ASTON UNIVERSITY

The Implementation of Industrial Robots in a Manufacturing Organisation

by

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SUMMARY

This thesis is concerned with the implementation of industrial robots within manufacturing industry. Its basis is an action-research study of the method by which an international food company adopted robot technology, carried out from the novel perspective of a direct participant in the adoption process.

Previous studies of robot adoption are shown to concentrate on particular aspects of the implementation process without providing the overall view that industry needs. In contrast, this study took the original approach of synthesising the organisational, financial and technical aspects of the implementation process within a common framework.

Identification and assessment of the opportunities for applying robotics, preparation of detailed design solutions, development and implementation of the first production system were carried out. It was found that many potential applications were not cost effective and required excessive floorspace in comparison with conventional manufacturing methods. It was also found that integration of the robot systems and organisational resistance to change were significant factors. It was further found that the poor cost-effectiveness of the robot systems was due to: the inadequacy of payback appraisal in accounting for qualitative factors; the short-term assessment of robot applications as discrete projects and the need for high levels of ancillary tooling.

Novel outline specifications for robot systems to meet the food industry's special needs were derived, an alternative method of financial appraisal, a new parameter for assessing robot system design and an original plan of work for managing robot implementation projects were developed.

It is concluded that a longer-term planning orientation which links the implementation of robotics to the company's business strategy and an integrated approach to managing the adoption process are crucial to successful robot use.

KEY WORDS: ROBOT, FOOD-INDUSTRY, IMPLEMENTATION

to my parents

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

This work is concerned with the effective implementation of robot[1] technology within a large manufacturing organisation, a subject whose importance has been emphasised in recent years in both the national and technical Press.

> "By any standards, whether absolute or relative, Britain is doing badly in the robot race. In 1982 British industry was able to muster a paltry 1,500 robots compared with some 13,000 in Japan" (2).
>
> "British Industry is not applying new technology to its products and production processes at anything like the rate of its overseas competitors, (and when it does)... many apparently sound investments in new technology are a failure" (3).

The gap between Britain and its foreign competitors is widening, by December 1985 the United Kingdom had installed 3,208 robots compared with Japan's 64,000, the USA's 20,000 and Germany's 8,800[4].

The implementation of any new manufacturing technology is a complex task; Bessant[5], for example, listed over sixty characteristic factors in his study of manufacturing innovation. However, the implementation of industrial robots is more complex than introducing other "new technologies". The Media portrayal of highly sophisticated "Star Wars" robots[6] and the overselling of the current technology by the industrial robot industry itself, has led to a situation where "both workers and managers are more sensitive to their introduction into the workplace than they are to the introduction of other new technologies"[7]. Although it is arguable that "robots tend to excite widespread comment far in excess of their actual current importance" [8], there is no doubt that a company trying to implement robots for the first time faces a considerable problem - a quarter of them never make it [9].

Problems with achieving successful implementation of new manufacturing technologies are not restricted to robots, or even to the UK however. Reporting on the application of new manufacturing technology by US industry Skinner[10] states that

> "... In the face of a pressing need to change the factory, increasing both its mechanisation and its humanization, we are apparently making slow progress.
>
> In the face of an increasing rate of technological change and potential for automation, actual applications are surprisingly cautious.
>
> In the face of expanding uses for the computer, its effects in reducing lead times and costs and in improving quality of output are disappointing.
>
> In the face of what appear to be enormous opportunities for retooling with modern numerically controlled gear we see a slowdown in orders."

> "The fact is that technology is too far ahead of its management. We already have enough technology available to transform the batch manufacturing industries. We do not have sufficient awareness of how to implement and manage it." (11).

The recent ACARD report [12] on advanced manufacturing technology [13] also confirmed this

> "... there was now a general awareness of the existence and scope of AMT. There was, however, considerable uncertainty as to how such technology could be put to work to reach its full potential and how to implement it".

Thus there is an urgent need for research into the implementation problem. As Voss states:

> "Effective technology based competition requires good management of new technology; of its development, selection and implementation. The current research thrust in areas such as Information Technology, Robotics, Computer Integrated Manufacture, etc., need complementing by research aimed at ensuring that the adoption and implementation of these technologies is effective (14).

1.2 Background

At the start of this research in September 1982, total UK expenditure on food accounted for 10% of overall GNP at £20 billions, of which £2 billions was spent on confectionery,[15] whereas the food industry used less than 0.2% of all industrial robots installed in the country at that time [16]. The adoption of robots by Trebor was therefore an example of a pioneering adoption of industrial robot technology and would therefore involve the whole range of problems which previous research had identified as accompanying pioneer robot adoption.

Trebor Limited is a family-owned international manufacturer and wholesaler of confectionery and snack-food products with a turnover of £231M in 1984. It employes approximately 3000 people and operates three manufacturing sites in the United Kingdom at Chesterfield, Colchester and Maidstone.

Although the food industry is generally traditional and slow to change, Trebor has a history of innovation in the technical and organisational fields, its links with Aston University stretching back to the "Aston Studies" in the late 1960's on production technology and organisational structure[17]. This appreciation of the importance of social psychology in industry was later developed into an explicit Company philosophy and the introduction of factory organisational structures based upon autonomous work groups. In the technical area Trebor was a pioneer in the application of microprocessor technology to batch and continuous food processes, and by the early 1980's had built up considerable experience and expertise, establishing a rationalised approach to system implementation at relatively low cost.

This project thus offered an excellent opportunity to study in depth the process of implementing robot technology, as the adopting company was not only a pioneer in its industry, but was also aware of the importance of managing innovation well, had previous experience of collaborative research [18] and had in-depth knowledge of implementing an allied technology.

The specific problem addressed by this research was therefore to:

a) successfully introduce industrial robot technology into Trebor Limited; and

b) research the robot implementation process as a case-study of manufacturing innovation.

1.3. Research Design

Substantial research has been carried out in the field of new technology adoption over the last thirty years since Carter and William's [19] influential study in 1957. Much has been learnt about the adoption process and the factors which influence it for a wide rage of technological innovations. (ref. for example Nabseth and Ray [20], Chakrabarti and Rubenstein [21], Rogers and Shoemaker [22], S.P.R.U. [23]).

However manufacturing innovation, as opposed to process or product innovation, has received comparatively little study. Manufacturing innovation refers to changes in the manufacture of goods which although radical do not change either the product or the basic process [24]; such as the use of industrial robots for example. Although robots have been in use since the early 1960's, the earliest work on their adoption and diffusion was not carried out until 1979 at the University of Aston (ref. Zermeno-Gonzalez [25]; Zermeno, Moseley and Braun [26]; and Fleck [27])

This research, covering a sample of 32 cases involving 147 robot installations, highlighted both the difficulty in achieving successful implementation and the complexity of the adoption process:

Analysis of the 32 cases (ref Fleck [28])

Project was an initial failure:	44%	
and subsequently abandoned:		22%
and further developed		6%
was eventually successful		16%
with simpler devices than originally used:		12%
		44%
Remaining projects were successful*	56%	
	100%	

* success defined as use in normal production, not merely technical success.

Factors in the Adoption of Robots (ref. Fleck, op cit.)

Favourable conditions for robotisation

An effective robot champion in the adopting organisation.

The commitment of top management.

Previous experience of automation.

Presence of existing automation in the process to be robotised.

Bad working conditions in the process to be robotised.

Labour problems (turnover, shortage, absenteeism) in the process to be robotised.

Careful consideration of automation alternatives, including robots.

Careful assessment and monitoring of the economic performance of proposed systems.

Unfavourable conditions for robotisation

The absence of the above favourable conditions.

Low investment levels in industry.

Unfavourable robot-labour cost relationship.

Weak robot supply and service infrastructure.

Unsuitable production patterns or volumes.

Advantages of robotisation.

Better process control.

Elimination of human variability.

Labour savings.

Improvements in quality and consistency.

Productivity improvements.

Problems over robotisation.

Difficulties in getting the overall system to run.

Selection of appropriate robot model.

Long development periods: more than two years in many cases.

Considerable managerial effort required.

Organisational resistance from various sources.

Need for extensive training.

Difficulties over retaining trained personnel.

The Aston research thus indicated the need for further study of the robot adoption process. The large number of factors which this early work identified, highlights the inadequacies of much of the previous (and in some cases) subsequent research on robot implementation as well as on manufacturing innovation in general. It shows that despite clear evidence that the process of manufacturing innovation is influenced by numerous factors across the technical, financial and managerial disciplines, many authors have tried to model the process from the perspective of their own discipline and have either ignored or oversimplified the areas outside it, even though it is clear that the areas are linked - not least by the fabric of the adopting organisation itself.

Thus engineering studies of robot implementation have tended to focus on the technical aspects of the problem. Where these authors have mentioned the non-technical issues, they have tended to restrict them to well-defined stages in the implementation programme, separate from the technical factors. Or, they avoid considering these wholly complex and difficult non-technical issues by oversimplifying the financial and organisational context of the problem. For example Davey's[29] model of the organisational context of robot adoption below.

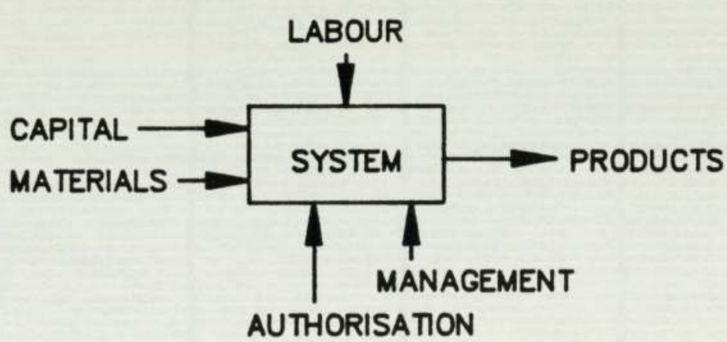


Figure 1.3.1 Model of the Organisational Context of Robot Adoption

The accountants and management scientists who have improved our understanding of these social and financial issues still, when discussing the technical factors, gloss-over the problems assuming that they have already been solved by the engineers. For example, Bessant [30] quotes Johnson

> "The technical problems we can solve - the people problems are hell!... the technology gets pushed aside because people don't understand it."

This lack of cross-fertilisation and the absence of work which attempts to understand the problem as a whole rather than from just one specialist aspect - is the major limitation of the literature on the implementation of new technology. The thesis of this research is that in reality these areas are not separate, it is only the professional and academic demarcation which appears to make them so. Thus it aims to test the hypothesis that an integrated multi-disciplined approach to robot implementation is crucial to successful robot adoption.

The case study approach which this work is based upon has received some criticism in the past for producing results which are:

> ".. highly specific, making little contribution to the general understanding of the problem under investigation." (31)

However, recent studies on manufacturing innovation (ref. for example Rothwell [32] and Utterback [33]) suggest that research methods in this field should in fact

> ".. gear themselves towards a closer study of a smaller number of firms - and aim at collecting richer and more specific information about their behaviour." (34)

> "Innovation research has produced plenty of factors associated with successful innovation, what are needed now are methods for achieving them; it is suggested that these will only be found by innovation researchers being involved with innovation and experiencing the process for themselves" (35)

Case study research is regarded as an effective methodology for researching manufacturing innovation [36], particularly when it is carried out within the framework of clear theoretical concepts. Bell [37] cites Heclo in arguing for the advantages of this approach.

> " If case studies represent confused realism in search of an analytical framework, the pragmatic approach resembles an analytic framework in search of realism. There is something to be gained from each but perhaps more to be gained from a mood combining both".

Thus this research aims to combine the currently separate, single disciplined studies of robot implementation by studying how these areas interact during the adoption process, in order to develop a multi-disciplined framework which will be of practical use during subsequent robot implementation projects. The practical orientation of this research project - the successful introduction of robotics at Trebor - also required that the research method provide predictive guidance as the project proceeded. Retrospective analysis would clearly not provide this, and so an action-research approach was adopted.

> " Action research aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of ... science by joint collaboration within a mutually acceptable ethical framework ... differing from other varieties (of research) in the immediacy of the researcher's involvement in the action process." (38)

This immediacy was obtained via the researcher's direct participation in the implementation process as leader of the robotics project. Thus the research became an integral part and strong influence upon the adoption of robots by Trebor and allowed

> " ...'privileged access' to data and situations which are normally not easily accessible to the basic researcher ..." (39)

which provided the insight into the reality of robot implementation in the industrial context needed to test the central hypothesis.

The contribution to knowledge provided by this thesis is that it shows that the introduction of robots by a manufacturing organisation has financial and organisational dimensions which are intertwined and inseparable from its central technical activities; and that because of this fact, an integrated approach to robot adoption is crucial.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Introduction

The magnitude and complexity of the robot implementation problem was established in Fleck's[40] study of the diffusion of robots in British manufacturing industry which identified thirty factors relevant to the adoption of robots by individual firms. A significant point was the diversity of these influencing factors, ranging across the technical, economic, organisational and labour aspects of robot adoption. The multi-disciplinary nature of the implementation problem is borne out by a later survey of the introduction of automation by manufacturing industry,[41] which identified nine "barriers to introduction":

1. A lack of funds.
2. Insufficient technical expertise.
3. A belief that further automation would not be economic for the product range.
4. Shop floor resistance.
5. Limitations of capital justification techniques.
6. Fear that technology will be better tomorrow than it is today.
7. Insufficient drive/support from top management.
8. Insufficient drive from middle management.
9. Other reasons.

As can be seen from the above list, the problem of introducing new technology crosses disciplinary boundaries to present a highly complex and unstructured picture. The recent report by the ACARD on AMT proposed a number of guidelines for its introduction. These included:

- Manufacturing technology is a top management responsibility and the main board must monitor its appropriate implementation.

- AMT investment cannot always be justified by a conventional financial analysis. Justification should include indirect savings, intangible benefits and the consequence of not investing.

- Implementation of AMT should take into account the eventual integration into an overall system.

- Commitment and detailed planning, involving competent, well-trained staff at every level are prerequisites for successful implementation.

