS 31, 293-299.
- 6.4 ELSHAFEI A.N. (1976) OR in developing economies: Some experience with applying OR in Egypt's national planning studies. In OR'75 edited by K.B. Haley. North Holland, Amsterdam, 13-23.
- 6.5 LOOMBA N.P., E. TURBAN and A. COHEN (1968) Implementation of Management Science in Latin America: A case study and generalization. Man. Sci. 14 B-695-B-704.
- 6.6 LUCK G.M. (1979) Barefoot ORSA. In OR'78 edited by K.B. Haley, North Holland Amsterdam, 213-233.
- 6.7 MCCARTHY S.J. (1978) Potential applications of OR in developing countries - a generalization from Botswana. JORS 29, 167-170.
- 6.8 MOHAN L. and A.S. BEAN (1976) Operational research in India: An evaluation of the current state of the art vis-a-vis potential. ORQ 27, 547-565.

- 6.9 MORSE P.M. and A.A. BROWN (1976) Operations research in the developing countries - A role for IFORS. In OR'75 edited by K.B. Haley, North-Holland, Amsterdam, 111-124.
- 6.10 OKITA S. (1976) Present issues in developing countries and future challenge for development. In OR'75 edited by K.B. Haley, North-Holland, Amsterdam, 49-61.
- 6.11 SAGASTI F.R. (1972) Management Sciences in an Underdeveloped Country: The case of operations research in Peru. Man. Sci. 19, 121-131.
- 6.12 SAGASTI F.R. (1974) Operations research in the context of Underdevelopment: Some case studies from Peru. ORQ 25, 219-230.
- 6.13 SAGASTI F.R. (1976) Thoughts on the use (and abuse) of OR/MS in the planning and management of development (Or. Can OR/MS help in the planning and management of revolutions?) ORQ 27, 937-948.
- 6.14 VERTINSKY I. (1972) OR/MS Implementation in Valle, Colombia S.A.: A profile of a developing region. Man. Sci. 18, B-314-B-327.
- 6.15 WALSHAM G. (1978) Education in Operational Research for the developing countries. JORS 29, 299-306.

#### Section 6.7

- 7.1 COLLCUTT R. (1980) IFORS in the 1980's. IFORS, Copenhagen.

#### Additional references

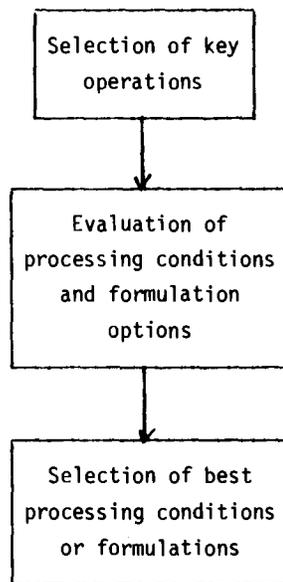
1. ETO H. (1980) OR/MS in Cultural Pluralism. Interfaces 10, 45-47.
2. GLEN T.M. and C.F. JAMES, Jr (1980) Difficulties in implementing Management Science Techniques in a Third World Setting. Interfaces 10, 39-44.

## 7. EXPERIMENTATION by A.M. Anderson

Potential strategies for process improvement are frequently of a technical nature. Modifications to processing conditions or formulations are often presented as possible options for improvement of a key operation.

Evaluation of processing conditions and/or formulations then becomes an important part of research into process improvement. These evaluations are frequently carried out in a haphazard and unplanned manner. Although such approaches can lead to satisfactory conclusions they frequently result in an expensive waste of time and money.

This section presents a selection of systematic and planned experimental design techniques which can be used for process improvement. The techniques are all statistically simple and the results can be analysed without the aid of a high powered computer.



### 7.1 Experimental Design for process improvement

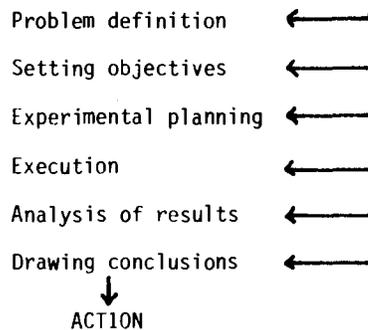
Systematic and planned techniques for product and process development will not only result in more detailed and conclusive information but will also cost less than the more traditional and unplanned approaches - at least in the long term. Frequently these systematic and planned techniques, broadly defined under the heading of experimental designs, are avoided by industrial experimenters because of their apparent complexity to plan and analyse. But this need not be so.

In fact it is frequently the simple experimental designs which offer the best results. There are many such design techniques which are relatively easy to formulate and to analyse.

This section studies briefly the procedure of experimental planning for product and process improvement and presents examples of some simple techniques which can be used with a minimum of statistical knowledge. Very little reference is made to the statistical basis for these techniques and the reader is referred to standard texts on experimental design for further information on this (Duckworth 1968 ; Lipson and Sheth 1973 ).

#### 7.1.1 Systematic Approach to Experimental Design

Successful experimentation is usually a result of careful forward planning and systematic working towards a pre-defined goal.



##### Problem definition

Before any form of practical experimentation takes place a brief summary should be made of the exact nature of the problem to be solved,

- e.g. A new product has been developed and a set of processing conditions is required ,
- or It has been necessary to make certain modifications to an existing piece of equipment. What effect will this have on product quality and throughput?

##### Setting objectives

Specific objectives must be set for the experimentation. What exactly is required? What information is needed?

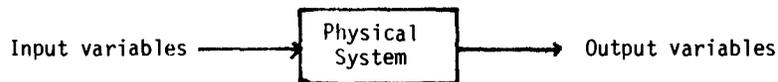
- e.g. To define the optimum processing conditions for a new roller-dried baby food including:
  - temperature
  - residence time
  - nip gap
  - solids content of feed

Objectives must be related to the problem definition inasmuch as satisfaction of the objectives through the experimental process should solve the problem at hand.

#### Experimental planning

This involves the design of a systematic and objective experiment which will provide information to satisfy the objectives and thereby solve the problem.

Before setting out to design the experiment it is important that the experimenter has a good understanding of the physical system that he is studying. In particular he must be aware of all the important input and output variables.



Output variables are those factors which respond to changes in the condition of the physical system. For example, where the physical system is a tray drier used for drying fish the output variables include moisture content of the fish, colour, texture, etc. Frequently the output variables are termed response variables because they respond to physical changes in the process or system.

Input variables are those variables within the system or process which can change and thereby result in an effect on the response variables. Input variables can be controllable, uncontrollable but measurable or uncontrollable and unmeasurable.

Before designing an experiment the important input and output variables must be defined. In particular the ranges over which the input variables can be varied should also be defined. These ranges must be large enough to give a recognisable response in the output variables, if one exists, but not so large as to be outside normally functioning conditions of the system.

Errors will occur in any experiment, no matter how well planned. Proper experimental planning should seek to minimise error. Basically, there are two types of error which occur in experiments - systematic errors and random errors.

Systematic errors occur due to some inherent pattern in the experimental design. For example, if an evaluation was made of 3 different meat boning procedures with the first procedure being tested in the morning, the second in the early afternoon and the third in the late afternoon, then systematic errors might occur due to progressive worker fatigue. These systematic errors might be overcome by either using control subjects under the same experimental conditions or by randomisation of the experimental conditions.

Random errors occur due to some uncontrolled variables in the system. They normally result from poor experimental technique. One of the best ways of accounting for random error is by using paired controls.

It is important that account of error be taken in any experimental planning. Some procedure should be built into the experimental design to measure error so that this can be isolated from the true responses to input variable alterations.

#### Execution

Once the experimental plan has been finalised it is important that this be adhered to exactly throughout execution of the experiment. Setting of input variables must be exact and remain unchanged - even if responses are not up to expectations. Whenever possible experimental runs should be randomised to reduce systematic errors.

Precision in setting and controlling the input variables and in measurement of the response variables will reduce random errors.

Some attempt should be made to estimate experimental error - normally by repeat experimentation.

#### Analysis of results

The significance of the effects of the input variables should be determined by comparison of the level of these effects with a measure of experimental error.

Wherever possible the significance of the interactions of the input variables should also be determined.

#### Drawing conclusions

The analysis of the significance of the effects should be related back to the initial objectives of the experiment. Results of any single experiment will not always completely satisfy the objectives but they should provide the experimenter with some new knowledge which will help him form a clearer picture of the functioning of the system. Frequently, results will lead to the planning of a new experiment so that the total picture for the system is built up from progressive experiments like fitting together pieces of a jigsaw puzzle.

#### Action

Properly designed experiments will ultimately lead to satisfaction of the experimental objectives and solution of the problem. It is important that real and decisive action be taken in response to conclusions from the experiments. Even more important, the process of experimentation and resultant action should be ongoing, so that product and process improvements can be made in a progressive manner.

## 7.2 Experimental Design Methods

It is important, in most industrial situations, that experimental designs be straightforward to plan and execute and simple to analyse. Naturally, the value of the experimental results should not be sacrificed in an attempt to oversimplify experiments. There are a number of basic experimental design methods which do meet the criteria of simplicity of planning, execution and analysis whilst still presenting the experimenter with extremely valuable information about his system. Some of these methods are outlined below. Case studies of the application of each method are presented in later sections.

### 7.2.1 Screening Experiments

One of the first steps in solving a development or production problem is to identify those input variables which substantially affect the response variable(s) under study. Frequently the list of potentially important variables might range from 10 to 20. It is usually possible to eliminate some of these variables by non statistical screening methods but often the experimenter is left with 6 to 10 variables to consider. Under these circumstances the problem may still be too large to solve using conventional factorial experiments (to be discussed in the next section). Ten factors require 1024 runs for a full factorial or 512 for a  $\frac{1}{2}$  replicate. What is required in this case is some sort of experiment which is very efficient at detecting main effects with a minimum amount of experimentation. There are several types of experiments which make these claims but one particular type, Plackett and Burman designs, have proven themselves in many industrial situations and are reputed to be the most efficient for screening large numbers of variables.

Plackett and Burman designs make it possible to screen N-1 variables in N experiments. That is, only 11 experiments are required to screen 10 variables. It is impossible to measure the effects of interactions but this is not usually important in screening as the main objective is to isolate the important variables.

Plackett and Burman have provided the first row of the design matrix for investigating various numbers of factors. The remainder of the design matrix is generated by shifting this first row one space to the left N-2 times, where N equals the number of experiments. The last row of the matrix, a row of minus signs, is added to the bottom of the generated matrix. For example, for 8 experiments to evaluate 7 factors the first row is:

+ + + - + - -

where + signifies the high level of a variable and - the low level.