- Manufacturing is a strategic issue and should be part of the overall corporate strategy[42].

If this report is correct, and these principles are necessary conditions for success in AMT adoption, then the aspiring project manager is faced with considerable problems, as they imply:

a) a radical shift in the attitudes of top managers;

b) a completely new method for appraising capital investment proposals;

c) the immediate development of interface and communications standards for computer controlled machinery;

d) a reversal of the current chronic shortage of skilled personnel.

Even if these points were not implicit in ACARD's recommendations, each of the guidelines is a significant task in itself and understates the radical changes needed in most companies to achieve them. A drawback of the report is that it omits to mention that all these disparate issues are interrelated, and that the interaction between the various aspets of the change process critically affects the success of the implementation project. In this ACARD follows the tradition of previous work on the introduction of advanced manufacturing technology. The breadth and complexity of the problem and the range of disciplines implicit in it, has led to a body of literature, which although well established, is segmented. Studies to date have, in approaching the problem from a particular point of view, tended to concentrate on that aspect of the problem and have not grasped the complete picture. If one extends the argument that the separate aspects of the problem must be linked in some way, because of the very nature of manufacturing firms, then the **interaction** of these **non-separate** issues will be a critical factor. This is the major hypothesis which this research aims to test.

Prior studies of the process of innovation have been of two main types: firstly those which aimed to identify the factors whch affect the successful development or adoption of a new innovation by an organisation, and secondly those which aimed to model the process by which an innovation diffuses through organisations, industries or society generally. A number of studies have attempted to measure the constraining and facilitating factors affecting innovative performance: (Ref. for example NEDO [43], SPRU [44], Bessant [45].) These studies uncovered a large number of factors of varying importance in a wide range of areas. However there is general consensus as to the key factors for success in the development or adoption of a new innovation.

> "Analysis of past technological innovations reveal a number of factors all of which appear to be present in many successes, and one or more of which are found to be frequently absent in failures".(46)

These are:

"* Top management must be committed.

* Innovation must play a role in the company's long term corporate strategy.

* Top management must accept risk.

* An environment must be created in which entrepreneurship can flourish.
* There must be good co-ordination between all in-house functions.
* There must be effective coupling with external sources of expertise.
* Companies must retain gifted and committed entrepreneurs."[47]

In the particular case of manufacturing innovations; Bessant[48] reports the following characteristics of firms which were successful.

i) Presence of technically orientated, informed management.

ii) Effective planning and control of projects.

iii) Innovation strategy including a portfolio of projects

iv) Greater consideration of training needs.

v) Use of participative design and introduction strategies.

Together with other innovation studies (ref. for example Ettlie [49], Chakrabarti and Rubenstein [50], Radnor et.al.,[51]) this body of knowledge clearly demonstrates the range and diversity of factors which influence the adoption of both manufacturing and process innovations. The adoption process is shown to be complex and variable, influenced by a large number of factors both internal and external to the innovating company. This has subsequently led to the concept of a "constellation of factors" influencing adoption [52] and the "growing emphasis upon the fact that it is the **combination** of factors which are important rather than single elements." [53]

In some opposition to this view however, have been studies which have focused on a particular aspect of the innovation process as being more important. For example, Twiss [54] suggests that 'management style' is of over-riding importance "acting as either a barrier or promoter of successful innovation." Fleck[55] reports that of the thirty factors found to influence the adoption of robots by manufacturing firms, three were generally more determinant of successful adoption than others:

a) The existence of extensive previous experience with automation.

b) The availability of appropriate electronic and programming skills.

c) The poor working conditions of the manual task before robotisation.

These findings are particularly relevant to the Trebor case as all three of these factors were present and influenced the adoption process. However, for Trebor, it was the existence of some negative previous experience with automation which hindered introduction. Poor working conditions or an unpleasant manual task were also significant factors in the selection and appraisal of both the first and second robot systems. Other factors however, have been stressed in studies which followed Fleck's early work. In fact, research since that time which has focused on the organisational aspects of the adoption/implementation process has taken a number of somewhat different viewpoints. Bessant argues that slow diffusion at the level of the firm "cannot be accounted for by a single causative factor or group of factors... it is a complex pattern." (56) He goes on to say that the "diffusion factors do not represent blocks so much as delays to the adoption of systems."(57) In arguing that adoption is a learning process within which there is an element of choice relating to the large number of variable factors he suggests that a contingency approach to the innovation process is the most appropriate. He develops this point in the concept of "design space" as a representation of the options available to the organisation undertaking technical change.

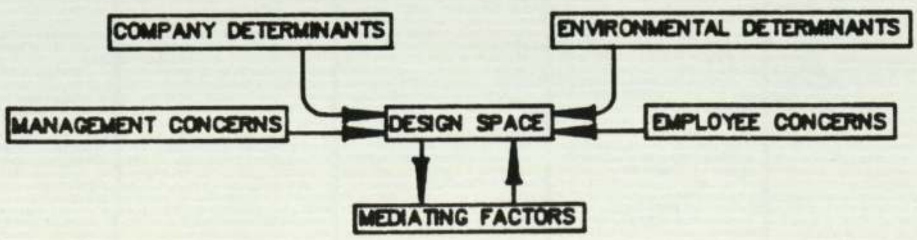


Figure 2.1.1 Design Space Model

The design space represents the degree to which the technology lends itself to being shaped to fit its organisational context, rather than being fixed as in the view of technological determinism. Bessant suggests that the contingency approach to the introduction of new technology offers the best descriptive theory of the "types and extent of choices open to managers and other decision makers within the firm". [58] Whilst it is true that the model helps to define the boundaries of the problem, it falls short of providing insight into its solution. To state that "it is impossible to prescribe a single 'best' solution to a given problem because the effects of so many variables . . . must be taken into account" [59] is to avoid the issue. The engineers faced with the task of achieving successful technical change within a company cannot avoid the fact that it is a solution orientated activity - an operational system is the expected end result. The implementation process involved in achieving that end is very important, but is not an end in itself. In adopting the contingency approach Bessant loses sight of this point. His model generalises the change process to such a degree that it is of little practical use in the actual company environment. It may be argued that theories of technical change are only valid if applicable to the real problem situation in its organisational context. As such, they must be implementation or solution orientated. Mills [60] case study of the introduction of new technology to the manufacture of cable looms at Westland is an example of this. Again, a certain aspect of the implementation process is stressed, as Mills strongly emphasises the participative nature of the Westland process between management and operators as being the key to successful technical change, although he also notes that the technology itself is a limiting factor on the rate of implementation, an often overlooked point.

However, Greenhalgh[61] suggests that relationships within the management structure itself are crucially important. Although both Mills and Bessant agree that the attitudes of management are important, Greenhalgh goes further to say that "the root of the (implementation) problem appears to lie in the intuitive model that is used by senior management when planning and implementing such projects "... when it comes to implementing high technology, the assumptions about the working of the individual, the group and the whole organisation are simplistic in the extreme".[62] Greenhalgh argues that the classical approaches, such as those presented by Bessant and Mills ignore two essential elements of technical change within an organisation. Firstly, he states that "technical excellence is always subservient to political expediency" in that the "decision about and the implementation of a high technology project must be negotiated with the power groups within the the organisation."[63] And secondly, that the implementation process is itself fluid and subject to change, as it exists within a changing organisational environment. Fleck agrees with Greenhalgh in that resistance to robot adoption was most prevalent at middle management level, rather than from the shopfloor.[64] However, he regards this as a direct result from the fact that "the particular set of skills and knowledge embodied in an individual ... represents an enormous amount of time and effort to which he is de facto committed (and which can) ... shape his perception at a subtle level in such a way that he may find it difficult to recognise the relevance and importance of other newer bodies of thought."[65] This concept of "cognitive inertia" and committment to particular bodies of expertise is presented as being at the heart of resistance to change within organisations. Fleck develops the argument to state that for these reasons the time to learn and adapt to the new expertise and knowledge is the principle delaying factor in the adoption of robots, and the management of expertise and knowhow resources within the firm is the crucial factor in effective implementation.

The question of the degree of relative importance of individual influences on adoption suggests two alternative hypotheses: either the adoption process within a given organisation has at its core a small number of "key factors for success" or adoption is always an 'organic' multi-variable process resulting from the interactions of many influencing factors. The validity of these two views can only be further investigated by in-depth study of individual organisations undertaking significant technical change, as recommended by Utterback[66]. This research, in studying as a participant the implementation of robot technology by a manufacturing organisation, aims to examine these alternative models of innovation.

In the Trebor project the organisational aspects were found to dominate the adoption process to an extent which surprised the researcher, whose background was predominantly technical. His training taught him to take an objective 'hard' solution-orientated view of the implementation process and to underestimate the 'softer' issues involved. This bias is also evident in the technically orientated approaches to the problem in the literature.

2.2 The Organisational Focus

To date there has been little research specifically on the organisational[67] aspects of robot adoption. However, there has been a long tradition of research on other new technologies in the past, such as microelectronics and numerically controlled machine tools, as well as extensive study of innovation and new technology adoption.

Carter and Williams' pioneering [68] study of industrial innovation in 1957 linked the 'technical progressiveness' of the firm to its 'general quality', and identified twenty four parameters of progressiveness such as: a deliberate survey of potential ideas; effective internal communication and co-ordination; rapid replacement of machines and the use of scientists and technologists on the board of directors. Burns and Stalker's [69] highly influential work on innovation mangement later identified two distinctly different types of company organisation: organic and mechanistic. They reported that the mechanistic form is appropriate to an organisation in an unchanging environment and stable conditions, and that the organic form is appropriate to changing conditions - such as the management of technological innovation.

Their mechanistic versus organic organisations are characterised in the following way.

Mechanistic	Organic
* problems/task broken down into specialist roles	* problems not broken down/divided
* each sees task as distinct from task of whole, as if each were a sub-contractor	* individuals have to perform specialised task in light of knowledge of tasks of whole
* precise definition of technical methods, duties, powers in each functional role	* jobs lose formal definition in terms of methods, duties, powers - continually redefined through interaction
* vertical integration within management.	* integration lateral as much as vertical

Much later, Kanter[70] linked this mechanistic/organic model with the problem solving approach needed for innovation, arguing that the organic form allows an "integrative" way of approaching problems

> ".. to see them as wholes related to larger wholes, and thus challenging established practices - rather than walling off a piece of experience and preventing it from being touched or affected by any new experiences"

and the "entrepreuneurial spirit" within a company to flourish. Burns and Stalker stated that although organic systems are not hierarchical, they are stratified according to seniority within the organisation. The formal structure replaced by the

> ".. growth and acretion of institutionalised values, beliefs, and conduct, in the form of commitments, ideology and manners, around an image of the concern in its industrial and commercial setting..." (71)

and that commitment of the individual to the goals of the organisation is "far more extensive in organic than in mechanistic systems."[72].

The organic/mechanistic model of Burns and Stalker was reinforced by the work of McGregor[73] at that time, his Theory X - Theory Y hypothesis provided two sets of cultural beliefs which paralleled their argument to some extent.

Theory X

1. The average man is by nature indolent - he works as little as possible.
2. He lacks ambition, dislikes responsibility, prefers to be led.
3. He is inherently self-centred, indifferent to organisational needs.
4. He is by nature resistant to change
5. He is gullible, not very bright, the ready dupe of the charlatan and the demagogue.

The implications for management are:

1. Management is responsible for organising the elements of productive enterprise - money, materials, equipment, people - in the interest of economic ends.
2. With respect to people, this is a process of directing their efforts, motivating them, controlling their actions, modifying their behaviour to fit the needs of the organisation.
3. People must be persauded, rewarded, punished, controlled, their activities must be directed.

Theory Y

1. People are not by nature passive or resistant to organisational needs. They have become so as a result of experience in organisations.

2. The motiviation, the potential for development, the capacity to assume responsibility, the readiness to direct behaviour towards organisational goals are all present in people. It is responsibility of management to make it possible for people to reorganise and develop the human characteristics for themselves.

3. Management is responsible for organising the elements of productive enterprise in the interest of economic ends, but their essential task is to arrange the conditions and methods of operation so that people can achieve their own goals best by directing their own efforts towards organisational objectives.(74)

Much more recently Mills has linked McGregor's X - Y model to the process of introducing new manufacturing technology at Westland Helicopters. The thrust of Mills' argument is the need to integrate the technological and personnel aspects of change during implementation of the new system. He reports how the implementation process is linked to the phasing of separate technological developments necessary for the eventual system, by implementing the development in three phases the technical risk is reduced - and the opportunity for bringing together the technical mechanistic aspects and the organic people aspects of the change process is enhanced, smoothing the adoption process and increasing commitment to the new technology.

McGregor's work is particularly pertinent to the Trebor case-study because it was the foundation for later work on work groups - an organisational form which was being introduced at Trebor during the robot's project. This work resulted in a body of opinion suggesting the organic model offered the best way to structure an organisation due to its compatibility with the then current social psychological view-point:

"1. Individuals are motivated by higher order needs as well as by economic needs.
2. Individuals derive their primary work satisfaction and motivation from work groups (they provide a source of norms, values and security.)
3. Therefore work groups should be developed instead of manipulated.
4. The role of the supervisor is to develop cohesive groups and motivate them by including group members in decision making.

5. The supervisors act as the lynch pins which hold the organisation together"[75]

The work-group form has been applied by Trebor in its new factory at Colchester throughout the organisational structure, and during 1985, was beginning to be applied at Maidstone. The form has however come under some criticism in the literature because

> "like the earlier mechanistic approach it implies that there is one best way for the development of organisations' structure and process."

despite the fact that

> "... the evidence is weak that this 'one best way' leads to happier people or greater productivity in a wide range of organisations." (76)

However, there is little doubt that the mechanistic form - which arose from the very early management science research - has severe and quite horrible consequences. For example, it has been argued[77] that the only reason that the (currently) unsophisticated industrial robots can be applied in today's industry is because of the long established Tayloristic approach to manufacturing organisation which has led to the fragmentation and deskilling of industrial work. Taylor,[78] and his successor Gilbreth developed three principles of scientific management which aimed to analyse and simplify work so that it could be better controlled and directed by management in order to increase efficiency. These were:

"1. Greater division of labour: production processes were to be analysed systematically and broken down into their component parts, so that each worker's job was simplified and preferably reduced to a single, simple task. Greater specialisation would lead to greater efficiency, while the deskilling of tasks would also allow cheaper, unskilled labour to be hired. Greater division of labour would in turn remove functions from the shopfloor.

2. Full managerial control of the workplace was to be established for the first time, and managers were to be responsible for the co-ordination of the production process that greater division of labour had fragmented.

3. Cost accounting based on systematic time-and-motion study was to be introduced to provide managers with the information they needed in their roles as the controllers of the workplace."[79]

The application of these principles since the thirties has led to the repetitive, dehumanising, and unskilled jobs which robots are now being used to automate. Scientific management has been and still is widely applied in industry. Its attraction lies in its universal applicability and its rational-scientific basis which makes it naturally attractive to engineers and management.

There have been hypotheses suggesting key individual explanations of innovative success as far back as 1884.[80] Since Schon's[81] pioneering study of military innovations in 1963 the concept of 'project champions' and their influence upon the innovation process has been the subject of extensive research. For example, Maidique lists nine different names for the championing role [82]. The common point made though is the importance of championing to the innovation:

"the new idea either finds a champion or dies" [83]

Project SAPPHO[84] carried out by the Science Policy Research Unit at Sussex University, researched forty-three matched pairs of innovations and provided evidence in support of the champion hypothesis, identifying four roles which influenced the probability of successful innovation:

Technical innovator - made the major contribution on the technical side to the development or design of the innovation.

Business innovator - responsible for the overall project process.

Chief executive - head of the company, M.D. or C.E.O.

Product champion - actively and enthusiastically promotes the progress of the project through its critical stages.

Even the Japanese with their essentially communal culture have recognised the need to foster individuals in this mould, as "samaurai teams" have been formed within the largest corporations to get non-routine tasks done more quickly.[85] The Western literature also stresses the heroic nature of the championing process - indeed the term itself conjures up visions of "white knights", and rugged pioneers,

> "What distinguishes 'winners' from 'losers' is the enthusiasm, determination and aggressiveness of the project champion"(86)

> "If he is in a company which needs fundamental change to survive, he must be prepared to put his job on the line at regular intervals by pushing through contentious issues which could bring the business crashing down around his ears".(87)

> "... the project champion must place the success of the project above all else - including career and personal interests." (88)

(He is an individual)

> ".. capable of using any and every means of informal sales and pressue in order to succeed." (89)

Not the sort of person to get in the way of ... however, some authors play down the more extreme characteristics.

> ".. they are not rugged individualists but good builders and users of teams... (they) use a process of bargaining and negotiation to accumulate enough information, support, and resources to proceed with an innovation ... not a matter of domination of others, but rather a coalition building to persaude others to contribute what they can to the innovation's launching" (90)

Not as exciting, but more reasonable perhaps. In fact a recent conference concluded that the reality of project championing is a subtle political process

> "... effective champions actually reduce the risks that they face by acting on probabilities and by presenting their arguments incrementally, but tenaciously, so as to reduce the perception of others that what they are doing is in any way unusual or risky. They saw the successful champions as both insightful and diplomatic, and skilled at organisational politics - an attribute not ascribed to them in much of the literature." (91)

Despite this disagreement as to the characteristics of project champions the literature is in close agreement as to their importance:

> "the weakest element in a company's business is not the level of technology it uses but the key people who manage the introduction of new technology and determine whether or not it is a success".(92)

The decision involved in the adoption of a new innovation was first proposed as a five stage process which occurs over a period of time by Rogers and Shoemaker. (93)

1. <u>The Awareness Stage</u>. At this point the individual learns of the existence of the new idea but lacks any kind of information about it.
2. <u>The Interest Stage.</u> The individual becomes more interested in the idea and consciously seeks out further details.
3. <u>The Evaluation Stage,</u> The individual considers how best the idea could be applied to the present or future situations and whether or not to try it out.
4. <u>The Trial Stage</u>. At this point the individual actually applies the idea on a small scale so that he may carry out tests and see if the idea can be incorporated in his own situation.
5. <u>The Adoption Stage.</u> At this stage the individual takes up the new idea completely.

The complete process is illustrated below. (Fig 2.2.1)

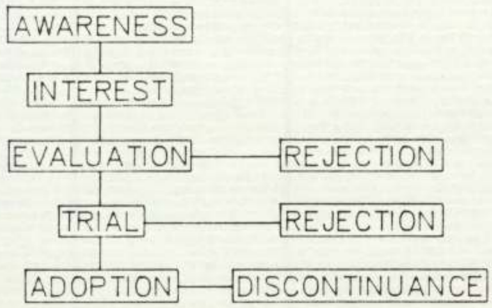


Figure 2.2.1 The Adoption Process

Later researchers have suggested alternative models of the adoption process (ref. for example Bessant,[94] Nabseth and Ray [95] but these have in general followed the format of a sequential series of information gathering steps. Bessant additionally lists the stimuli which may be responsible for bringing the attention of a company to a new innovation:

a) rational development from existing work already being carried out:
b) review of the state-of-the-art technology as a response to an identified need within the company;
c) promotion by outside agencies, government, trade associations or suppliers;
d) awareness that adoption was already being undertaken by a competitor. [96]

2.3 The Technical Focus

Of the three aspects to the problem of implementing robot technology - organisational, technical and economic - the technical aspects have been the most well documented during the diffusion of the technology over the last twenty years. Work in this area has been of two main forms: either prescriptive methodologies for implementing the technology in a manufacturing organisation, or case-study material describing the experiences of the early pioneer adopters. Much of the case material is unstructured and application specific. However, the remaining work is well developed and contrasts strongly with the organisational focus reviewed above.

Tanner[97] presented the earliest systematic approach to robot applications development in 1976, based upon ten years experience of using robots in the U.S. automotive industry. In it he states that "the development and implementation of industrial robot applications can best be approached through a logical sequence of steps (which) generally follows the same basic sequence as any other manufacturing process. However, the robot's unique combination of flexibility and limitations requires some special consideration for successful application." This contrasts markedly with the contingency approach described above and indicates the wide gap between the organisational/innovation theorists and the robot applications engineers. The implementation process recommended by Tanner consisted of six stages:

i) Become familiar with the basic capabilities and limitations of the equipment available.
ii) Carry out an initial survey for potential applications.
iii) Consult with robot manufacturers on feasibility of identified applications.
iv) Select the simplest jobs for the first application.
v) Study the job in detail.
vi) Design the system, evaluate non-robotic solutions.
vii) Implement the design solution.

In these stages he makes no mention of any of the non-technical aspects to implementation in the same way as the social scientists tend to omit the technical aspects in their studies of the process. Liff[98] brought the two sides closer together in a 1977 paper where he stressed the importance of identifying and analysing the prospective application areas, examining the socio-economic aspects of these areas and forecasting their significance for the company in the long term before investing in any hardware. Haupt[99] of IBM, one of the adoption pioneer companies outside the car industry, disagreed with this view. He argued for a more pragmatic approach - "in order to be successful you have to make an up-front investment.. the way to gain experience and credibility is to start with a simple application and grow in complexity as you learn from experience" Estes [100] of General Electric and Macri[101] of Ford also emphasised the importance of learning quickly through hands-on experience and of choosing the right first application. This ties in with Fleck's point that skills and expertise in the technology are the major limiting factors in adoption.

(ref. Tanner)

- review state of the art
- carry out initial application survey
- consult with robot manufacturers on applications
- select simplest job first
- study job in detail
- design a system
- implement a system

(ref. Warnecke & Schraft)

- define area of study
- carry out rough analysis of each workplace
- select suitable applications
- carry out detailed analysis of the selected applications
- prepare system specification
- design system
- implement system

(ref. Teale)

- prepare automation strategy
- implement support organisation
- sell proposals to workforce
- get some basic knowledge
- agree ROI policy
- identify, prioritise and select applications
- implement first system

Figure 2.3.1 'Technical' Approaches to Robot Adoption

The two striking features of the technically orientated approaches listed above are firstly their close agreement (Figure 2.3.1). They are all sequential processes based upon the identification and development of the optimum first application. Secondly, they are all structured methods. The technical school repeatedly make the point in the literature that the complexity of the issues involved in developing robot applications requires that a structured approach is adopted. (ref. Tanner, Estes, Warnecke & Schraft [102], Teale [103], Dorf [104].) This conflicts directly with the organisational school who argue that the complexity of the problem demands an unstructured, flexible approach, which can be adapted to match the problem situation as it develops.

The literature upon design methods for robot applications is generally either specific to a particular type of application such as palletisation (ref. Grab [105] for example) or to a particular industry. Although it is clear that the scope and diversity of robotics technology has led more general studies to simplify the system design process, some work has been carried out which identifies the general principles involved, although there are substantial differences of opinion within this body of work. For example Warnecke and Schraft [106] describe a highly structured application planning and design methodology based upon the use of functional diagrams and checklists, whereas Nof and Lechtman focus on "traditional industrial engineering approaches to work system design"[107] and apply these in the robot context. They recommend "a skills analysis approach to identify the skills and abilities a robot operator will need to best perform the tasks of a given job" and a method of robot-time-and-motion study to model the robot operations from knowledge about their mechanical design and work patterns. This is truly ironic; the very methods which led to people being analysed as machines in 'Tayloristic' fashion - the method is "analogous to methods time measurement, which has long been in use for human work analysis" - are now being applied to the work of "robot operators". The language reflects some confusion here; there seems to be some difficulty in distinguishing between people and machines. An earlier paper by Nof et. al.[108] takes the comparison of humans and robots to almost obscene lengths, applying bogus scientific analysis to human skill in order to decide if it is robotisable. Such work is not only of questionable morality, but it leads to the design of systems where all the tasks that can be automated are done by the robots, and the fragmented, often deskilled work that is left is done by people. A study of the use of robots in Volkswagen has demonstrated that rather than the introduction of robots leading to the improvement of working conditions:

> "... on the contrary, there are even some cases which are to be characterised as deterioration. This occurs, above all, in cases where the robots have assumed the task of handling the tools and left the worker only with the task of handling the material, that is, feeding new materials into the machine.
>
> ... especially conspicuous was that in many cases the factory control of the work rhythm was increased and the workers freedom of movement was thereby further restricted." (109)

Thus instead of robots being used to free man from the drudgery of some kinds of work, they are being used to even further control and deskill it. Taylorism is not dead - it is alive and kicking in some robot engineers. Rosenbrock highlights the fundamental attitudes which lie behind this approach:

> "If watches were made in the old way it would be very easy now to replace the woman who picked up the watch plate and placed it in the jig for drilling by a general-purpose robot. No engineer would do this because it is too extravagant: the robot has much greater abilities than are needed for the task which can be done by a simple pick and place device. The human being has still greater abilities but they are not subject to the same concern" (110).

He thus argues that it is the attitude and philosophy of engineers in seeing the consequences of their designs in their social context that is key to ensuring that we do not use robot technology to misuse human ability.

Parnaby[111] reports from studying Japanese manufacturing systems that the design of flexible manufacture involves a "shrewd and professional combination of new technology with methodology which developes the adaptive capabilities of people and uses simplified systems and procedures". He links this particularly closely with organising for innovation and "combining manufacturing systems design skills within a framework of business strategy appreciation." He further specifies five basic stages common to all problems of flexible system design or redesign

"1. System 'steady-state' or average performance design, starting at the end of the process and working back, each sub-system is designed using detailed input-output analysis. A preliminary simplification into basic key functional needs of the homogenous cell elements and their interactions starting from a simplified conceptual design is required.

2. Dynamic design of each cell or module based on what if questions about disturbances to product volumes, product mixes and machine reliability.

3. Definition of all control functions and their information and exception report needs.

4. Control and information-flow systems design using a hierarchical multi-level approach - top down planning.

5. Design of the task-force team and procedures for performance improvement".

The key principles of Parnaby's approach, i.e. design of component modules or cells from a consideration of the total manufacturing process, conflicts directly with the workplace focus of the Warnecke Schraft and Nof methodologies, but the total system view has gained increasing attention following experiences with flexible manufacturing systems for component machining (ref. for example Bjørke [112] and Vuzelov [113]). Vuzelov for example cites the following advantages of the modular approach:

- reduction of prime cost
- shortening of system design, planning and installation lead time;
- increased capability for small batch manufacture;
- gradual introduction of sub-units to match learning curve;
- application of standard hardware and software;
- high reliability

The literature on the use of robots in the food industry has been in the form of reviews of the technology, (ref. Smith [114], Lee [115],Sutcliffe [116]) very little case-study material on actual applications has been published as yet. An important exception is a paper by Grab[117] of Unimation, West Germany on the use of robots for packing yoghurt cartons into plastic trays and tray palletising-depalletising. This is very similar to a number of Trebor applications and so is especially pertinent. (Figure. 2.3.2)

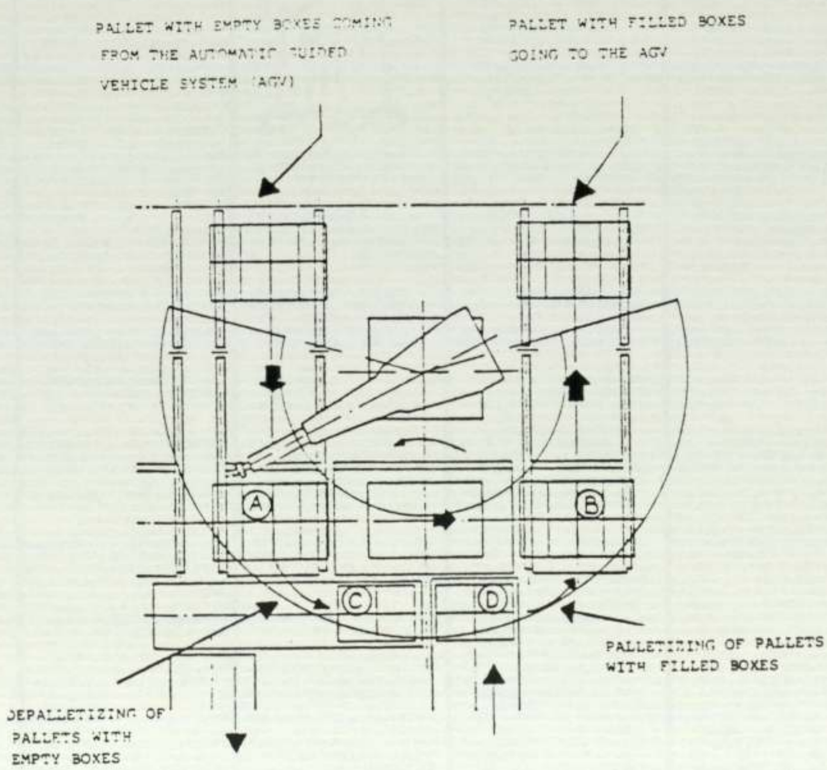


Figure 2.3.2 Robot Palletising Station (ref. Grab loc.cit.)