The full design matrix then becomes:

Run No.	A	B	C	D	E	F	G
1	+	+	+	-	+	-	-
2	+	+	-	+	-	-	+
3	+	-	+	-	-	+	+
4	-	+	-	-	+	+	+
5	+	-	-	+	+	+	-
6	-	-	+	+	+	-	+
7	-	+	+	+	-	+	-
8	-	-	-	-	-	-	-

Plackett and Burman provide experimental plans for the following number of experiments:

N = 8 ; + + + - + - -  
 N = 12; + + - + + + - - - + -  
 N = 16; + + + + - + - + + - - + - - -  
 N = 20; + + - - + + + - + - + - - - + + -  
 N = 24; + + + + + - + - + + - - + + - - + - - - -

In general to use these designs one determines how many variables are to be screened and uses that plan which will handle at least that number of variables. Where there are effects left over (e.g. to screen 9 variables one uses N = 12 which will estimate 11 effects) these are used to calculate the experimental error and to test the significance of the effects of the variables being tested. In conducting the experiment no attention is paid to these "dummy" variables.

#### Analysis of results from Plackett and Burman experiments

Every Plackett Burman design includes, for each variable, the same number of runs at the high level and the low level. To calculate the effect of any input variable one subtracts the average result at the low level of that variable from the average result at the high level of the same variable. For example, in the case of an experiment using the N = 8 plan whose design matrix is given above, the effect of variable A would be calculated as follows:

$$\text{Effect (A)} = \frac{① + ② + ③ + ⑤}{4} - \frac{④ + ⑥ + ⑦ + ⑧}{4}$$

where ① = value of the response variable in run 1.

Similar calculations are repeated for each of the effects including those of the dummy variables. The ease of such calculations will be appreciated by those who do not have access to a computer.

The calculated effects of the dummy variables are used to test the significance

of the real effects. As there was no attempt made to assign the levels of the dummy variables to any experimental variable the magnitude of the dummy variables should be zero. This, of course, rarely happens and the values obtained for the dummy effects reflect the level of "noise" in the experiment. In fact, they can be likened to estimates of the standard error of the effects. In cases where there is more than one dummy variable the values can be pooled to get a pooled estimate of the standard error as follows.

$$\text{S.E. (effects)} = \sqrt{\frac{E_d^2}{n}}$$

where  $E_d$  = dummy effects

$n$  = number of dummy effects

Having obtained a measure of the standard error of the effects, the real effects can be subjected to a t-test to see if they are non zero. t values are calculated for each of the effects by dividing the effects by the standard error calculated from the dummies.

$$t = \frac{\text{effect}}{\text{S.E. (effect)}}$$

These calculated t values are then compared to the table value whose number of degrees of freedom is equal to the number of dummy effects making up the error term. It is wise to use a significance level which reduces the risk of overlooking an important factor. For this reason 90% rather than 95% or 98% significance is recommended (this means smaller effects will be judged significant).

A good description of Plackett and Burman designs and applications is given by Stowe and Mayer (1966). An example of the application of a 12 run design for process improvement is given in Section 7.4.

### 7.2.2 Factorial Experiments

In the discussion of factorial experiments we will be restricted to 2 level experiments - that is where the input variables are considered at a high and a low level.

In a full 2 level factorial experiment all combinations of the input variables are run at both the high and low levels. Therefore, for 3 factors a total number of  $2^3$  or 8 experimental runs are required. These would be as shown in Table 7.1.

Table 7.1 Factorial design for a 3 factor, 2 level experiment

Experiment	Treatment Code	Variable A	Variable B	Variable C
1	1	low (-)	low (-)	low (-)
2	a	high (+)	low (-)	low (-)
3	b	low (-)	high (+)	low (-)
4	ab	high (+)	high (+)	low (-)
5	c	low (-)	low (-)	high (+)
6	ac	high (+)	low (-)	high (+)
7	bc	low (-)	high (+)	high (+)
8	abc	high (+)	high (+)	high (+)

The treatment codes shown in Table 7.1 are commonly used in experimental design. The presence of a lower case letter in the treatment code indicates that the corresponding variable is at the high level for that run whilst all others are at the low level. For example, in run 2 the treatment code is a indicating that variable A is at the high level and the other two variables are at the low level.

#### Analysis of factorial experiments

The results of factorial experiments can be quickly and simply calculated by hand using Yates' method. This method applied to a two-factor experiment is as follows: We write down the treatments (1) a, b, ab in column form as shown in Table 7.2. Alongside these we put the actual responses obtained for each treatment. We then proceed to carry out a simple mathematical exercise by adding the first two figures in the second column and placing them at the top of the third column. Then add the next two figures and place them beneath the first figure in the third column. Then subtract the top result in the second column from the second result in the second column and place the answer in the third place in the third column, and finally, we subtract the third result in the second column from the last result and put the answer at the end of the third column. This process is repeated for a further column.

Table 7.2 An example of Yates' Analysis

Treatment code	Result	3rd column	4th column	Effect ( $\beta_j$ )
(1)	1	1+4=5	5+7=12	3.0
a	4	2+5=7	3+3=6	1.5
b	2	4-1=3	7-5=2	0.5
ab	5	5-2=3	3-3=0	0.0

The effects of each treatment code are calculated by dividing the 4th column by 4. This gives the  $\beta_i$  values which can be used in predictive equations (see Section 7.5).

The significance of these effects should be tested by relating their levels to the experimental error. The experimental error will normally be calculated from repeat runs of the same treatment. The standard error can then be calculated from the variance in results. Section 7.5 fully describes the application and analysis of a full factorial experiment for process improvement.

This discussion and the case study in Section 7.5 describes only the simplest of factorial design. All books on Experimental Design will cover the more complex designs including more variables and/or higher levels. In addition to these full factorial designs one should be aware of the use of fractional factorial designs. These enable the experimenter to obtain a more limited range of information by reducing the number of experimental runs (see Duckworth, 1968, chapter 4).

### 7.2.3 EVOP (Evolutionary Operations)

EVOP is a form of experimentation which is used right on the production line. For this reason, EVOP is considered to be a tool of quality control rather than of research and development. The experimental design is relatively simple and the statistics used are readily understood by production personnel. EVOP will not answer all of the problems in the optimisation of a product or process, but it is a powerful tool to be used by quality control personnel to improve the current operation and to strive towards the optimum.

Most importantly EVOP is a simple and effective procedure for ongoing product and process improvement. It calls for the continuous probing for a change that brings improvement in product quality or process efficiency.

A full discussion of application of EVOP is given by Fox (1968).

### 7.2.4 Mixture Designs

Factorial designs are usually unsuitable for the development of food products involving more than one ingredient. In mixture experimentation it is impossible to vary one ingredient or component while holding all others constant. As soon as the proportion of one component is altered so is that of at least one other component altered, since the sum of all components is always 1.0. To cope with this situation a set of experimental plans, called mixture designs, has been developed.

In mixture designs the sum of the variables must always be 1.0 or 100%. Experimentation is subject to the constraint

$$\sum_{i=1}^q X_i = 1.0$$

where  $q$  is the number of components in the mixture. This constraint is not applicable in the study of independent variables. Figure 7.1 shows a graphical representation of independent and mixture spaces for two and three variables. The two-variable mixture space is limited to the line  $X_1 + X_2 = 1$ , and the three-variable mixture space is limited to the plane  $X_1 + X_2 + X_3 = 1$ .

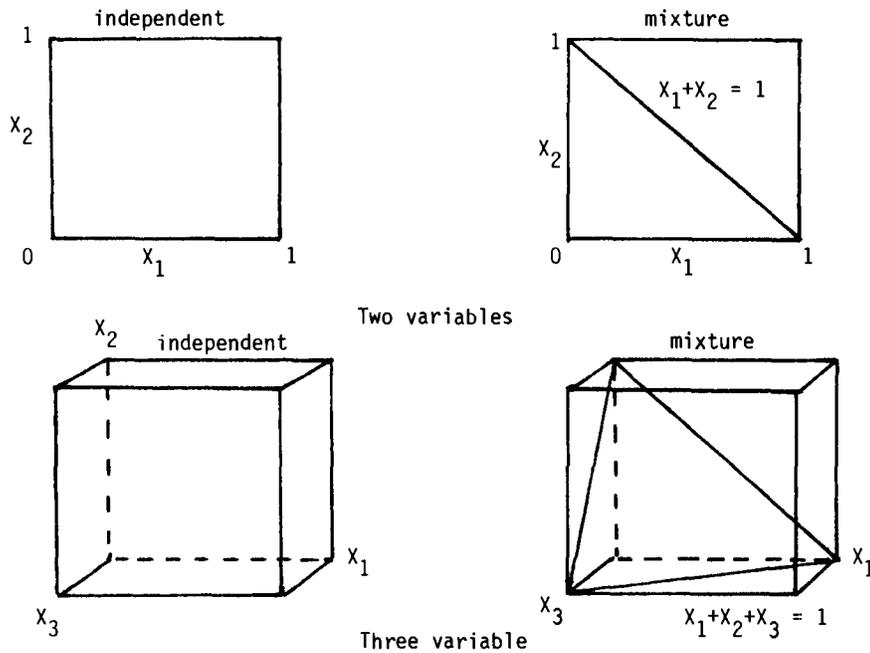


Figure 7.1 Independent and Mixture Spaces

The two-factor mixture space is therefore represented by a line, the three factor mixture space by an equilateral triangle and the four factor mixture space by a solid pyramid. Higher level mixture spaces become difficult to visualise.

Figure 7.2 shows the mixture space for three variables A, B and C. Any combination of these three variables can be represented within this triangle. The level of each ingredient is measured as the perpendicular distance from its axis.

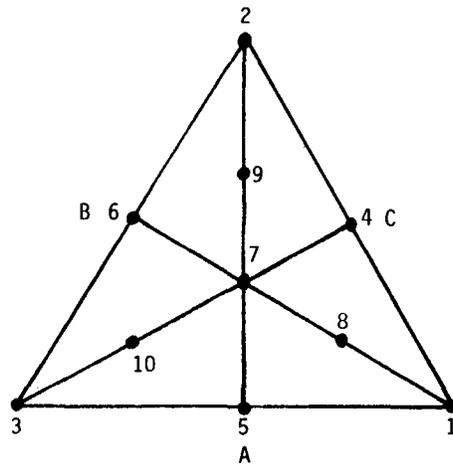


Figure 7.2 Three variable mixture space

A full and balanced representation of the potential mixture of the three variables can be obtained by taking mixtures at the vertices (points 1, 2 and 3); at the midpoints of each axis (4, 5 and 6); at the centre point (7) and at the midpoints from the central point to each vertex (8, 9 and 10). The resultant mixture design is shown in Table 7.3.