The following advantages of the robot palletising station are reported

- universal use in spite of different, permanently changing products and variable quantities
- off-line programming of different palletising arrangements (both compound arrangements and simple arrangements, different layers with different configurations and parts orientation in one layer)
- easy alternation of the programme after a production run
- short time adaption to new product types (high machinery reuse)
- high reliability (96-98% uptime) provides higher outputs than manual methods.

Specification

Robot: Unimate 2570

Load capacity: 58kg; reach 220^{0} @ R2.8m

Capacity: 1200 empty + 1200 filled trays palletising/depalletising per hour

Robot handles 4 trays per grip: 625 pick/place operations per hour

Cycle time: 11.5S average, inclusive of pallet enter and exit.

System control: Siemens 631 simatic PLC, programme on EPROM.

Grab also described a more complex system, again in the German food industry, palletising boxes onto three pallet positions. Pallet board infeed and load outfeed is achieved using AGVs transporting to and from a high-bay warehouse, thus closing the loop between the packaging line and despatch, (figure 2.3.3)

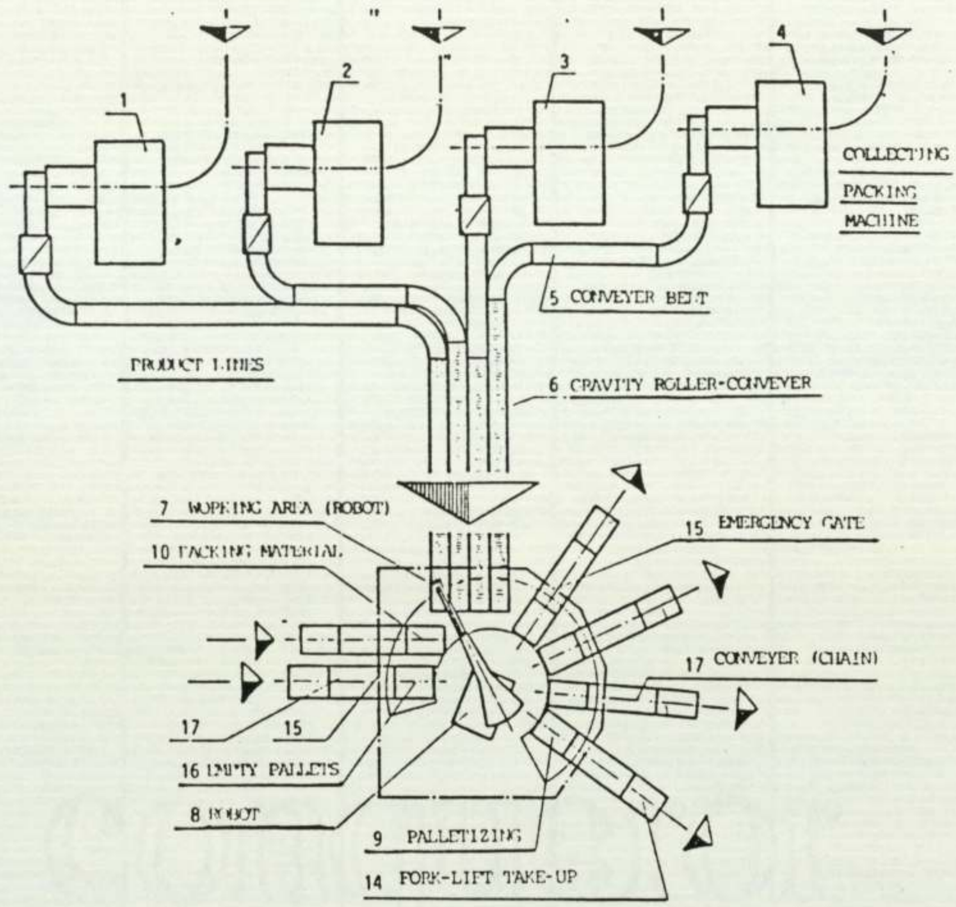


Figure 2.3.3 Robot Palletising Centre (ref. Grab.)

Specification:

Palletising	600 pieces per hour on 3 pallets
Dimensions of boxes	L - 340mm W - 120 - 255mm H - 200mm
Weight of boxes	3.2 - 5.4 Kg
No. of layers per pallet	7
Pallet type	Euro 800 x 1200 mm
Stacking height	1400mm
Pallet board capacity	12
Max reach of robot	1800m
No of palletising patterns on programme	7

Sutcliffe[118] mentions palletising as a major application in the food industry, for shrink-wrapped fruit juice packs, beer kegs, flour sacks and tea chests. Smith[119] argues that until recently "the food industry has lagged behind other industries ... on account of the inherent complexity and variability of the raw material, and the rigours of satisfying the demands of the consumer market." However, since 1976 the application of microprocessors has permitted the automation of a wide range of batch-food processs. In particular Smith focuses on the combination of machine-vision with flexible manufacturing systems and robots as "many of the manual operations within the food industry are required owing to the need for visual evaluation of a complex food material followed by judgement of an appropriate subsequent action." He further discusses their application to:

- inspection and grading
- decoration
- cutting
- biscuit packing

Packaging is one area which has been reported to be ripe for robot automation:

> "New robot techniques, specifically for parts handling ... provide unique opportunities for the application of robots in the packaging area and the potential here is enormous". (120)

The Japanese in particular have recognised the potential impact in this area. A recent survey by the Japanese Packaging Machinery Manufacturers Association found that 95% of its members expected robotics to become an important element in future systems.[121] Nakai [122] provides an excellent summary of the problems of applying robots in the packaging field and the development trends needed to overcome them. The difficulties he reports as:

1. The rather slow operating speeds of current robots.
2. Existing packaging lines tend to move the product through the machine

which is the reverse of robotic operation where usually the robot moves around the workpiece.

3. A robot system cannot be introduced without rearrangement of the surrounding machinery.
4. The long established and highly rationalised packaging technologies and their efficient techniques used in conventional packaging machinery.

He reports that operations with a suitable speed range will be robotised first, for example palletising and depalletising, the main problem being end-of-arm tooling design. Next, the packing of large sized products such as motorcycles, electrical appliances etc., will be robotised to meet the future diversification of products. Where cycle times are low enough, small parts will also come within the robotic capabilities, if the positioning accuracy required is not too rigorous. He comments that the main obstruction to the more widespread application of robotics to packaging is that of actuator performance; actuators are required which meet the speed, power and cost of dedicated mechanisms and which are remotely controllable. He predicts that stepping motor direct actuation of each movement in the mechanism and the level of sophistication reached in computer printers etc., suggest that these requirements will be achieved. The general trend he argues will be that the presently separate packaging machinery and robot technologies will merge to " be regarded as one mixing combined body".

2.4 The Economic Focus

The economics of implementing an advanced manufacturing technology such as robotics has received scant attention until quite recently. The growth in interest has been caused by an increasing realisation of the significant difficulties involved in the financial appraisal and measurement of capital investment projects which involve these new technologies. Most of the work has been carried out and presented from the point of view of the engineer or manager wishing to prepare a financial justification for a proposed project. This has therefore led to four main areas of literature.

i) Studies which identify and measure the benefits of robotic manufacturing ref. Hasegawa [123], Froehlich [124].

ii) Reviews of existing approaches to the accounting of project proposals ref. Bublick [125], Lewis et. al. [126]

iii) Critical reviews of existing approaches with an analysis of the problems and shortcomings inherent in current practice ref. Hastings [127], Goldhar[128], Owen [129], Small [130], Senker [131]

iv) Alternative approaches to the justification and assessment of projects ref. Hanify [132], Gold [133], Knott and Getto [134], Gerwin [135], Heginbotham [136] Primrose and Leonard [137].

The use of payback [138] methods of project appraisal are roundly criticised (as they are in the wider accountancy literature, see for example Glautier and Underdown [139] or Lumby [140]) for the following reasons:

a) Payback appraisal cannot cope with the complex and extended pattern of cashflows associated with the implementation of AMT.

b) Time dependent cashflows such as taxation and capital grants are not adequately assessed.

c) The payback method itself is analytically uncertain and is therefore open to different interpretations.

(ref. Primrose and Leonard [141])

It is argued that discounted cashflow [142] techniques such as net present value or internal rate of return[143] provide a much sounder basis for project appraisal, although even these have significant limitations. Another common theme is the difficulty experienced in quantifying the indirect [144], intangible or qualitative factors which are relevant to the investment decision. Although it may be argued that the concept of "intangible benefits" - like, as Sir George Porter recently commented about Unidentified Flying Objects -"presumably they must remain unidentified..."[145] - is a dubious one, an apology for inadequate theory. Primrose and Leonard [146] in fact report that:

> "Most authors, when describing the advantages of FMS, suggest that a large number of intangible benefits exist which by implication are unquantifiable and thus precluded from any rigorous financial evaluation. Upon investigation, however, the present authors have found that all the intangible advantages normally quoted can, in fact, be quantified and that upon examination, some of these are actually shown to be disadvantages."

Their method is based upon simulation techniques, the processing of a large quantity of data, and considerable thoroughness in the development of the simulation model, thus it is only viable for very large projects such as the FMS discussed by the authors. It would not be applicable for companies at the early stages of the adoption process, such as Trebor, as the cost and time required would be prohibitive. However, the concept that analysis of the intangible benefits can be achieved through use of a thorough decision model is an important one. In some contrast to this though, Gold [147] argues that the adoption of robotics and other programmable automation alters the fundamental productivity relationships within the firm to the extent that localised appraisal of discrete projects, such as in the Primrose-Leonard model, provides misleading results. Reporting on studies which suggest that:

> " ... the most important source of major improvements in the cost-effectiveness of manufacturing operations over the next 10-20 years will be programmable automation." (148)

he states that the use of robotics alters the relationships between the interacting components of productivity relationships (figure 2.4.1).

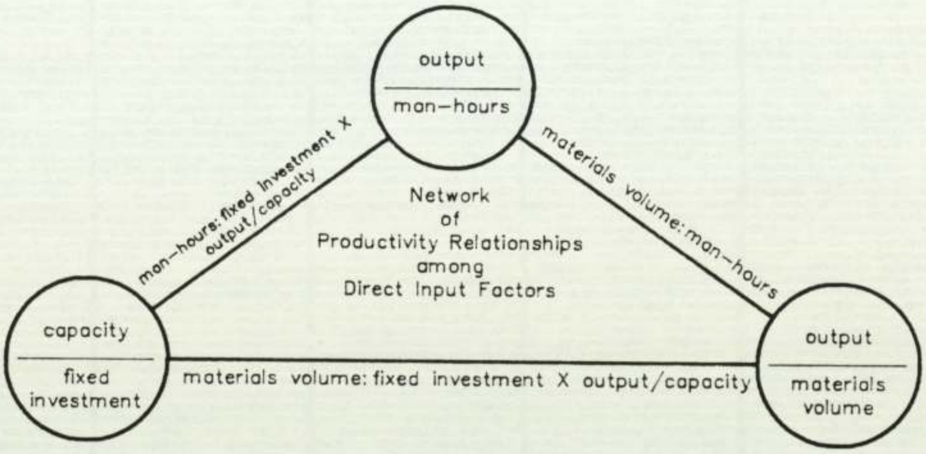


Figure 2.4.1 The Network of Productivity Relationships in Manufacturing (ref.Gold (149))

The following changes are said to occur:

a) The ratio fixed investment:direct labour input increases

b) direct man hours:unit output decreases

c) productive capacity:fixed investment decreases

d) direct materials: unit output may either increase or decrease, but certainly changes

e) indirect man hours: unit output increases

Moreover Gold argues that existing methods fail to take into account not only the above changes but also their 'inter-connectedness'. He cites the following example:

> "... mechanising some manual operations would first affect the ratio of actively - utilised fixed investment to man-hours. This would tend to reduce man-hours per unit of output, while the attendant increase in fixed investment might alter its ratio to capacity. And if the innovation reduced scrap rates, it would also decrease the materials input volume per unit of output". (150)

Gold's argument is especially pertinent to this research on the question of investments which although increasing the ratio of capital to labour inputs fail to improve productivity because of the low utilisation of existing capacity, because at Trebor a number of production lines are run for less than ten hours per week, (ref. a Trebor production manager January 1983).

When one considers that the majority of work on the economic aspects of the problem has arisen from the technical management disciplines it is surprising how isolationist and theoretical the results have been. The process of carrying out the financial assessment of a project is almost never linked to either the project selection or development tasks, or even to the overall management and organisational aspects of the adoption/implementation process. Financial justification is presented as an unconnected task within the overall development process, usually with the aim of preparing a case for the project.

Moving away from the focus on methodology, a number of authors blame the poor rates of robot diffusion in this country upon the domination of boardrooms by accountants - "to whom the bottom line is sacrosant" [151] - who are unconvinced by arguments based around unquantified or intangible benefits. Hasting's [152] has cited engineers' generally poor grasp of accountancy as an important factor here. It is significant that there has been no investigation of the special problems of justifying AMT projects by the professional accountants.

Apart from the effects of demarcation at the professional level within manufacturing organisations, the literature indicates that accounting techniques used by a company often do not completely determine the project appraisal procedure. A number of writers describe how the financial appraisal criteria for capital investment projects are often 'modified' or even completely ignored as decisions are made based upon considered judgement of the various aspects of the proposal. Nabseth and Ray [153] reported that:

> "Calculating the profitability of a new process is more difficult than is usually acknowledged in studies on the subject ... This does not mean that firms do not try to estimate the relative advantage of a new process, but rather that their calculations are very subjective ... It follows that profitability calculations for new processes are very much linked with management attitudes, especially when experience of the technology is scarce and perhaps contradictory."

More recently Hastings [154] quotes an Arthur D Little Inc. survey:

> "only one third of the (Fortune 500) respondents used rigorous return on investment or external auditors to justify systems . . . a surprisingly large number used management judgement."

This agrees with Gerwin's [155] view that "Only a veneer of objectivity surrounds the adoption decision for major technological innovations."

In his study of the introduction of FMS to caterpillar in the US Gerwin also confirmed Bower's earlier conclusion that:

> " capital investment evaluation is a process of study, bargaining, persuasion and choice, operating at many levels of the organisation and over long periods of time".

If this is the case generally, then the actual accounting mechanism used is not such a crucial issue and does not explain the difficulties engineers are facing. Rather it would seem that a lack of skills in being able to pursue the bargaining and persuasion process effectively would be more determinant. This argument ties in with the dichotomy between the engineers' rational, sequential approach to implementation, and the management school's flexible contingent approach. As bargaining and persuasion are generally unstructured iterative processes the contingent approach seems more appropriate.

A second corollary of the isolated nature of work on the economic aspects of robot adoption is the lack of understanding of the effect of accounting procedures on the subsequent form that the installed new system takes. Common sense would suggest that engineers would design systems which maximise their return on investment (ROI) - therefore the way ROI is measured should in turn influence system design. There is some evidence that this is the case. Holland [156] noted in his review of BTR's experiences in applying robots that there was a surprising relationship between project capital cost and payback period. (see fig. 2.4.2)

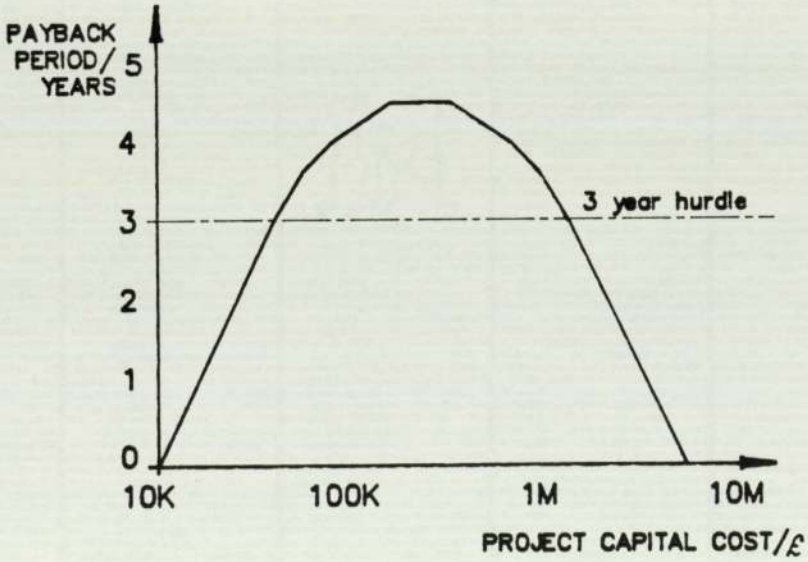


Figure.2.4.2 Graph of Payback Period for a Range of Robot Projects (ref. Holland[157])

The question this raises is: what causes the better return on the mid-range projects? Is it the unsophisticated payback method BTR used for their appraisal? There is no doubt that the use of payback biases selection towards projects which have the highest yields in their early years. Such assessment focuses attention on direct cost as the prime benefits of the investment, particularly direct labour as is the case in the BTR projects. This focus on direct labour costs, despite the fact that they represent on average less than 20% of median factory cost prejudices against the development of systems which bring benefits in other areas, such as improved quality, reduced set-up times etc., as these variables do not get quantified. The remark "if it doesn't get someone out the door, we're not interested"* sums this attitude up. The effect of capital investment appraisal methodology upon manufacturing system design is therefore a crucial interaction between the technical and non-technical aspects of robot adoption.

* (ref. a Trebor manager July 1983) although this is not Company policy.

2.5 Summary

The preceding review of literature provides a perspective to both the scope of the robot implementation task and to the level of development of prior research in the field. It shows that a robot adoption project has only a moderate chance of success and is influenced by a diversity of factors across the organisational, technical and financial disciplines. Particularly, it shows that it is not a purely engineering problem; non-technical issues are of equal importance. Thus the need to adopt an interdisciplinary study of robot implementation is suggested.

However, the review has demonstrated that on the contrary much of the prior research has taken the narrower perspective of one of the specialist disciplines from which to approach the problem. This has led to significant differences and conflict within the literature, particularly between the three key disciplines. Despite these differences, it has been shown that there are indications of linkages between the specialist areas within the overall implementation process. These 'hint' at the possibility of integrating the currently separate perspectives within a common framework, which would allow an overall picture of the robot implementation/adoption process to be gained. This would be a valuable tool for improving the management of future robot projects.

As well as providing insight into the research 'problem' the review has indicated the direction that the research 'method' taken to solve the problem should follow. A number of authors have recommended that future work should concentrate on studying the complexities of implementation as a dynamic process in order to provide the detailed understanding of the problem 'in action' which will allow the currently diverse and separate lumps of knowledge to be brought together within a coherent framework; aiming to provide a picture which has both an outline which has form and structure complemented by detail which reflects reality.

Thus the gap in knowledge which is to be filled by this research has been identified. It is to provide an understanding of the dynamic robot implementation/adoption process from the perspective of the engineer/manager responsible, highlighting the interactions between the various aspects of the problem which occur during the manufacturing innovation process.

CHAPTER THREE

A CASE STUDY OF ROBOT TECHNOLOGY ADOPTION - THE TREBOR PROJECT

3.1 Introduction

This chapter describes the methodology used by Trebor to investigate, evaluate and adopt industrial robot technology. The Rogers and Shoemaker model of innovation is used to provide a framework for discussion of the three major stages in the methodology: awareness and interest in robotics, investigation and evaluation of its potential for the Company and trial adoption.

It is shown how the robot adoption process was quite different from the Company's routine activities, and that it was influenced by the simultaneously organisational, financial and technical context in which it took place.

3.2 Awareness and Interest in Robotics

It is likely that individuals within Trebor first became aware of industrial robot technology in the late 1970's, as a result of the widespread publicity which accompanied its use in the European car industry. This awareness was sharpened in 1980 by work carried out to identify potential applications for microprocessor technology within the company (ref. for example Gregory[158]). One of the possibilities considered at this time was the use of pick and place robots for carton packaging, unit-load palletising and materials handling. Also in March of that year it was reported that Rowntree-Mackintosh, leader in the market at that time, were actively considering a multi-robot chocolate packaging line (ref.Marsh [159]). Two factors which correspond well with Bessant's analysis of adoption stimuli; i.e. in response to an identified need or from awareness that adoption was already being undertaken by a competitor (ref. Bessant [160]).

During 1980 and 1981 robotics was discussed within the Technical division as an attractive development area and this was reflected in the Company's 1981 Technical Policy document which stated:

> "... in 1981 we will begin engineering research aimed at providing flexible mechanical devices to complement the application of microprocessors and thereby endorse our Production and Personnel Policies which aim to enrich the type of work we ask people to do."

Therefore it is clear that Trebor's interest in robotics also developed from the wish to further apply microprocessors, a technology with which they had developed substantial expertise as a pioneer user since the mid 1970's.

In late 1981 the Technical Division was approaching a zenith, both in terms of its level of activity and its influence within the Company. At that time a number of bold, highly innovative projects had been undertaken, ranging from the sequential control of packaging machinery through to the construction of an advanced new factory at Colchester in Essex. Many of these projects had been personally 'championed' by the Technical Director, who pursued strict policies on engineering and technical matters throughout the Group, and who had brought technology to be a highly visible issue in an essentially low-technology, traditional industry. His personal interest in the robotics idea was also a strong influence on its investigation being made part of Company Policy. Thus the main influences upon Trebor's awareness and interest in robotics where: firstly, in response to an identified need; secondly, awareness of their possible adoption by a competitor and thirdly, a strong commitment to the project from a senior manager (see figure 3.2.1).

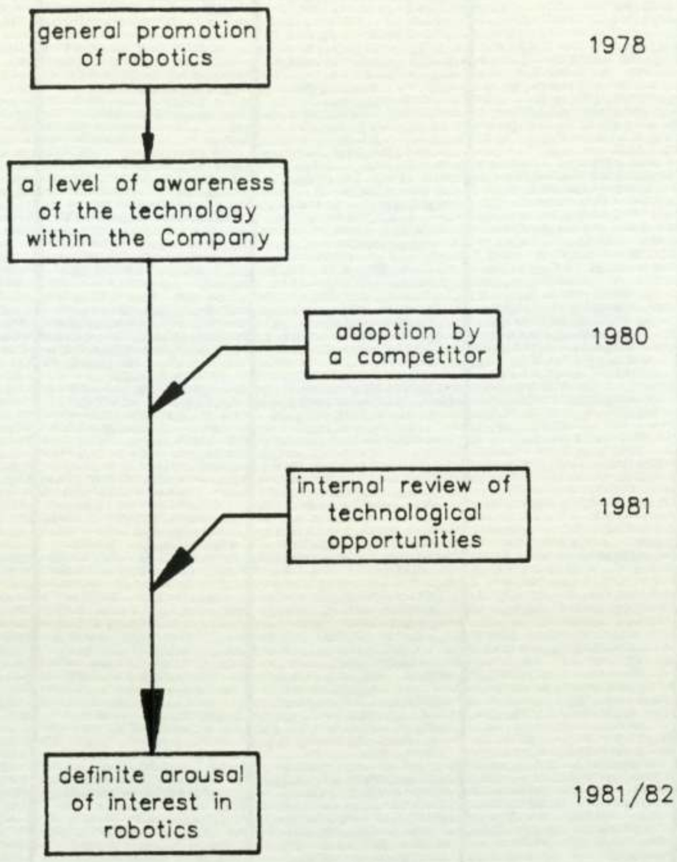


Figure 3.2.1 The Process of Conception of the Robotics Project

Having identified robotics as offering potential advantages for the Company, Trebor management were faced in 1982 with the decision of how best to respond to this opportunity. The following factors were relevant to this decision:

- robotics was a new, advanced manufacturing technology
- there was almost no experience of using robots in the U K food industry
- the confectionery industry was highly secretive, there was therefore no access to opinion leaders to discuss or share experience and risk
- the company had no experience or expertise in robotics
- substantial experience of a related technology had been acquired and a rationalised approach to their implementation had been developed
- a good R & D team, skilled in 'mechatronics' were based centrally in Technical, although they were fully occupied on existing projects.

The solution approach chosen by Trebor management was to set up a project in joint collaboration with Aston University and recruit a graduate engineer to work on it full-time. The Company had experience of collaborative research with Aston through a previous project and considered this to be a good way of managing an innovative project as well as bringing extra engineering skills into the Company.

The key factors in this approach were that:

- the engineer was not an existing employee of the Company.
- he had twelve months previous experience in the development of robot applications in the car industry (however Trebor had not regarded this as an essential criterion in recruitment for the position).
- the emphasis of the project was to be mainly technical, aiming at the development of robot systems suitable for Trebor's special needs.
- the engineer was to be jointly supervised by the Technical team and Aston University (figure 3.2.2) via the Total Technology, Interdisciplinary Higher Degrees (IHD) Scheme.

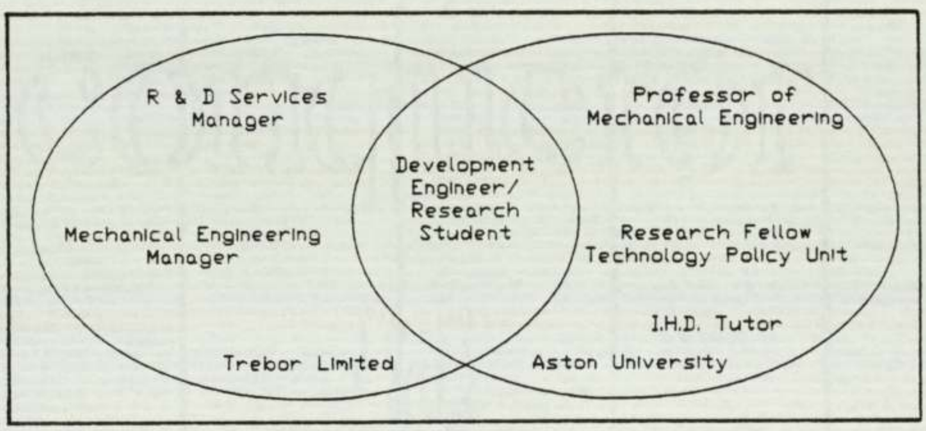


Figure 3.2.2 The Robotics Project Supervisory Team

The author therefore joined Trebor in September 1982 to manage the project and to achieve the following objectives within three years:

a. To identify and assess the potential and implications for using industrial robot technology in Trebor's manufacturing processes.

b. To implement the first robot based manufacturing system in a current production process.

c. To prepare detailed proposals for the second and third systems.

d. To research the process of change involved in the robot implementation process, as a case study of manufacturing innovation.

The scope of the project was specified as covering all manufacturing operations in the U.K. and all aspects relevant to the successful introduction of robotics into the Company.