Table 7.3 Ten-run mixture design for three components

Run No.	A	B	C
1	1	0	0
2	0	1	0
3	0	0	1
4	$\frac{1}{2}$	$\frac{1}{2}$	0
5	$\frac{1}{2}$	0	$\frac{1}{2}$
6	0	$\frac{1}{2}$	$\frac{1}{2}$
7	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
8	$\frac{2}{3}$	$\frac{1}{6}$	$\frac{1}{6}$
9	$\frac{1}{6}$	$\frac{2}{3}$	$\frac{1}{6}$
10	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{2}{3}$

Fewer runs may be carried out if the experimenter is willing to accept less information about his mixture system.

The results of mixture designs can be subjected to rigorous analysis to obtain mathematical models relating the ingredient levels to some response variable. A full discussion of this procedure is presented by Hare (1974). Rigorous mathematical analysis is not always necessary, however, and one of the advantages of mixture designs is the relative ease of making subjective judgements for product improvement from a visual appraisal of the responses throughout the mixture space. This does become rather difficult, of course, when the number of ingredients exceeds four.

An example of the subjective application of mixture designs is presented in Section 7.6.

### 7.3 References

- DUCKWORTH W.E. (1968) Statistical techniques in technological research. Methuen, London.
- FOX Major M. (1968) EVOP: Tool for in-plant research. Food Technology, Vol. 22, 293. p.45, 1968.
- HARE L.B. (1974) Mixture designs applied to food formulation. Food Technology, March 1974, p.51.
- LIPSON C. and N.J. SHETH (1973) Statistical Design and Analysis of Engineering Experiments. McGraw-Hill Inc.
- STOWE R.A. and R.P. MAYER (1966) Efficient screening of process variables. Industrial and Engineering Chemistry, Vol. 58, No. 2, p.36.

### 7.4 Example of a screening experiment

#### 7.4.1 Problem Definition

A dried food manufacturer has been investigating the potential for a new high nutritional, dried drink base. The formulation of the product has been finalised and the company now wishes to define the optimum processing conditions for the product which is to be roller dried.

#### 7.4.2 Objective

To define the optimum processing conditions for roller drying the new drink base.

#### 7.4.3 Experimental Variables

##### Response variables

The following response variables were considered important to the product:

- a. Moisture content of dried product
- b. Viscosity of prepared drink
- c. Sediment in prepared drink after a prespecified time
- d. Acceptability of drink to consumers

#### Input Variables

Seven variables were defined as important to the process. Upper and lower limits for these variables are shown in Table 7.4.

Table 7.4 Variables and limits for roller drying

Variable	Upper limit	Lower limit
A. Water/solids	2.0	1.5
B. Soak time <sup>(1)</sup>	75 minutes	30 minutes
C. Soak temperature	65°C	15°C
D. Steam pressure	350 kPa	230 kPa
E. Nip height <sup>(2)</sup>	4 cm	2 cm
F. Nip gap <sup>(3)</sup>	35 mm	20 mm
G. Drum speed	2.8 rpm	1.4 rpm

- (1) Soak time - time of soaking dry mix prior to drying  
 (2) Nip height - depth of slurry between rolls  
 (3) Nip gap - distance between rolls at closest point.

#### Experimental Design

Seven variables were too many to consider in a full or even a fractional factorial experiment. A Plackett and Burman screening experiment was therefore planned to define the important process variables. A 12 run experiment was planned with the 7 process variables and 4 dummy variables to estimate experimental error (see Table 7.5).

Table 7.5 Plackett and Burman design for roller drying

Run No.	A	B	C	D	E	F	G	H	I	J	K
1	+	+	-	+	+	+	-	-	-	+	-
2	+	-	+	+	+	-	-	-	+	-	+
3	-	+	+	+	-	-	-	+	-	+	+
4	+	+	+	-	-	-	+	-	+	+	-
5	+	+	-	-	-	+	-	+	+	-	+
6	+	-	-	-	+	-	+	+	-	+	+
7	-	-	-	+	-	+	+	-	+	+	+
8	-	-	+	-	+	+	-	+	+	+	-
9	-	+	-	+	+	-	+	+	+	-	-
10	+	-	+	+	-	+	+	+	-	-	-
11	-	+	+	-	+	+	+	-	-	-	+
12	-	-	-	-	-	-	-	-	-	-	-

Note: Variables A to G are defined in Table 7-4. Variables H, I, J and K represent dummy variables.

An attempt was made, as far as possible, to randomise the runs. It was, however, considered important to run all common nip gap runs consecutively to avoid error due to resetting of the rolls.

#### 7.4.4 Analysis

The results of the experiment are shown in Table 7.6.

Table 7.6 Results of Plackett and Burman Experiment

Run No.	Moisture percent	Viscosity cps	% Sedimentation (a)	Sensory (b) Score
1	2.32	15.0	64	5.8
2	1.65	29.0	88	5.0
3	2.02	10.5	54	7.0
4	3.30	20.0	59	7.0
5	3.57	16.5	78	5.3
6	3.25	31.0	83	5.0
7	2.94	26.0	58	6.5
8	4.27	12.5	38	6.8
9	2.22	32.5	74	6.4
10	5.93	27.5	69	5.5
11	5.69	16.0	41	5.5
12	2.18	37.5	66	6.2

(a) Sedimentation % - defined as completeness of particle distribution (i.e. 100% = complete distribution)

(b) Sensory score - average acceptable score on a 10 point scale (5 people).

#### 7.4.5 Calculation of Effects and Error

Effects of the variables A to G and the four dummies H to K were calculated as follows:

$$E_A = \frac{R \text{ at } (+)}{6} - \frac{R \text{ at } (-)}{6}$$

where  $E_A$  = effect of A and R = response or result.

Effects for the four response variables moisture, viscosity, sedimentation and sensory score are shown in Tables 7.7 and 7.8.

The dummy effects were combined to estimate the variance of an effect.

$$V_{\text{eff}} = \frac{\sum(E_d)^2}{n}$$

where  $V_{\text{eff}}$  = variance of an effect,  $E_d$  = effect of dummy and  $n$  = number of dummy variables.

The standard error of an effect was calculated as

$$\text{S.E.}_{\text{eff}} = \sqrt{V_{\text{eff}}}$$

The significance of each effect was determined by using the t-test.

$$t = \frac{\text{effect}}{\text{S.E.}_{\text{eff}}}$$

Tests of significance are shown in Tables 7.7 and 7.8.

Table 7.7 Variables and effects - Moisture and Viscosity

<u>Code</u>	<u>Moisture</u>		<u>Viscosity</u>	
	<u>Effect</u>	<u>t-test</u>	<u>Effect</u>	<u>t-test</u>
A	0.117	0.24	0.667	0.17
B	-0.183	-0.38	-8.883	-2.18 (90%)
C	1.063	2.22 (90%)	-7.167	-1.77 (85%)
D	-0.863	-1.80 (85%)	1.167	0.29
E	-0.090	-0.19	-0.333	-0.08
F	1.687	3.52 (95%)	-7.833	-1.93 (85%)
G	1.220	2.55 (90%)	5.333	1.32 (75%)
H	0.530	1.11 (70%)	-2.167	0.54
I	-0.573	1.19 (70%)	-0.167	0.04
J	0.523	1.09	-7.333	-1.81 (85%)
K	0.183	0.33	-2.667	-0.66

Table 7.8 Variables and effects - Sediment and Sensory Score

<u>Code</u>	<u>Sediment</u>		<u>Sensory Score</u>	
	<u>Effect</u>	<u>t-test</u>	<u>Effect</u>	<u>t-test</u>
A	18.33	3.01 (95%)	-0.800	-1.67 (80%)
B	- 5.33	0.88	0.333	0.69
C	-12.33	-2.03 (85%)	0.267	0.56
D	7.00	1.15 (70%)	0.067	0.14
E	0.67	0.11	-0.500	-1.04
F	-12.67	-2.08 (85%)	-0.200	-0.42
G	- 0.67	-0.11	-0.033	-0.07
H	3.33	0.55	0	0
I	3.00	0.49	0.333	0.69
J	-10.00	-1.65 (80%)	0.700	1.46 (75%)
K	- 5.33	-0.88	-0.567	-1.18 (70%)

7.4.6 Discussion of Results

A summary of the significant effects (above 80%) are shown in Table 7.9.

Table 7.9 Summary of significant effects

<u>Response variable</u>	<u>Significant effects</u>
Moisture	soak temp., steam pressure, nip gap, drum speed
Viscosity	soak time, soak temp., nip gap
Sediment	water/solids, soak temp., nip gap
Sensory score	water/solids

The results indicate that specific variables are important in determining the different response variables.

In considering the variables to be evaluated in a further experiment, priorities were set on the four response variables. These were as follows:

- 1 Moisture
- 2 Viscosity
- 3 Sediment
- 4 Sensory score

Sensory score was ranked last because most of the drinks were acceptable and there were only minor differences in overall acceptability between samples.

It was decided to run a 3-variable full factorial experiment in an attempt to further optimise the process conditions. The variables chosen were

Nip gap  
Soak time  
Drum speed

Soak temperature was set at ambient because it was considered too difficult to maintain high temperature soak conditions within the factory. There may also be problems with microbial spoilage. This step is contrary to that suggested by the experimental results which indicated an inverse relationship between the response variables viscosity and sediment and the soak temperature. If a satisfactory product cannot be obtained at ambient temperature soaking then consideration of higher temperature soaking will be made at a later stage.

Water/solids ratio was set at the high level as suggested by the high positive relationship between the water/solids ratio and sedimentation, i.e. a better dispersion was obtained as a result of a high water/solids ratio feed to the roller drier.

Steam pressure was the fourth variable in order of importance to effect moisture. As this was the only response variable that it affected, it was decided to set steam pressure at the low level - consistent with giving a high moisture which is desirable for the product.

#### 7.4.7 Conclusion

The Plackett and Burman screening experiment indicated that 6 of the 7 original process variables had some effect on one or more of the response variables. The results of the experiment were used to select 3 of these 6 process variables for further experimental evaluation and to set the levels of the remaining 3 variables for that experiment.