3.3 Investigation and Evaluation

Following an initial review of the literature on robot applications engineering and study of the problem as presented, an outline plan for the whole project was agreed by the project team in October 1982 (see figures 3.3.1.).

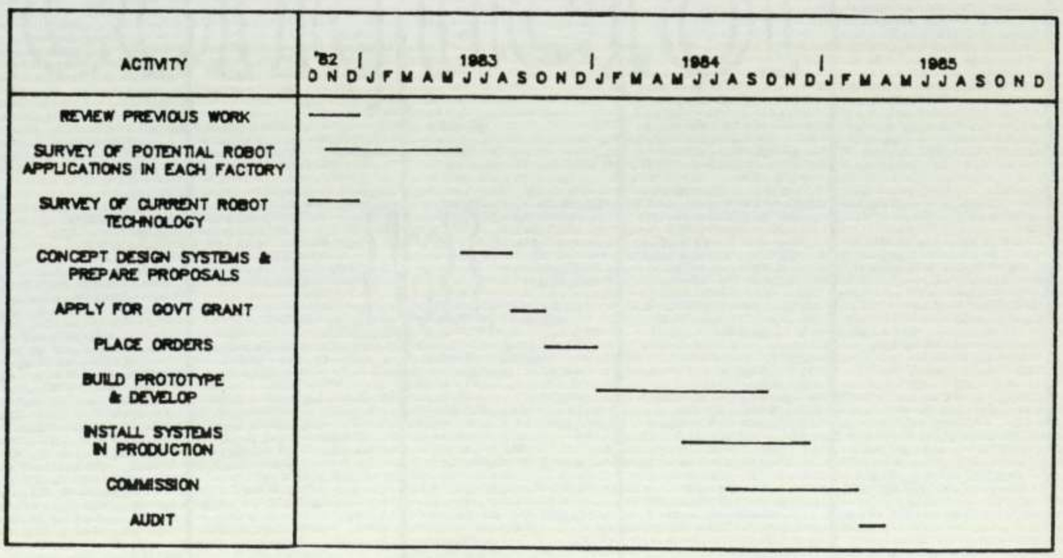


Figure 3.3.1 Outline Plan for the Robotics Project

This plan drew heavily on the work of Ottinger [161] and Tanner in outlining the implementation method, as it was expected that the major problems would lie in the technical area, developing the robot system design solutions to Trebor's special needs. The first stage in the plan was a study of Trebor's current manufacturing processes. Therefore in late 1982 a study tour of the three Trebor factories was undertaken to gain a familiarisation with the technologies, policies and procedures used to manufacture the Company's products. The manufacturing task was identified as: low cost production, to a quality standard of a complete range of confectionery products which vary widely in sales volume, profit margin, life cycle and process technology (figure 3.3.2)

PRODUCT	SALES VOLUME	PROFIT MARGIN	PROCESS TECH'GY	LAYOUT	PRODUCT LIFE-CYCLE
brands	high	high	continuous	flow	long
weighout	medium	medium	batch	functional	medium
children's lines	low	low	batch	functional	short

Figure 3.3.2 Summary of the Trebor Manufacturing Task

Following the audit of the existing manufacturing situation, a survey was carried out at each factory to identify all feasible applications for industrial robots within the current processes. Methodologies for robot-application surveys have been previously researched in some depth[162]. This work has been heavily orientated towards the use of checklists for data-gathering and analysis of possible applications, in common with the larger body of literature on the selection and evaluation of research and development projects. For example Twiss lists fourty-four criteria for evaluating R & D projects (ref. Twiss [163]). The use of a methodology based upon checklists was therefore regarded as being on firm ground in the Trebor case.

In the early stages of the study the Warnecke Schraft checklists for workplace analysis were used, however these were found to be unsuitable for the Trebor study. The main disadvantages were that they were heavily biased towards handling applications; other application types such as process operations tended to be overlooked. Also it became clear that the assessment criteria were not always suitable for the particular needs of food industry applications. In addition the emphasis on consideration of the robot system solution as a separate unit, rather than as an integrated part of the overall manufacturing system was a significant drawback - this had implications for the design of systems at a later stage. Despite these disadvantages the use of checklists was found to be useful. An alternative set were therefore drawn up, designed for the particular needs of the Trebor applications (see figure 3.3.3). However, these were only used to collect data on workplaces which had been already identified as possible robot applications. The study technique and the application data sheet were both improved during the factory surveys. It was found that individual studies took less time as similarities emerged between the factories and between the production processes. The emphasis on following the data gathering procedure diminished as an understanding of the capabilities of robot technology in the context of the underlying principles of Trebor's manufacturing process was acquired.

By the end of the survey of the second factory it was found that the discipline implicit in using the checklists constrained the "thought-process" involved in assessing potential applications as any channelling of ideas in the early stages led to the exclusion of unorthodox but elegant concept-solutions. The basis for this statement is that applications which had not been identified early on using the checklist-method were subsequently considered as feasible. The first robot installation - jar capping is a pertinent example. As a result of experiencing these

TREBOR R&D

ROBOT APPLICATION
DATA SHEET

1. Application No: Date: By: Factory:

2. Application Name:

3. Location: Personnel:

4. Description of Object:

5. Dimensions: L mm W mm H mm Weight: Kg

6. Description of Task:

7. Occasional Variations:

8. Inspection:

9. Load/Unload Time: s Positioning Accuracy:± mm

10. Operation Cycle Time: s Overhead mounting possible?

11. How is Object Presented:

Removed:

12. Machines to be interfaced to this operation:

13. No. of Operators this Operation: No. of Shifts:

14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	:___	5	___
Muscular strain	:___	3	___
Noise	:___	4	___
Dust, vapour	:___	3	___
Temperature	:___	3	___
Monotony	:___	4	___
Eyestrain	:___	3	___
Prot. Clothing	:___	1	___
Oil, grease	:___	2	___
Coldroom Conds	:___	3	___
		TOTAL:	

15. Check location of columns, services, expansion joints etc.

16. Space available for new equipment:

Figure 3.3.3 Robot Application Data Sheet difficulties, the use of checklists was supported by an aide-memoire of study criteria in the later stages of the survey and in subsequent reviews.

Criteria for Study of Robot Application

1 Is the task within robot capability in terms of load, reach envelope and complexity?
2 Is the task heavy, unpleasant or monotonous?
3 Does the operation add value to the product?
4 Is the task labour intensive?
5 Is the cycle time greater than 6 seconds?
6 Can workpiece orientation be controlled?
7 What visual inspection is required during the operation?
8 What is the line output capacity and present output?
9 What is the likely future output?
10 What is the frequency of product variation?
11 What is the relationship of this operation to the process as a whole w.r.t. material flow and machine interfaces?
12 What is the physical nature of the workpiece?
13 What level of positional accuracy is required?
14 How much floor space is available?
15 Has a similar operation already been successfully automated elsewhere?
16 How successful is the present operating method?

These points helped to communicate the key issues in identifying potential applications and promoted the synthesis of expertise between the factory personnel, experienced in the existing situation, and the technical personnel experienced in the robot technology. This is a factor which has been reported by Teale [164] as being essential for successful robot applications engineering. This participative approach also had the advantage that factory ownership of any subsequent proposals would be enhanced, an aspect which had been overlooked in the earlier Trebor studies. In retrospect, involving a member of the factory engineering staff in the study itself would have reduced some of the resistance which was later encountered.

In summary, the robot application survey evolved into a loosely structured study of each production process. Following material flow from goods-in to goods-out all of the applications for robots were identified. Task and process information for each application was recorded on an application data sheet, sketch layout and process flow diagram. This information was supplemented with background data such as product specifications. The results of the survey were then summarised in a report (Appendix A).

Results of the Robot Application Survey

The 1983 survey identified eighteen feasible robot applications in the three factories. Following the installation of the first robot at Colchester in September 1984 this work was reviewed and supplemented by a further study which identified a further ten projects, bringing the total to twenty-eight robot applications identified in the Trebor factories. (figure 3.3.4) These applications were grouped as follows

	No	%
By type of application:		
Packaging	12	34
Palletising	10	29
Materials handling	10	29
Assembly	3	8
	35*	100
By type of product:		
Major Brand	11	39
Brand pack derivative	5	18
Total brands	16	57
Wrapped weighout	2	7
Unwrapped weighout	1	4
Children's line	7	25
Total commodities	10	36
Others	2	3
Total	28	100

Thus the majority of applications were in the areas of packaging or handling of major brand lines.

*Double counting for multiple-operation applications.

APPLICATION NUMBER	APPLICATION	APPLICATION TYPE*	PRODUCT TYPE
XX001	export-case packing	PK	BD
XX002	carton (rolls) palletising	PA	MB
XX003	multipack packing	PK	BD
XX004	carton palletising	PA	MB
XX005A	jar packing	PK	BD
XX005B	jar line	MH-PK-PA-AS	BD
XX006	bin filling	MH-PA	MB
XX007	jar capping	AS	BD
CC009	1p chew packing	PK	CL
CC010	5p chew packing	PK	CL
CC011	bin filling	MH-PA	WW
CC012	jar manufacture	MH	-
CC013	lollybag packing	PK	CL
CC014	jar packing	MH-PK-PA	UW
CC015	lollypop carton packing	PK	CL
CC016	imperials carton palletising	PA	MB
CC017	lollyade manufacture	MH	CL
MM020	transwrap-bag packing	PK	MB
MM021	case palletising	PA	MB
MM023	jar manufacture	MH	-
MM024	jar conveyor loading	MH	MB
MM026	case packing	PK	WW
MM027	packing assortments	PK	CL
MM028	palletising carton assortments	PA	CL
MM029	hopper loading	MH	MB
MM030	driam pans loading	MH	MB
MM031	jar capping	AS	MB
MM032	multiple palletising	PA	MB

*Key

PK - packaging
PA - palletising
MH - materials handling
AS - assembly

MB - major brand
BD - brand pack-derivative
WW - wrapped weighout
UW - unwrapped weighout
CL - children's line

Figure 3.3.4 Applications for Industrial Robots in Trebor

Having established the potential for using robots in production the first stage in the project, investigation and gathering of data, was complete. In order to move on to the next stage it was necessary to gain commitment from Production Division to the project. This corresponds to Kanters [165] "waves of activity" in innovation:

problem definition -	The acquisition and application of information to shape a feasible focused project.
coalition building -	The development of a network of backers who agree to provide resources and/or support.

Production Division's agreement to the project method was gained via the production management meeting (PMM)[166] which was attended by the author in April 1983. At this meeting the emphasis of the project was made clear: the first robot installation in production, whatever it did, must be totally reliable and be seen to be effective. The Company had lost confidence somewhat in its ability to achieve successful technical innovation, therefore a successfully installed first system working well, would be more important than its cost saving benefits. Its major value would lie in proving that the technology works and that Trebor could use it effectively. Consequently a simple application should be attempted first as a trial adoption. In this area Trebor closely followed previous robot pioneering companies in emphasising the learning aspects of the first project and in keeping it simple. Tanner for example had in 1976 recommended tackling the simplest application first and this point was later reinforced by Macri[167] who argued that choosing the 'right first application' was crucial. Behuniak [168] reported that it was unrealistic to expect significant operational benefits from the first system, as it was necessary to "make an up-front investment to even test the applicability of robots" and to get on the learning curve. Trebor senior management was also convinced of the soundness of this strategy, and agreed that the next step of the project should be for the author to work with the factory management teams in selecting an application which met these two criteria of simplicity and reliability.

Appraisal of the Robot Applications Identified by the Factory Surveys

The method used to compare the applications identified was developed following a review of the literature on robot application appraisal [169]. This previous work focused on the use of assessment sheets listing the criteria to be considered, each weighted to reflect their relative importance.

A wider review of the literature on innovation management suggested that a number of other techniques for project assessment were also suitable, particularly project profiles (ref. Twiss [170]). This work also highlighted that the concept of portfolio selection could also be useful applied to the selection process. An assessment technique based upon a project profile of twenty-two parameters was used (figure 3.3.5) because this offered the advantage of a visual rather than a quantitative representation of the project, aiding its communication to interested parties. Each potential application was assessed using this method in conjunction with the management team of the factory concerned (see Appendix B). A shortlist of preferred projects was then agreed at each factory on the basis of these joint assessments. These shortlisted projects were then further investigated in greater detail. The analysis of each proposed application included a financial appraisal, which followed the Company's normal appraisal method for capital expenditure projects i.e. three year payback. This analysis showed that the majority of proposed robot applications did not meet the Company's investment hurdle of three year payback.

PROJECT PROFILE

EVALUATION / FACTOR	V.GOOD	GOOD	AVERAGE	POOR	V.POOR
SOCIAL					
System benefits workers in terms of: health					
Safety					
unpleasant work					
new skills					
FINANCIAL					
Low capital investment					
High net benefits					
High % rate of return (DCF)					
Revenue time profile					
TECHNICAL					
Probability of technical success					
Operational simplicity					
Little visual inspection required					
Proportion of process automated					
Remaining life of existing plant					
Few changes to existing process					
Floor area adequate					
Technology applicable to other areas					
Little one-off development					
Allows further use of new technology					
Improves process flexibility					
Improves process control					
Improves product quality					

COMMENTS

Figure 3.3.5 Project Profile Sheet

Outline Design of the Shortlisted Applications

Outline design studies were prepared for each of the shortlisted projects, based upon specifications agreed with the factory management teams (see Appendix C).

The literature on robot system design was found to be well established, so that although no work had previously been carried out specifically on the design of applications in the food industry, a method based upon the common elements of the previous work of Warnecke-Schraft, and Tanner was adopted. Their close agreement and depth of experience suggested that such an approach was well founded. The method used for the design of the Trebor robot application is summarised below (figure. 3.3.6).