### 7.5 Example of a factorial experiment

#### 7.5.1 Introduction

The Department of Agricultural Products at Khon Kaen University, supported by the International Development Research Centre (IDRC), is studying the introduction of cowpeas into the diet of the villagers of Northeast Thailand.

Although cowpeas are consumed at present in the villages they are usually in the form of the immature pod. Very little use is made of the mature seeds which contain a high level of protein, approximately 25 percent, are high yielding and relatively inexpensive. The Department of Agricultural Products has developed a number of recipes utilising the mature cowpea. These recipes are all

closely allied to dishes which are already consumed in the villages. In most recipes the cowpeas are used in the dehulled form or as a flour.

A preliminary study by Pisanu Vichiensanth showed that none of the traditional dehulling machines available in Thailand was suitable for dehulling cowpeas. A dehulling machine was shipped from IDRC in Canada and this report studies its processing characteristics using one variety of cowpea - Red Cowpea 6-IUS. This variety has proven to be particularly suitable for growing in the Northeast.

#### 7.5.2 The dehulling process

The IDRC machine is a laboratory model fitted with eight abrasive discs, each 25 cm in diameter. These discs are driven by a variable speed electric motor.

Dehulling takes place through the abrasive action of the rotating discs on the seed coat. It should be noted that the discs are not selective for the seed coat only and there is considerable cotyledon loss during prolonged processing. Flour was produced from the dehulled cowpeas using a small pin mill with a screen containing holes of 0.035 inch in diameter.

#### 7.5.3 Experimental Design

Evaluation of the characteristics of the dehuller was carried out using a full factorial experimental design with three variables at two levels.

<u>Variable</u>	<u>Lower Level</u>	<u>Upper Level</u>
Time (minutes)	2	10
Batch size (kg)	1.5	2.5
Speed (r.p.m.)	600	1400

When the dehuller was loaded with cowpeas there was some reduction in rotational speed. This reduction was dependent on the weight of the load. The rotational speeds used in the experiment were those under load, not free run.

The complete experimental design is shown in Table 7.10. After each run the percent yield and the percentage hull remaining in the dehulled cowpeas were measured. The loss of cotyledon in the waste fraction was calculated.

Table 7.10 The factorial experimental design

<u>Run</u>	<u>Time (mins.)</u>	<u>Batch (kg)</u>	<u>Speed (rpm)</u>
1	2	1½	600
a	10	1½	600
b	2	2½	600
ab	10	2½	600
c	2	1½	1400
ac	10	1½	1400
bc	2	2½	1400
abc	10	2½	1400

Measurement of Percent Yield

The weight of cowpeas retained on a  $\frac{1}{8}$  inch screen was recorded as a percentage of the initial weight before dehulling.

Measurement of Percent Hull Remaining

Whole cowpeas (100% hull) were combined with totally dehulled cowpeas (0% hull) in specific proportion to give 7 samples of standard hull content. Standard flours were prepared from the 7 samples. The proportions of whole and totally dehulled cowpeas and the resultant percentage of hull remaining in the standard flours are shown in Table 7.11.

Table 7.11 The preparation of Standard Cowpea Flours

<u>Percent whole cowpeas (100% hull)</u>	<u>Percent dehulled cowpeas (0% hull)</u>	<u>Percent original hull in flour</u>
100	0	100
85	15	85
70	30	70
50	50	50
30	70	30
15	85	15
0	100	0

A 30-g sample of each standard flour was made to a paste by addition of 45 ml of water. The pastes were allowed to stand for 15 minutes to achieve constant mixing, water absorption and leaching of colour from any remaining hull. The absorbance of the 100% and 0% standard flour pastes was measured at wavelengths from 400 nm to

650 nm using a Spectronic 20 and reflectance attachment. The most sensitive wavelength was 550 nm (see Figure 7.3).

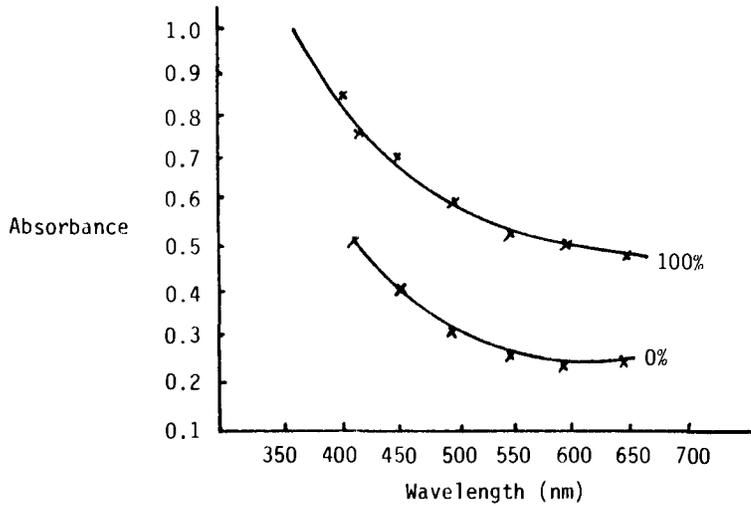


Figure 7.3 Calibration Curve - Absorbance vs Wavelength

The absorbance of each standard flour paste was measured at 550 nm. A standard curve of absorbance against percent hull remaining in the flour is shown in Figure 7.4.

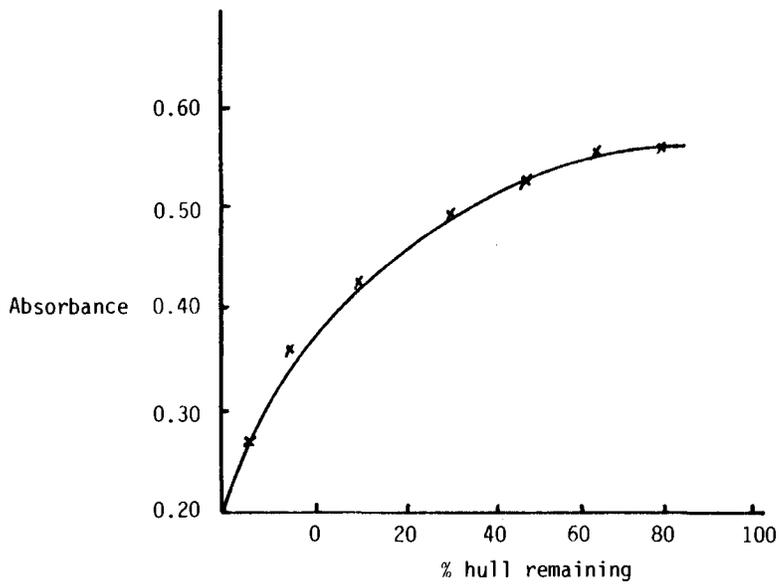


Figure 7.4 Standard Curve - Percent Hull Remaining vs Absorbance

The standard curve was not entirely suitable, especially in the 70-100% hull range. Some improvement in this curve might be achieved by reducing the screen mesh size of the pin mill to 0.015-0.020 inch. This should result in a more complete breakdown of the hull fraction and therefore a more even distribution of hull throughout the flour.

Flour was prepared from each of the eight experimental runs and the absorbance of the flour pastes was measured. The percent hull remaining in each sample was derived from the standard curve.

#### Calculation of Cotyledon loss

Previous studies in the Department of Agricultural Products showed that the seed coat of red cowpea 6-IUS is approximately 14% of the total seed weight.

The expected yield, given no cotyledon loss, was calculated as:

$$\text{Expected Yield}(E_y) = 100 - 14 \times H$$

where  $H$  is the fraction of hull removed. The percentage loss of cotyledon was then calculated as:

$$\text{Percent loss of cotyledon} = \frac{E_y - A_y}{E_y}$$

where  $A_y$  is the actual recorded yield.

#### 7.5.4 Results

Results from the experiment are shown in Table 7.12.

The results for percent yield, percent hull remaining and percent cotyledon lost were analysed by Yates analysis (see Section 7.5.6).

Table 7.12 Results of the full factorial experiment

Run	Percent yield	Percent hull remaining	Percent cotyledon lost
1	95.8	82	2
a	81.9	41	11
b	97.9	81	0
ab	85.1	48	8
c	83.5	35	8
ac	62.7	14	29
bc	89.1	52	5
abc	61.9	7	29

Predictive equations were derived for each factor (see Section 7.5.6).

1. Percent Yield =  $107.1 - 0.83 \times \text{Time} - 0.0108 \times \text{Speed}$   
 $- 0.0015 \times \text{Time} \times \text{Speed}$
2. Percent hull remaining =  $116.3 - 4.4 \times \text{Time} - 0.045 \times \text{Speed}$
3. Percent cotyledon lost =  $-2.63 - 0.25 \times \text{Time} + 0.0019 \times \text{Speed}$   
 $+ 0.0022 \times \text{Time} \times \text{Speed}$

#### 7.5.5 Discussion of Results

The predictive equations may be used to estimate the percent yield, percent hull remaining on the seed, and the percent loss of cotyledon at specific speeds of rotation and processing times. Batch size was not significant within the range tested. It is expected, however, that at very high batch sizes, for example 5 kg, there will be a reduction in processing efficiency due to the limiting of movement of the seeds and therefore the reduction in time that each seed is in contact with the abrasive discs.

Cooking trials indicated that flour with a hull content of 30 percent remaining was acceptable. The processing trials indicated that there is no real advantage in using slower speeds to improve the quality of the dehulled seed. There is, however, an advantage in reducing the time required for processing by using higher speeds. Also at higher speeds there is a reduction in the cotyledon loss. Table 7.13 shows the predicted time required to achieve a 70 percent removal of hull (i.e. 30 percent hull remaining) at speeds of 1400, 1500, 1600 and 1700 rpm and the resultant loss of cotyledon. There may be some error in the predictions because they were made outside the range of speeds used in the experiment.

Table 7.13 Predicted Cotyledon loss at various speeds

Speed (rpm)	Time (mins)	Batch size (kg)	Percent hull remaining	Percent Cotyledon loss
1400	5	2½	30	14.2
1500	4	2½	30	12.4
1600	3	2½	30	10.2
1700	2	2½	30	7.6

Although there are definite advantages in reducing the processing time, it is suggested that this should not be too low. At very low processing times the recording of this time will become extremely critical and any small extension over the required time will result in a significant increase in cotyledon loss.

It is therefore recommended that for red cowpea 6-IUS a speed of 1600 rpm be used for 3 minutes. Under these conditions 70 percent of the hull should be removed with a loss of approximately 10 percent of the cotyledon.