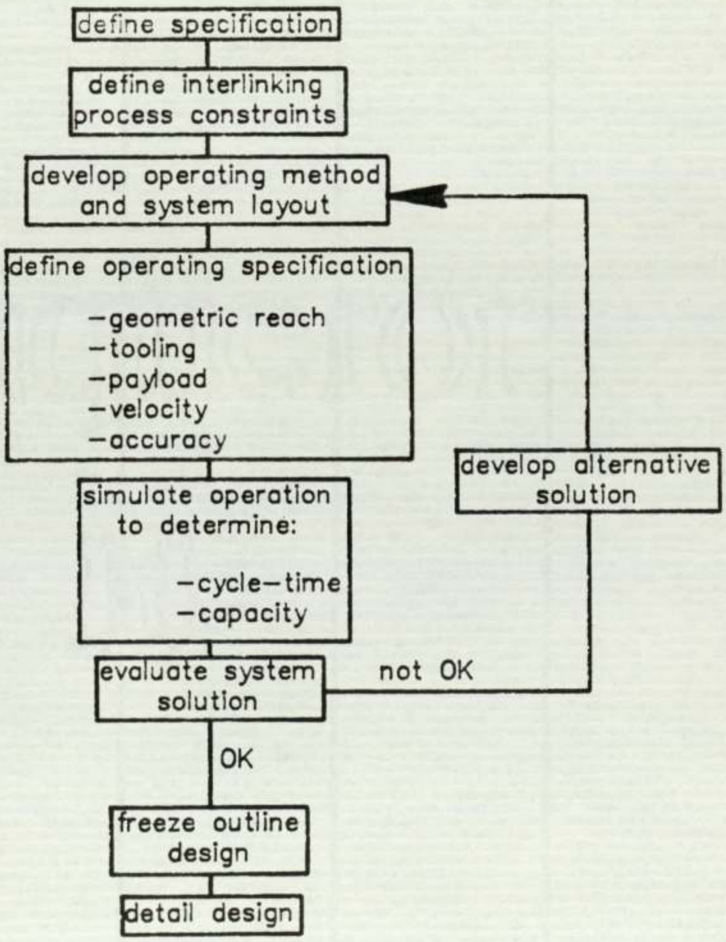


Figure 3.3.6 Robot System Design Method

During the three year project nine applications were studied in detail. This experience gave some insight into the structure of the robot application design problem, the way in which the design engineer has to perform a juggling act between the various parameters of the problem, within the constraint that they are all linked within a web of relationships (figure 3.3.7). For example, the reach[171] required by the robot for the task determines tool centre point[172] velocity and accuracy and therefore tooling design and cycle time. Cycle time is determined largely by the process constraints which fix the boundaries on method and layout - determining reach required ...

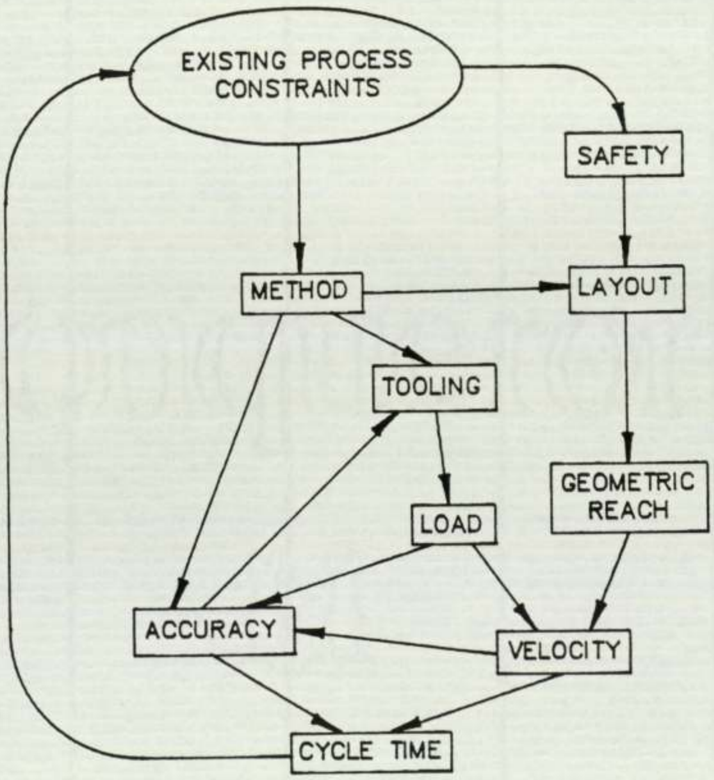


Figure 3.3.7 Diagram of the Robot Application Design Problem

Thus system design was largely an iterative process, exploring tentative method and layout solutions and then investigating the implications for the subsequent design parameters with the aim of increasing the elegance of the design; i.e. providing a simple solution to a complex problem.

These tentative solutions were then evaluated in terms of the original brief and specification. Finally a checklist for the design was used to remind the author of the really important factors after being enmeshed in the technical detail:

Check:

1. Has the real problem been solved?

2. Overall, does it look right?

3. Have any of the subtleties of the present method been missed? e.g. - cleaning, inspecting, orienting?

4. Is there enough in reserve capacity/reach/speed for the unexpected?

5. Is the cost reasonable?

6. Is the level of technical uncertainty reasonable at this stage?

Once the concept design had been vetted against these points the proposed solution was discussed with the relevant factory personnel. It was at this stage that the design specification was usually modified, changed, or the proposal objected to on various grounds.

Major Problems Associated with the Proposed Projects.

PROBLEM	TOTAL NUMBER OF PROJECTS AFFECTED
system used excessive floorspace	15
payback exceeded 3 years	11
integration with the existing process difficult	6
other process development prevented implementation	7
conventional machine was more suitable	4
sales volume too low to justify investment	4

Often the changes would be quite subtle, but because of the web of chained design parameters it would usually require a complete redesign. With all four of the applications shortlisted in June 1983 there were objections to the systems proposed which related to the interlinking of the robot system with the existing process, and the up and down stream changes that its implementation would require. This stage in the project over-ran its planned timing by four months, primarily because it was extremely difficult to gain agreement on the selection of the first application with the factory management teams. Changes in specification, new information and other issues required repeated redesigns and re-submission of proposals, so that rather than a sequential objective process of design appraisal and selection as described in the literature, in practice it was found that this stage of the project was an iterative process of bargaining and negotiation with factory management, aiming to get their commitment to making these changes and accepting the disruption to the factory situation that the robot installation would entail. Generally these problems were regarded as evidence that "... robots aren't really right for Trebor" (factory manager July 1983) rather than difficulties associated with technological change which just had to be overcome.

Thus, although much of the resistance to the proposals arose from real objections, there were non-technical influences which affected people's willingness to overcome them. For example, an application considered twice over an eighteen month period was objected to on the following grounds (see Appendix C).

Date	Work Done	Objections Raised
June '83	Concept design	Floorspace, access to other machines.
July '83	Redesigned	Local weakness in factory floor, robot system exceeded rated load.
Aug '83	Redesigned	Process developments in adjacent area prevent installation of robot.
Jan '85	Reconsidered	None
Feb '85	Redesign	None
March '85	Detailed design	Other process development work suggested 100% increase in line capacity likely, therefore robot solution unsuitable.
April '85	Project abandoned.	

Such an example was not unusual during the selection of the first and second robot applications, similar difficulties also occured during the introduction of microprocessor technology (ref. factory engineering manager, R & D engineering manager June 1985). Clearly there was a need to investigate these problems in greater depth as they had a very strong influence upon the ability of the Company to manage technological innovation. An analysis of these problems and the conclusions drawn are reported in chapter five.

The selection of the first robot application took five months in total, ending with the decision to proceed with a jar capping project at Colchester. This involved using a 3-axis[173] robot to put twist-caps onto jars of Extra Strong Mints (ESM). This particular application had not been identified during the factory survey, firstly because the application did not exist at Colchester at that time as ESM jars were produced at Maidstone and secondly because it was not recognised as an application which required programmable automation. Up until August 1983, when jar capping was first suggested, work had been concentrating upon a shortlist of four projects then thought to be most suitable:

MM029	Hopper loading
XX005	Jar packing
CC011	Bin filling
CC016	Carton palletising

However, each project had significant difficulties associated with it, primarily in their integration with the existing process. Substantial problems were experienced designing the interface between the robot systems and the existing process equipment as the need to make up and downstream changes were prevented for cost and operational reasons. The integration problem was common to most projects and was therefore studied in detail. Chapter 7 discusses this area in the context of the systems engineering method used and the design of the current generation of robots. It shows that there is a link between the technical problems with implementing robot systems and the management approach taken to introducing new technology generally, which has implications for the organisational and financial aspects of the wider innovation process. This interaction between key influences is reflected here in the decision to progress the jar capping application.

Its advantages were that: firstly, Colchester had to prepare for transfer of ESM jar production in Spring 1984; jar capping was recognised as a longstanding quality problem throughout the Company and robotics offered the best way of solving it. Secondly, there were no financial obstacles as the robot system would not come out of the budget for the new jar line - a very big advantage. Thirdly, because it was a new line there were no integration, floorspace or process-development problems. Colchester were also experienced in introducing new technology; the whole factory was innovative in concept and organisation and the management team were committed to the idea of using robots. Colchester engineers had attended the 1983 Automan exhibition and a feasibility demonstration of jar capping using a robot at Dainichi-Sykes, reflecting their positive interest in the technology.

Once agreement had been reached between Colchester factory and the R & D team on the outline design of the jar capping system, this application was recommended to PMM as the most suitable project. The project was approved in October 1983.

Application for Grant

Once the decision had been taken to go ahead with the jar capping application, contact was made with the Department of Industry to discuss Trebor's eligibility for support under the Flexible Manufacturing Systems Scheme in parallel with the initial development work.

Investigation of the scheme in February 1983 had established that support up to one third of project cost was available. However by October 1983 demand for grant aid had increased dramatically, leading to a policy of competitive selection by the Department's officers. It was made clear that Trebor would have to "demonstrate very significant justification" (ref. scheme officer November 1983) based upon two criteria: additionality and innovation. It had to be shown that Trebor would be unable to carry out the project without additional financial support from the

Government or that the high degree of innovation represented by the project was accompanied by equally high risk which the Company could not carry alone. Early discussions with the Department of Industry showed that Trebor's application would rate very poorly on these two counts. The Company was large and had its own engineering resources whereas the proposed application was of moderate cost and of low complexity. It was also pointedly noted that the Department was concerned that "too many companies were installing robots piecemeal, not adopting the technology in a way that allowed the full productivity benefits to be gained". This view corresponded exactly with the conclusion which was emerging within the robotics team at that time: Trebor needed to view robots as a long term investment requiring sustained commitment to adoption but linked to a staged approach to implementation. Therefore a revised application was made to the Department of Industry for support for a two year project involving the implementation of the first 'learning' project: jar capping, and a second more complex packaging and palletising system. The application stressed Trebor's commitment to taking the long term view but with the proviso that consideration needed to be taken of the time it takes to develop the necessary in-house expertise to tackle ambitious schemes. It was argued that a two stage approach would "enable us to take a longer term strategic view on implementation and to plan ahead with greater confidence".[174] The application for £100,000 grant for two systems was approved in February 1984.

The emphasis put by the Department of Industry upon tackling innovative projects may have pressured some other first time users to do so in order to improve their chance of receiving grant aid. Certainly their robot supplier would be pushing for the most sophisticated project and would underplay the likely problems associated with complex applications. These two factors were both experienced in the Trebor case and may have been contributory causes behind the high failure rates of U.K. robot applications identified by the Aston Study.

3.4 Development, Implementation and Trial Adoption

Having decided which robot application was to be implemented first, this third stage in the project involved the design, development, installation and commissioning of the system itself. At this point two alternative routes were open to the project team.

1. To contact a robot systems supplier to provide a turnkey system.
2. To purchase the component-systems and develop the system in-house.

The following factors were relevant to this decision:

a) probability of technical success

b) experience gained within the Company

c) resources available, both human and financial.

The literature[99] suggested that given adequate resource within the company it was preferable to develop the system internally. The reasons given were that firstly, in a new application area or pioneer industry sector (this project was both of these) expertise in robotics is less important than a thorough understanding of the application itself. In other words a robot supplier with no previous experience of the confectionery industry or jar capping automation is less likely to develop a successful system than the company owning the problem. Secondly, expertise in robotics can best be developed within the company by actually developing application solutions. This is particularly important later on when the system has been installed and has to be maintained by the company.

The main disadvantage of developing the system in-house was that Colchester engineers preferred the turnkey option; they believed that they could control projects more easily when dealing with outside suppliers. Working with Technical was complicated by all the same factors which had delayed the project decision in the first place, also the difficulties associated with the introduction of microprocessors as an in-house venture meant that such problems had only recently been experienced. It was partly because of this that the robotics project's remit to "analyse the process of adoption involved in introducing robots" had been set. This was another factor in favour of the in-house route.

In October 1983 Technical management decided that the first system should be developed internally. Two development engineeers (including the author) and one development fitter were assigned full-time to the project to meet the target installation date of the end of September 1984.

The Jar Capping Project

A joint project team was set up in late October 1983 to manage the jar capping project as it was believed that the additional considerations associated with the first robot installation warranted a joint steering group. It consisted of

Colchester	- development engineering manager
	- maintenance engineering manager
	- production manager
	- development engineer
Technical	- development engineer
	- development engineer/research student - (the author)

The group's task was to coordinate the work on the robot cell and the rest of the jar line. The Technical engineers were responsible for developing the robot cell itself. Prior to setting up the joint team it had been suggested by Colchester that Technical build the complete jar line, including developing an automatic jar filling system. This was however rejected due to a lack of resource and because it countered the project's original objective of simplicity and reliability set by PMM.