#### 7.5.6 Appendix of analyses

##### Yates Analysis for Percentage Hull Remaining

	Percent Hull	1st Col.	2nd Col.	3rd Col.	Mean Effect	t = Effect/0.69
1	82	123	252	360	45.0	65.2
a	41	129	108	-140	-17.5	-25.4**
b	81	49	-74	16	2.0	2.9
ab	48	59	-66	-16	-2.0	-2.9
c	35	-41	6	-144	-18.0	-26.1**
ac	14	-33	10	8	1.0	1.5
bc	52	-21	8	4	0.5	0.72
abc	7	-45	-24	-32	-4.0	-5.8

Standard error of repeat runs = 0.69

$$\alpha_{0.01} = 4.54$$

Only the two main effects time and speed are significant at the 99.9% level.

The predictive equation is:

$$Y = 45.0 - 17.5X_1 - 18.0X_3$$

where  $X_1$  = Time and  $X_3$  = Speed (coded units)

The uncoded predictive equation is:

$$\text{Percent hull} = 116.3 - 4.4X_1 - 0.045X_3$$

Yates Analysis for Percentage Yield

	Percent Yield	1st Col.	2nd Col.	3rd Col.	Mean Effect	t = Effect/0.55
1	95.8	177.7	360.7	657.9	82.2	149.5
a	81.9	183.0	297.2	-74.7	-9.3	-17.0**
b	97.9	146.2	-26.7	10.1	1.3	2.3
ab	85.1	151.0	-48.0	-5.3	-0.66	-1.2
c	83.5	-13.9	5.3	-63.5	-7.9	-14.4**
ac	62.7	-12.8	4.8	-21.3	-2.7	-4.9**
bc	89.1	-20.8	1.1	-0.5	-0.06	-0.11
abc	61.9	-27.2	-6.4	-7.5	-0.47	-0.85

Standard error of repeat runs = 0.55.

The predictive equation is:

$$Y = 82.2 - 9.3X_1 - 7.9X_3 - 2.7X_1X_3$$

where  $X_1$  = Time and  $X_3$  = Speed (coded units).

The uncoded equation is:

$$\text{Percent Yield} = 107.1 - 0.83X_1 - 0.0108X_3 - 0.0015X_1X_3$$

Yates Analysis for Percentage Endosperm in Waste Fraction

	Percent endosperm	Col. 1	Col. 2	Col. 3	Mean Effect	t = Effect/0.55
1	2	13	21	92	11.5	20.9
a	11	8	71	62	7.8	14.1**
b	0	37	17	-8	-1.0	-1.8
ab	8	34	45	2	0.25	0.45
c	8	9	-5	50	6.3	11.4**
ac	29	8	-3	28	3.5	6.4**
bc	5	21	-1	2	0.25	0.45
abc	9	24	3	4	0.5	0.91

Standard error of repeat runs = 0.55.

A	total rank = 29	coded notes	hi.T, Lo.S, Lo.F
B	total rank = 31		hi.T, Lo.S, hi.F
C	total rank = 30		Lo.T, hi.S, hi.F
D	total rank = 45		Lo.T, hi.S, Lo.F
E	total rank = 45		median

hi = high, Lo = low

#### 7.6.4 Study of effects

The effects of each of the 3 ingredients was evaluated by comparing the total ranks at the high and low levels of each ingredient.

##### Tapioca effect

high amount tapioca	low amount tapioca
score	score
$29 + 31 = 60$	$30 + 45 = 75$

∴ high amount of tapioca was preferred (positive effect).

##### Soya flour effect

high amount of soy	low amount of soy
score	score
$30 + 45 = 75$	$29 + 31 = 60$

∴ lower amount of soy flour preferred (negative effect).

##### Fish effect

high amount of fish	low amount of fish
score	score
$30 + 31 = 61$	$29 + 45 = 74$

∴ high amount of fish was preferred (positive effect).

This simple analysis shows that an excess of the 'beany' or 'nutty' flavour resulting from high soya levels was not well accepted. A high proportion of soya is required, however, to give a high protein content in the snack food. Formulae A, B and C gave similar acceptability ranks, indicating an interaction between the fish and soya tastes. Increasing the proportion of fish tends to offset the soya taste. Figure 7.6 shows the overall direction of acceptance for the mixture.

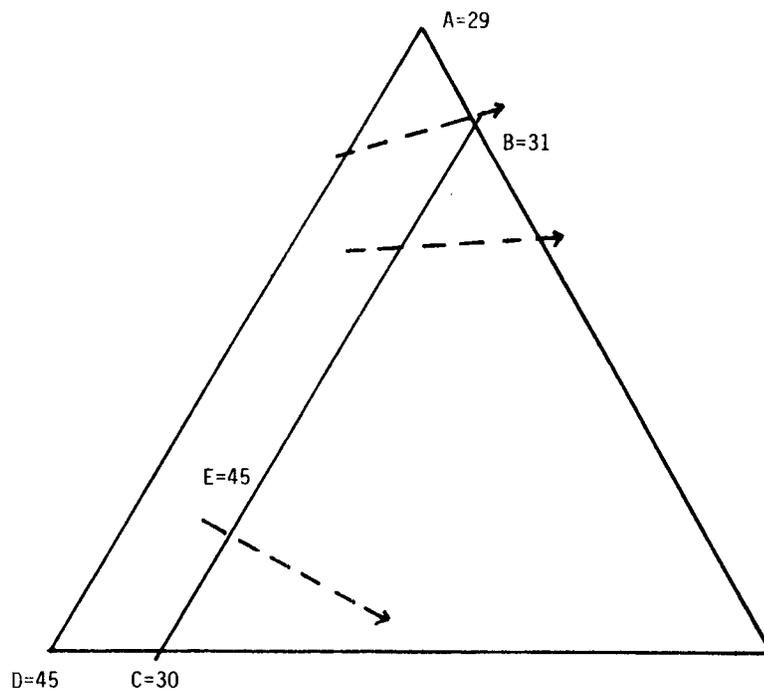


Figure 7.6 Direction of acceptance for the mixture design

#### 7.6.5 New area for experimentation

A further design was planned in the direction of acceptance shown in Figure 7.6. The new area in the mixture space was selected to preserve a high level of soya but at the same time to increase the level of fish. The new area of investigation is shown relative to the initial area of experimentation in Figure 7.7.

The predictive equation is:

$$Y = 11.5 + 7.8X_1 + 6.3X_3 + 3.5X_1X_3$$

where  $X_1$  = Time and  $X_3$  = Speed (coded units).

The uncoded equation is:

$$\text{Percent endosperm lost} = -2.63 - 0.25X_1 + 0.0019X_3 + 0.0022X_1X_3$$

## 7.6 Example of a Mixture Experiment

### 7.6.1 Problem definition

A new puffed snack food utilising a high percentage of tapioca is to be designed for the Malaysian market. Preliminary formulation trials indicate that the snack food should contain soya flour, tapioca flour, fish, water, MSG, salt and phosphate. A high protein snack food with a high level of consumer acceptance is required.

### 7.6.2 Aim of experimental formulation

To select a combination of ingredients and define their respective levels so as to produce an acceptable, high protein snack food.

### 7.6.3 The mixture design

This experiment was planned to optimise the protein without lowering the acceptability of the puff. Salt content, phosphate, monosodium glutamate (MSG) and water were held constant, while the tapioca, fish and soy content were the components subjected to the study.

Requirements:	tapioca (T)	50 - 80%
	fish (F)	5 - 10%
	soy (S)	20 - 45%

(expressed in the % of mix T + F + S).

Figure 7.5 shows the complete space available for the mixture design. The limits on the three ingredients, given above, restrict the area of experimentation to the shaded feasible region.

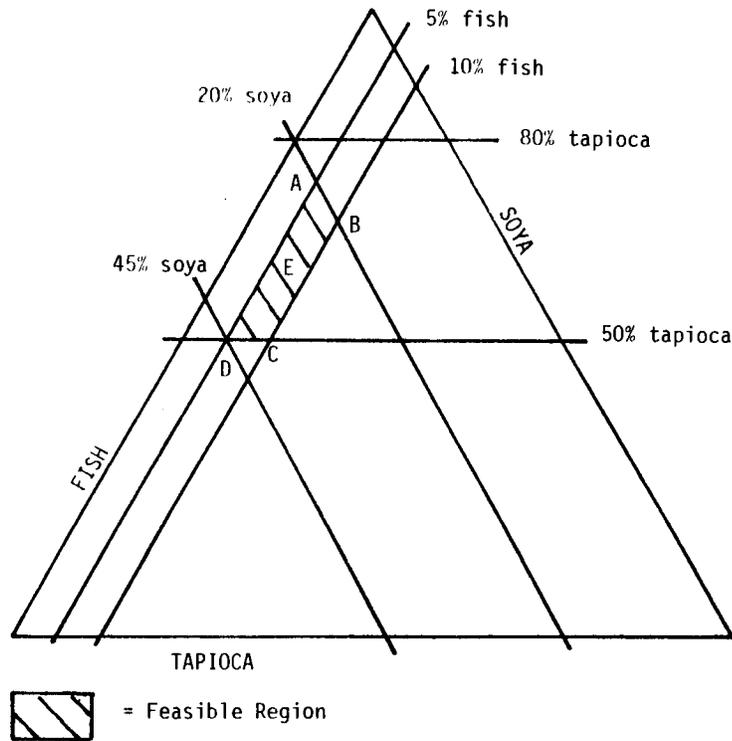


Figure 7.5 Complete mixture space showing feasible area for experimentation

Vertices suitable for experiments are:

- A = 75T, 20S, 5F
- B = 70T, 20S, 10F
- C = 50T, 40S, 10F
- D = 50T, 45S, 5F
- E = 62T, 31S, 7F,    centre point

Batch sizes of T + S + F = 200g were prepared as follows:

150T + 40S + 10F )				
140T + 40S + 20F )				
100T + 80S + 20F )	Water	MSG	Salt	Phosphate*
100T + 90S + 10F )	+ 143 ml	+ 3.2 g	+ 6.3 g	+ 1.5 g
124T + 62S + 14F )				

A panel of 12 Malaysians were asked to rank the 5 snack foods in order of preference giving a rank of 1 to the best and 5 to the worst. Total ranks from the 12 respondents are given below:

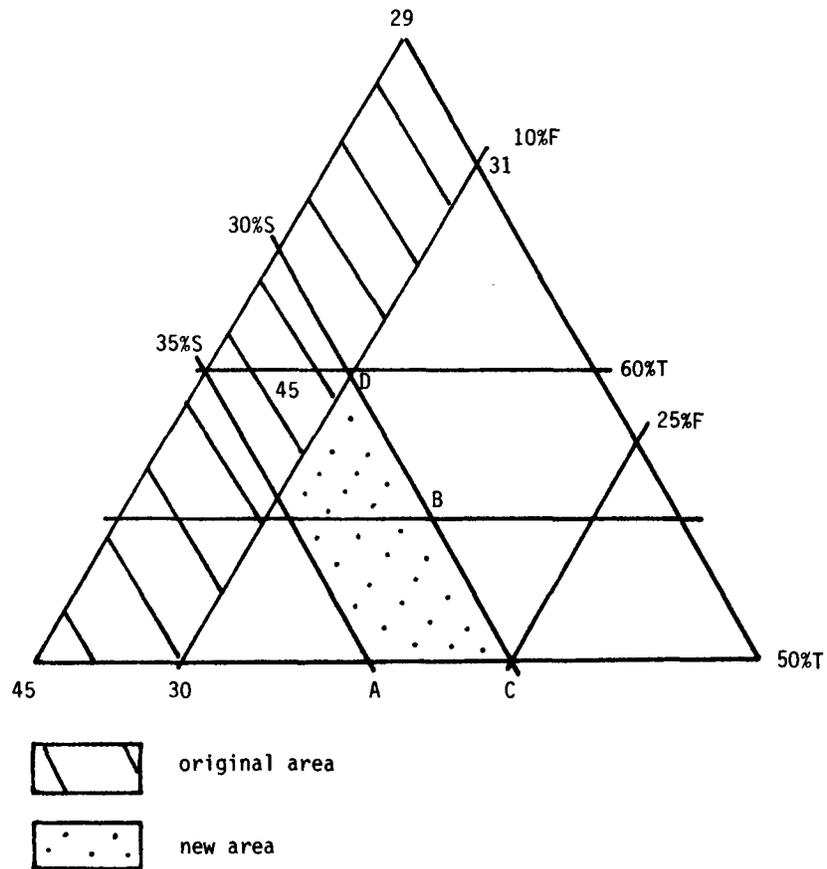


Figure 7.7 Mixture space showing original and new areas of experiment

The 4 points A, B, C and D in Figure 7.7 represent the vertices of the new area for experimentation.

A: 50T + 15F + 35S

B: 55T + 15F + 30S

C: 50T + 20F + 30S

D: 60T + 10F + 30S

The full recipes were as follows:

100 g.T + 30 g.F + 70 g.S )				
110 g.T + 30 g.F + 60 g.S )	143 ml	3.2 g	6.3 g	1.5 g
100 g.T + 40 g.F + 60 g.S )	+ Water	+ MSG	+ salt	+ phosphate
120 g.T + 20 g.F + 60 g.S )				

A panel of 17 Malaysians rank the four products in order of preference. The total ranks were as follows:

A	total rank	48
B	total rank	27
C	total rank	32
D	total rank	33

#### 7.6.6 Conclusion

Mixture B gave the most preferred product. This mixture was chosen for further pilot plant and process development.

32.0%	tapioca flour
8.4%	fish
16.9%	soya flour
40.3%	water
1.0%	MSG
1.8%	salt
0.6%	phosphate

This mixture fulfilled the aim of the experimental formulation. It utilises a large amount of tapioca, it is high in protein and it is acceptable to the consumer.

## **PART 3**

### **CASE STUDIES**

## CONTENTS

	<u>Page</u>
8. Case Studies from the Thai workshop	164
8.1 Mung bean noodle plant	164
8.1.1 Overview of company	164
8.1.2 Process flow chart	165
8.1.3 Identification of key operations	168
8.1.4 Improvements to key operations	169
8.1.5 Screening of possible improvements	169
8.1.6 Selection of process improvement strategy	170
8.1.7 Operations research and experimental design	170
8.2 Fermented and dried fruit plant	172
8.2.1 Overview of company	172
8.2.2 Process flow chart	172
8.2.3 Identification of key operations	174
8.2.4 Improvements to key operations	174
8.2.5 Screening of possible improvements	174
8.2.6 Selection of process improvement strategy	175
8.2.7 Operations research and experimental design	175

## 8. CASE STUDIES FROM THE THAI WORKSHOP

During the workshop in Bangkok, four factories were visited. Two of these factories have been chosen as case studies to demonstrate the potential for application of the process improvement techniques discussed in this manual.

The factories are a mung bean noodle plant and a dried fermented fruit manufacturer. The following approaches were applied in each case:

1. Presentation of a brief overview of the company.
2. Study of the process and presentation of a complete process flow chart.
3. Identification of key operations.
4. Suggestions for changes to the key operations.
5. Screening of potential changes.
6. Selection of process improvement strategies.
7. Decision on operations research or experimental design techniques which may be applicable to the selected process improvement strategies.

The limited time available during a 10 day workshop did not allow for a detailed study of Steps 5, 6 and 7. The case studies do, however, demonstrate what can be achieved in a relatively short time and point the direction for future research.

### 8.1 Mung bean noodle plant

#### 8.1.1 Overview of company

Location - 40 km southwest of Bangkok.

Products - Bean noodles - grade A (pure mung bean starch)  
- grade B (blend of bean starches)

Raw Materials - Mung bean, and possibly other starch sources.

Staff - 1 Managing Director  
1 Deputy Managing Director  
2 Plant Managers  
5 Plant Department Managers  
150 Labourers

Throughput - 5 - 6 tonnes noodles per day

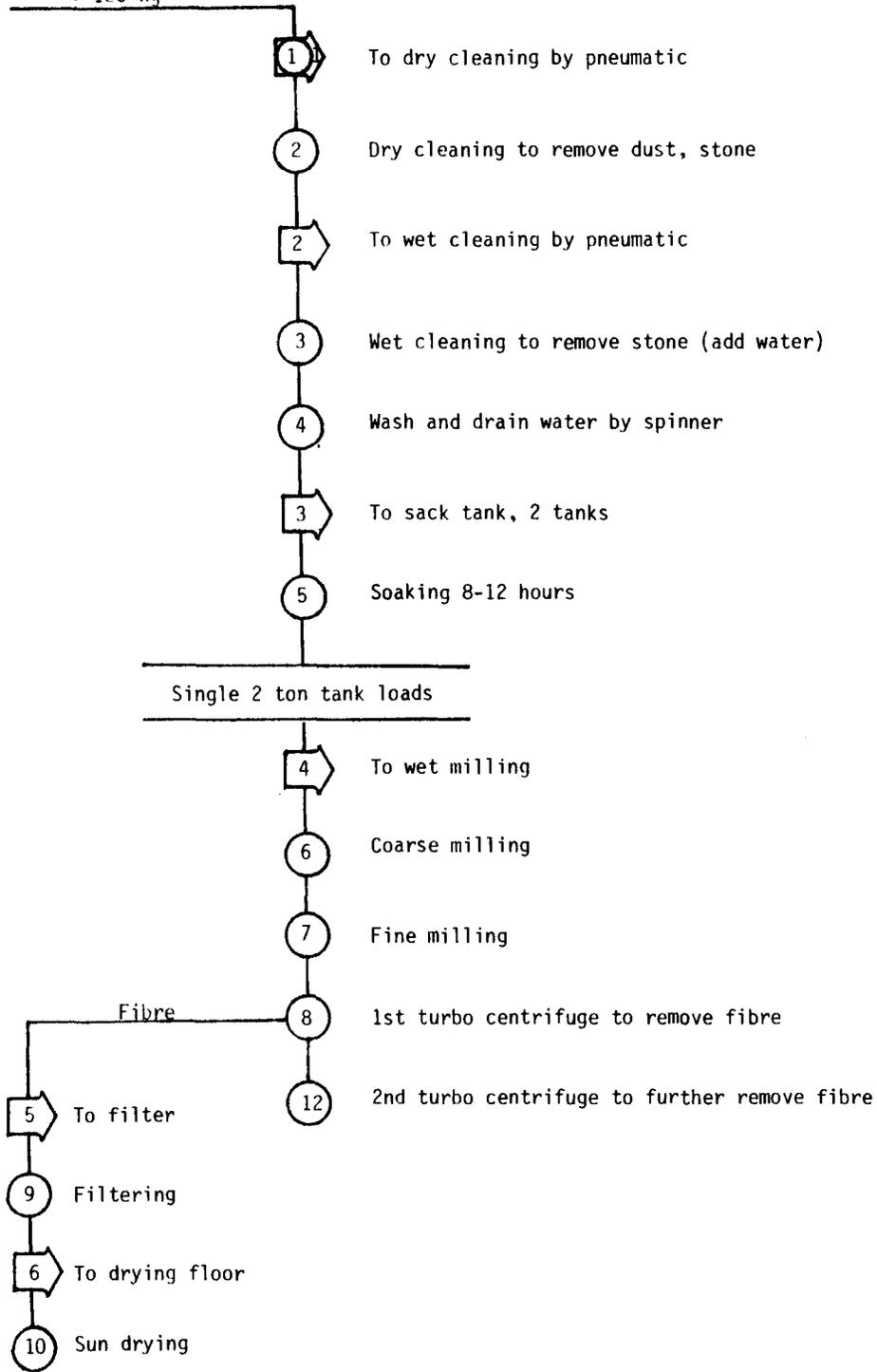
Quality Control - Staff - 1 chemist and 1 technician.  
Analyses - moisture, texture and size.

Product Price - Grade A, 50 baht/kg  
Grade B, 35 baht/kg

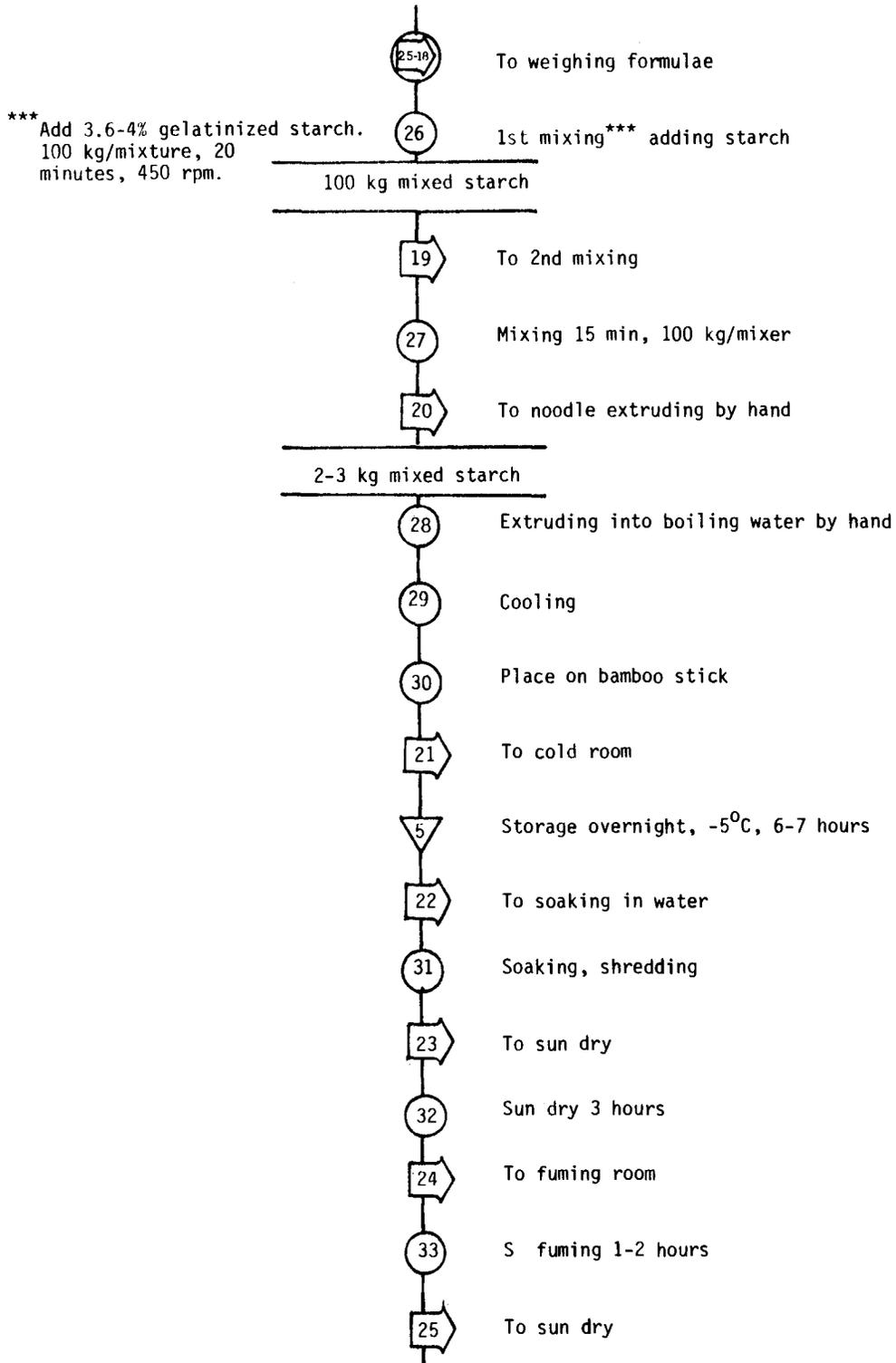
Market - Grade A to Bangkok market and Grade B to rural areas. None for export.

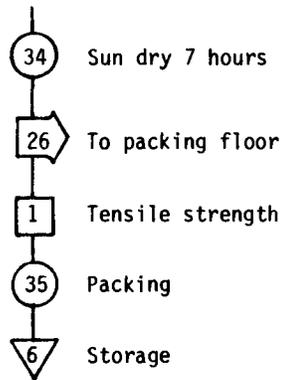
8.1.2 Process flow chart

Mung Beans  
in 4 silos @ 400 sacks  
@ 120 kg



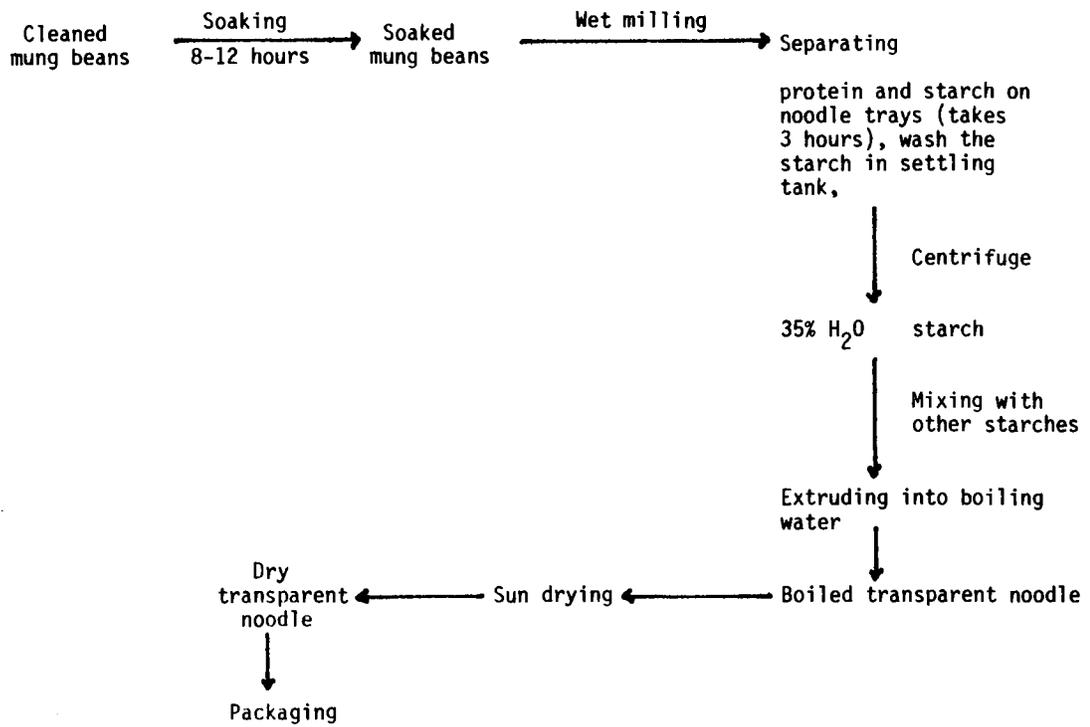






8.1.3 Identification of key operations

Processing method



#### 8.1.4 Improvements to key operations

Possible process improvements were listed for each key operation. The short time available restricted the list of improvements. More would be expected before further research is carried out.

<u>Key Operation</u>	<u>Possible Improvement</u>
Soaking	1. Use warm water 2. Adjust pH of soak water
Wet milling	3. Replace with dry milling followed by soaking
Separation	4. Adjust pH of suspension to aid separation 5. Use vacuum drum filter
Starch mixing	6. Use a composite of starches from cheaper sources to complement mung bean starch
Extrusion into boiling water	7. Use steam cabinets
Sun dry	8. Cabinet dry a. electric 9. b. solar energy
Packaging	10. Machine packing

#### 8.1.5 Screening of possible improvements

The list of possible process improvements was screened on the basis of certain criteria important to the company. These criteria were ranked in order of importance and allotted a possible score.

<u>Screening criteria</u>	<u>Possible Score</u>
Low capital investment	28
Improvement in product quality	25
Reduction in product cost	21
Low technology input	15
Minimum disruption to labour	11
Total possible score	<u>100</u>

(See Table 8.1).

Table 8.1 Screening of Possible Process Improvements - Noodle Manufacture

Possible improvement \ Criterion	Low Capital Investment (28)	Better product quality <sup>(1)</sup> (25)	Reduced product cost <sup>(1)</sup> (21)	Low technology (15)	Minimum labour disruption (11)	TOTAL SCORE
1	28	10	14	14	11	<u>77</u>
2	26	10	14	11	11	<u>72</u>
3	15	9	14	11	10	59
4	26	16	16	10	9	<u>77</u>
5	10	20	16	8	6	<u>60</u>
6	28	13	20	12	11	<u>84</u>
7	8	15	8	10	8	<u>49</u>
8	0	20	5	9	5	39
9	5	20	6	7	5	43
10	10	18	9	10	6	53

- (1) Mid-points of 13 and 11 respectively were used for Product Quality and Product Cost to denote no change. Lower scores indicate lower quality and higher cost.

The process improvement with the greatest potential was clearly the use of a composite mixture of starches to reduce raw material cost.

Screening also pointed to a distinct lack of knowledge on the factors affecting soak time and starch separation.

#### 8.1.6 Selection of process improvement strategy

In this case priority should be given to the investigation of the potential for use of composite and cheaper starch sources.

Further research should also be carried out into bean soaking and starch separation to establish methods for reducing soaking time and for speeding up and making more efficient the separation of starch.

#### 8.1.7 Operations research and experimental design

##### a. Composition of starches

Providing that there is no marked reduction in noodle quality, a blend of starches from different sources could be used to minimise the raw material cost. Possible sources are red bean, black bean, potato, cassava and corn. Others may be available if more extensive investigations were made.

This problem now lends itself to solution by linear programming where:

Objective function is cost minimisation or profit maximisation;

Constraints are based on starch quality to achieve an acceptable product quality and on certain processing parameters;

Inputs are the sources of starch.

Unfortunately such an L.P. problem is not readily solved because of the lack of information on the starch quality of the various sources and its effect on noodle quality. This information would have to be gained by experimentation before solution of the linear programme. The L.P. could then be used as an experimental tool and possibly later as an on-going production planning tool where the sources of starch are chosen on a daily basis to maximise profit to the company.

b. Soak time

A simple experimental design could be set up on a laboratory scale to evaluate the effect of certain soaking parameters on starch extraction rate and final noodle quality.

Input variables would be soak temperature, soak time, pH of soak solution and ratio of soak water to beans. Other input variables might be included after a fuller investigation.

Output variables would be rate and ease of starch extraction and noodle quality.

Possible designs. Plackett and Burman screening experiment would select the most important input variables and gain knowledge of the system; followed by a more extensive factorial design leading to more complete knowledge of the effects of the important input variables.

c. Starch separation

A similar procedure could be followed as for the soak time experimentation with definition of the input and output variables followed by systematic experimentation leading to a complete understanding of the mechanism for starch separation.

Laboratory experimentation on soaking and starch separation should lead to a complete knowledge of the mechanisms of each process. This should enable the researcher to proceed to pilot plant or factory experimentation where optimum process conditions and the effects of changes to these conditions can be established under the normal factory operation.

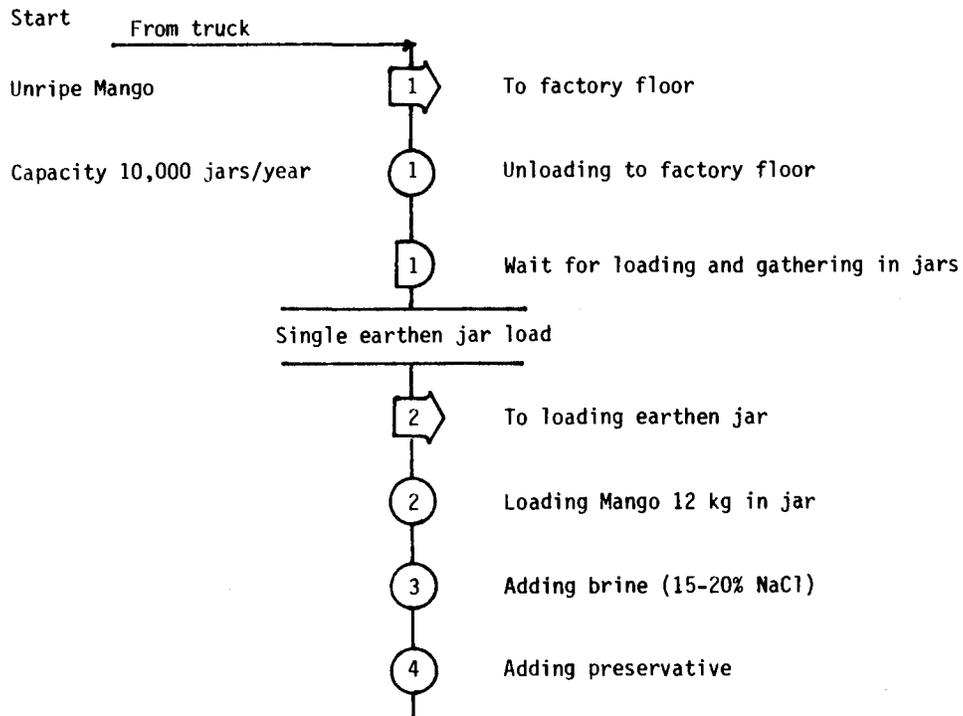
## 8.2 Fermented and Dried fruit plant

### 8.2.1 Overview of company

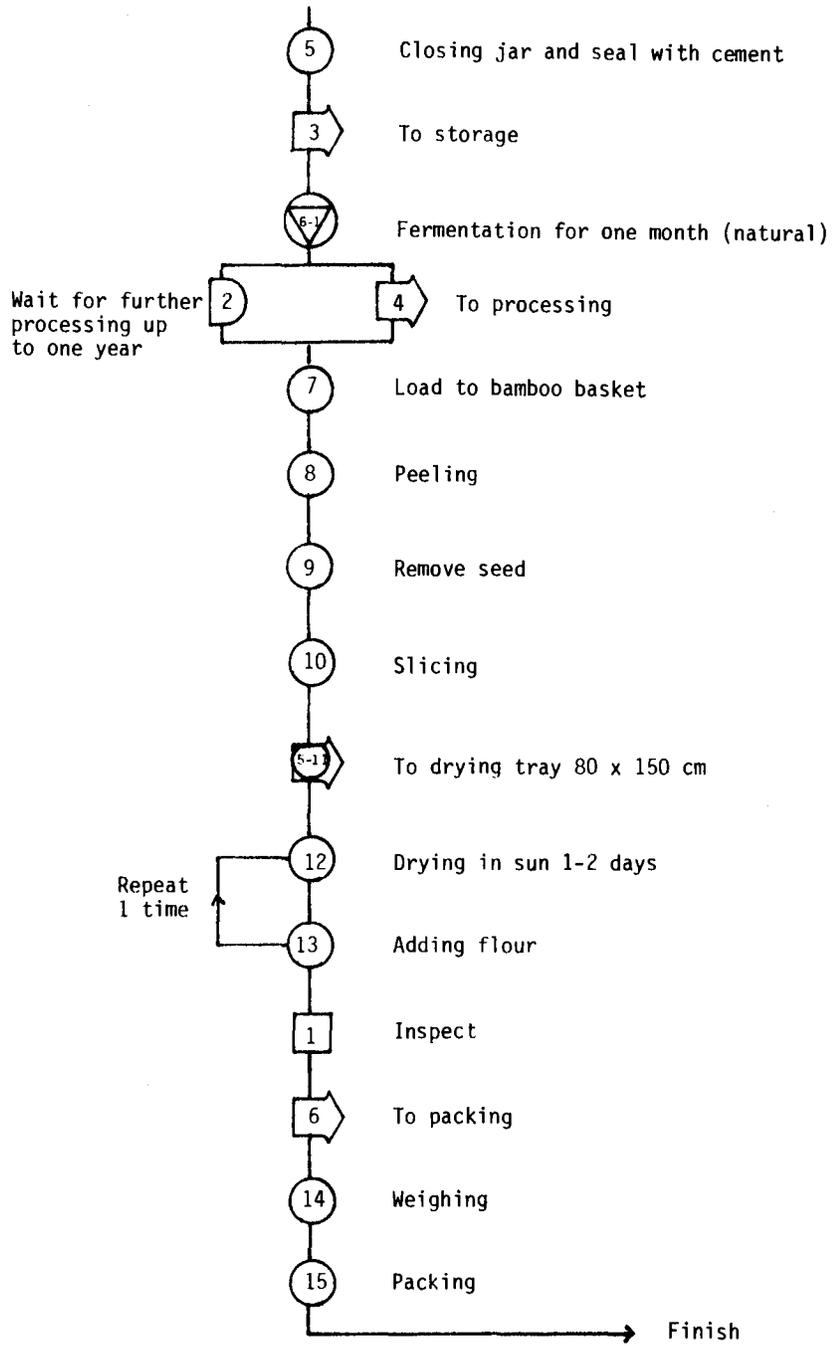
- Location - 20 km south of Bangkok
- Products - Variety of fermented and dried fruits. Main product is mango.
- Raw Materials - Various fruits when in season. Price - 4 baht/kg unripe mango.
- Staff - Family based operation with 3 family members acting as directors and management. Labour force of 10 employees.
- Labour Costs - 400 baht/month/person.
- Throughput - 120,000 kg of mangos per year to produce 20,000 kg of fermented, dried product.
- Product Selling Price - 50 baht/kg.
- Market - Bangkok area

### 8.2.2 Process flow chart

A process flow chart is presented with mango as an example of the fruit used.

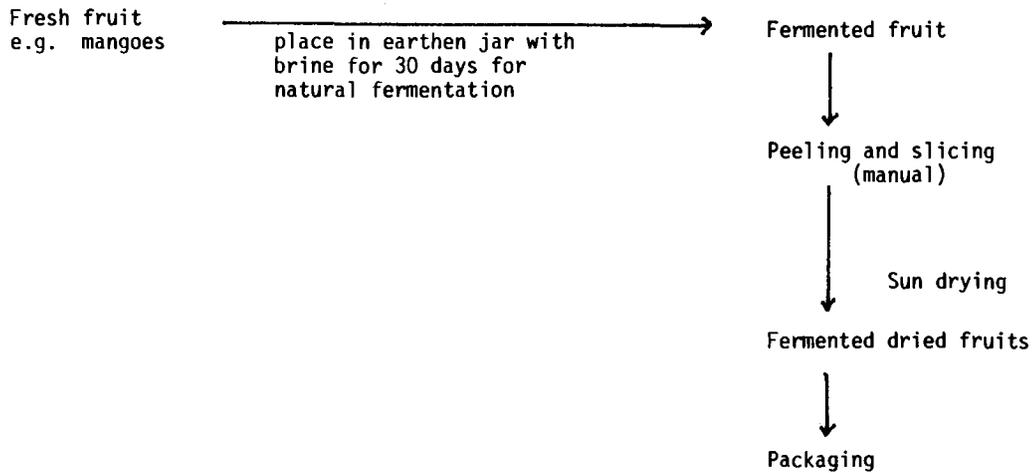


continued...



### 8.2.3 Identification of key operations

#### General processing method



### 8.2.4 Improvements to key operations

Potential process improvements were listed for each key operation.

<u>Key operation</u>	<u>Possible improvement</u>
Fermentation (natural)	1. Use control conditions of microbial culture, time, temperature etc.
Peeling and slicing (by hand)	2. Automatic peeling and slicing 3. Hand peeling and automatic slicing
Drying (sun)	4. Cabinet dryer - electric 5. Cabinet dry - solar energy
Packaging (by hand)	6. Machine packing

### 8.2.5 Screening of possible improvements

The list of possible improvements was screened on the basis of criteria important to the company. As this is a very small, family operation there was very little finance available for capital investment. This was seen as by far the most important factor in considering any process improvement. Minimum disruption of the labour force was also considered to be very important as the factory acted as a place of employment for a nearby village. Replacement of some of the labour force by machines would result in financial hardship in the village and social pressure on the company to retain the labour.

<u>Screening criteria</u>	<u>Possible score</u>
Low capital investment	40
Minimum disruption to labour	25
Low technology input	20
Improved consistency of product quality	15
Total possible score	<u>100</u>

Table 8.2 Screening of possible process improvement - fruit dehydration

<u>Possible improvement</u> / <u>Criterion</u>	<u>Low capital investment</u> (40)	<u>Minimum labour disruption</u> (25)	<u>Low technology</u> (20)	<u>High product consistency</u> (15)	<u>TOTAL SCORE</u>
1	35	23	12	13	<u>83</u>
2	10	5	10	8	33
3	15	10	12	6	43
4	15	20	15	8	58
5	20	20	13	8	61
6	15	12	15	5	47

#### 8.2.6 Selection of process improvement strategy

The use of natural fermentation, although seldom resulting in an unsaleable product, does result in a product of inconsistent quality. The use of controlled fermentation conditions should produce a product of more consistent quality without the requirement for either high capital investment or high technical input.

#### 8.2.7 Operations research and experimental design

Step 1 - Evaluate alternative cultures on the basis of speed of fermentation and quality of final product.

Step 2 - Define optimum conditions for the selected culture.

Input variables - Microorganism  
 Temperature  
 pH  
 Nutrients in fermentation medium  
 Time

Output variables - Flavour of fruit  
Texture of fruit  
Colour of fruit  
Keeping qualities of dried product

A laboratory experiment should be designed to evaluate the efficiency of the specific microorganisms. This could either be coupled to or followed up with a planned experiment to establish optimum fermentation conditions. Once these are established they should be tested in the factory environment.

All efforts should be made to minimise the need for extensive process control which could be neglected in this cottage industry.