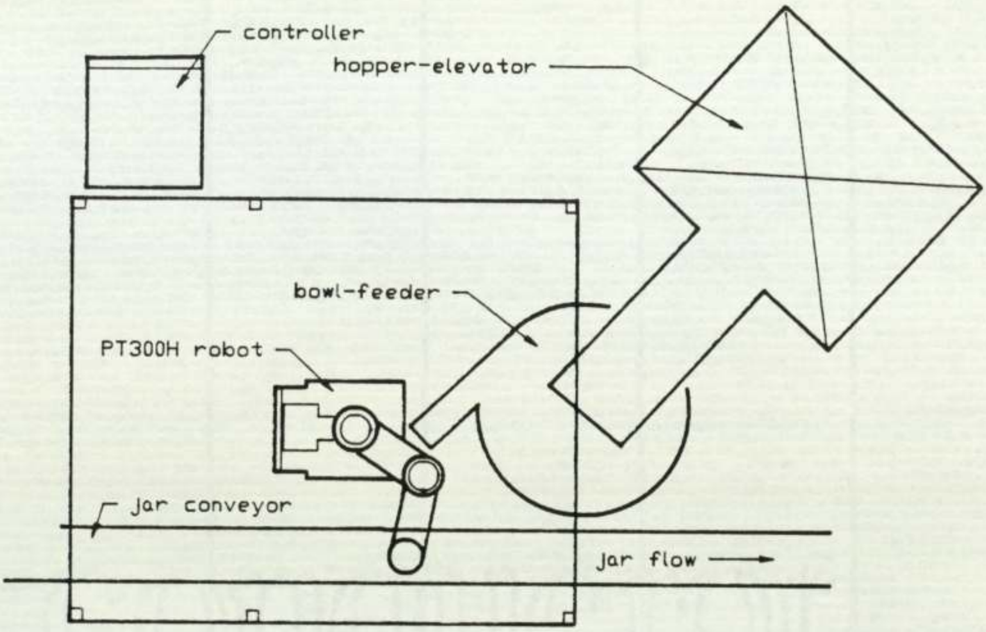


Figure 3.4.1 Robot Jar Capping Cell

It was agreed by the joint team in November that it was important to involve the operators who would eventually run the system in its design, and also to communicate the purpose and scope of the project to the factory work-groups. This was done in two stages. Firstly in December 1983 a presentation was given to all ESM production and maintenance people about the project. This included showing a video of the robot taken during the feasibility trials and an outline of the reasoning behind using a robot based system. It also provided an opportunity to answer any questions about the work, or robots in general. Secondly, a number of meetings were held early in 1984 with the work groups concerned to discuss the project in detail, including its design. These efforts were very successful. The operators were primarily concerned about whether robots would put them out of work; once it had been guaranteed that this would not happen they were very enthusiastic about the project. In fact they took the attitude that the Company was not introducing robots fast enough - "why can't we have robots doing the rough jobs like palletising and case packing as well?" (ref. ESM operator April 1984). There was also good commitment to making suggestions for improving the layout of the system. A particular concern was the safety of the robot system; there was some fear about 'the robot', even after seeing it work on video, which required reassurance. The enthusiasm of the operators also gave a boost to the morale of the Technical engineers who gave the presentations.

The development of the robot capping system itself caused comparatively few problems for the project team, and was completed on schedule within seven months. The main areas of difficulty were:

a) designing the tooling to cope with three types of jar and two types of cap.
b) selecting proximity and position sensors which would function in the factory environment.
c) developing the software to orientate the randomly orientated caps without the facility of parallel processing.[175]
d) meeting the 7.5s overall cycle time
e) protecting the system components to IP55[176]

The solutions achieved to these problems are reviewed in Appendix D which describes the jar capping cell in more detail.

The installation of the robot cell at Colchester was originally scheduled for September 1984 to coincide with the completion of the new jar line and transfer of production from Maidstone factory. The Technical team were very keen to meet this deadline in order to refute the doubts that were raised about their ability to do so in October 1983. However, when the system was finished in early September the new jar line was not ready for installation at Colchester and transfer of jar production from Maidstone had been put back to Spring 1985. The cause of this was a high level of unforeseen workload for Colchester engineers over the Summer months, which had greater priority than the jar line. Also, a cut back on the budget for the new system meant that some existing machinery had to be refurbished and used in the new line, contributing to the delay.

Despite this however, it was decided by the joint team to install the robot cell as planned because it was felt that the delay gave a good opportunity for training people in operating and maintaining the robot cell before it was put into production. The literature also suggested that this was a useful opportunity as it stressed the need for a quiet period between commissioning and full production to enable people to become familiar with the new robot system (ref. Macri[177]). The robot cell was therefore installed and commissioned at Colchester in late September.

Although the jar line was completed in Spring 1985, it was not in continuous production until Autumn due to further delay in the transfer of jar production from Maidstone factory. This was due to an increase in demand for ESM which could not be met solely by production at Colchester factory. During this time work was begun on the second robot application.

Second Robot Application

The design studies carried out on the four shortlisted applications in 1983 had shown that the most attractive project after jar capping was end-of-line carton palletising. A number of areas existed at both Chesterfield and Colchester for automated palletising so that the advantage of spreading development costs over a number of repeat applications could be envisaged. The best application of these was at Colchester factory, to palletise cartons, export and multipack cases of Trebor Mints. This project offered the advantages of adequate floorspace and

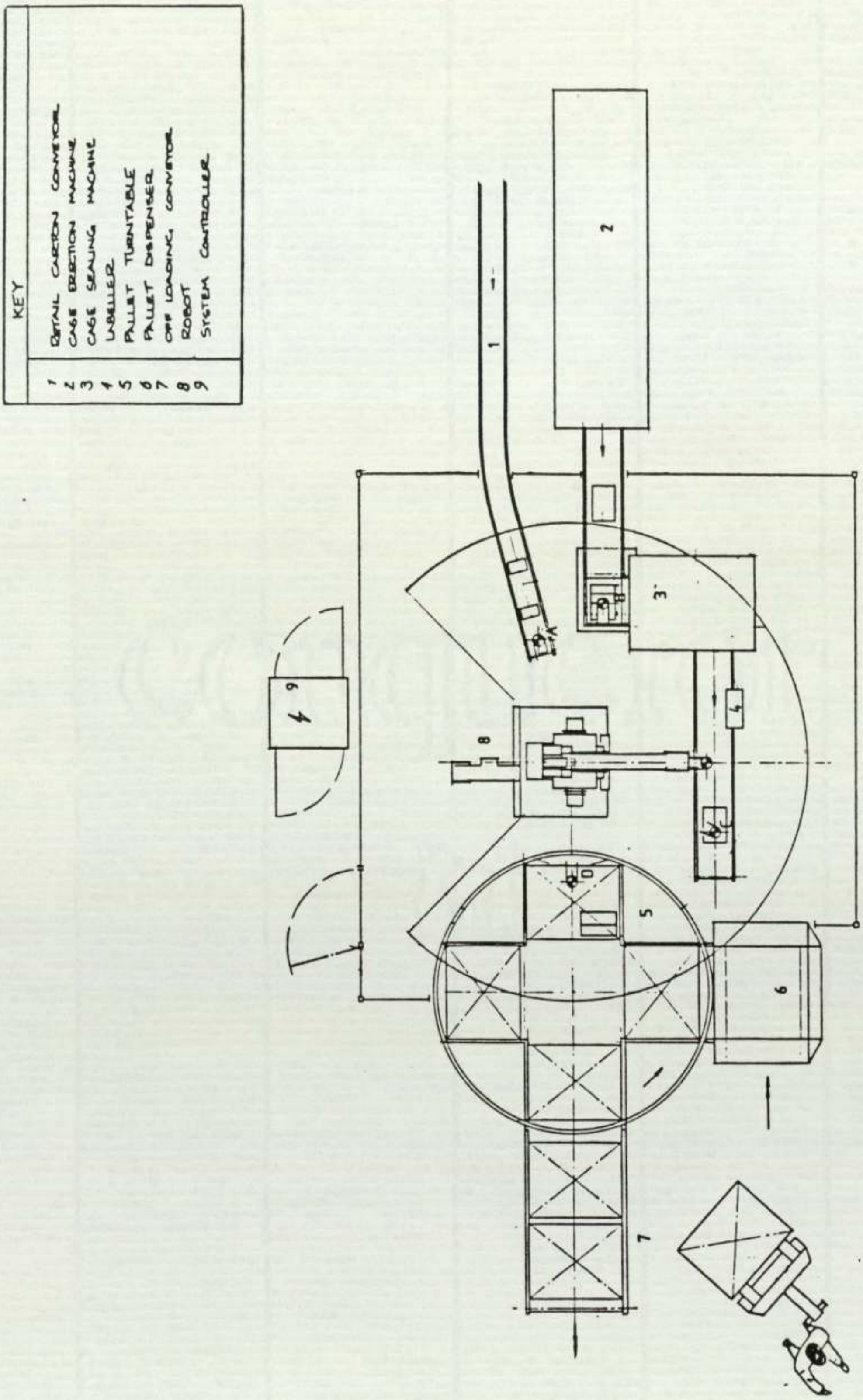


Figure 3.4.2 Robot Palletising System (plan view, scale 1:100)

ceiling height, the possibility of integrating three pack derivatives into a single line, but above all the opportunity of automating all palletising and case-packing of products at Colchester in the future and linking these end-of-line systems with the on-site warehouse via automatic unit load carriers (figure 3.4.2). This project therefore offered a first step to making significant productivity gains whilst maintaining flexibility to respond to product or packaging changes. This concept had been discussed earlier on with the robot systems suppliers, and had been shown to be feasible - similar systems were already installed in other companies. A staged implementation approach could also be followed if an overall plan, design and interface standards were establised at the outset. It was this approach which had been agreed with the Department of Industry in Februrary 1984 as using robots in the most effective way and which was supported by grant aid. The first step was the detail design of the building block of the system - the end-of-line robot palletising cells.

The palletising system proposal was raised at the next Production Management Meeting by the production director. However, it met fierce opposition from the Colchester management team because they were "angry that the idea had not been discussed with them first .. they didn't want a second robot - they hadn't even got to grips with the first one yet" (Colchester manager December 1984). The robot palletising concept was therefore not taken any further, instead the robot project overall was dicsussed between the production director and general works managers and the decision taken to go ahead with a second robot application which would be agreed with individual factory management teams in the same way that the first project was selected.

The earlier factory surveys were reviewed and discussions held with each of the factory management teams; identifying a new shortlist of projects.

Chesterfield: End of line carton palletising - Mint Imperials

Maidstone: End of line carton palletising - Softmints; Hopper loading -Bon Bons

Colchester: no applications at the present time.

The palletising project was therefore restarted in February, this time concentrating on the Chesterfield and Maidstone applications which were very similar. The hopper loading project was also looked at again. This had been the subject of a detail design study in 1983, but had been subsequently rejected.

Fully developed proposals were prepared in conjunction with three robot suppliers for these two projects. These were discussed with the factory management teams and then PMM in April 1985. The Maidstone hopper loading application was approved by PMM as the second robot application and the amount of £55,000 allocated from the capital expenditure budget. The reasoning behind this decision was that:

a) the palletising projects were less technically risky and could be left until after the collaborative links with Aston University had ended in September 1985. It was better to use these resources on the hopper project which was more technically uncertain;

b) the palletising project was nearly twice the cost of the hopper project, putting great strain on the capex budget;

c) Maidstone factory management were very committed to doing the hopper project whereas Chesterfield were already heavily committed on existing development work scheduled for the Mint Imperials line.

The Hopper Loading Project

A project group[178] was set up at Maidstone in early April to carry out the project, led by the development engineer who had been transferred from R & D after working on the jar capping project. The group consisted of

- development engineer
- the supervisor of the Bon Bon jar filling area where hopper loading was carried out
- electrical foreman
- mechanical foreman
- industrial engineer
- R & D development engineer (the author)

The Maidstone development engineer reported to the factory works engineer who reported back to the factory management team. On the R & D side, the author reported to the robotics project team.

At the first project group meeting it emerged that there was other development work underway on the Bon-Bon production line which would affect the robot application. Specifically the speed of jar filling could be increased by 100% if trials due to be carried out with new weighing systems later in April were successful. At the second meeting on 17th April it was confirmed that the specification agreed for the robotic hopper filling system would need to be changed to meet the faster filling rate of 20 jars per minute. This corresponded to a robot cycle time of 7.5 seconds. As the original design could not meet this time, alternative solutions were considered but proved to be infeasible because they required substantial up and downstream changes to the Bon-Bon line. The project was therefore abandoned on the 23rd April. Both Maidstone and R & D were enthusiastically committed to the hopper loading project and were severely disappointed that it had to be rejected. Other projects at Maidstone were investigated, particularly Softmints palletising but because of ongoing development work on Softmints they could not be progressed at that time.

Again the robot project had run into the same problems: interfacing with the existing process (see Appendix C).

<u>Operation of the Jar Capping Robot Cell</u>

Before the jar capping system was installed at Colchester in September 1984, four maintenance fitters from the factory attended the PT300H robot electrical and mechanical maintenance course at Dainichi-Sykes. Although the literature reports that making one person responsible for looking after the robot system is important during the run-up stage - the "factory robot-man" concept - it was decided to train four people: two mechanical, two electrical to ensure that there was always a trained fitter on site at all times. Also identifying one person as the robot expert did not sit easily with the principle of work-group organisation used at the factory, which discourages demarcation of tasks.

Once the robot was installed and commissioned, short refresher sessions were held and training given on the overall jar capping cell to both the maintenance personnel and the jar line crew. It was found that people's enthusiasm for the system and their commitment to dealing with any snags quickly were greatly increased once they began to feel confident in their ability to cope with the system. This is of course very important during the run-up stage when problems are likely to arise and have to be overcome quickly. Because there had been a significant delay between the commissioning and operation of the system, it was beginning to be regarded as a "dust gathering ornament", (ref. ESM operator - March '85) so there was some doubt as to whether there would be any commitment to running the system once production had been transferred from Maidstone.

Project Review

When it became clear that it would not be possible to implement the hopper loading application the decision was taken by the robotics project team not to focus on an alternative application but to step back and review the project overall. It was clear that the first and second robot projects had highlighted recurrent problems which needed to be better understood and overcome if the use of robots by the Company was to be more widespread. The following work was therefore carried out during May to June 1985:

a) interviews with key personnel involved in the project
b) analysis of the Trebor robot applications
c) review of Trebor's business strategy,Technical and Production three year plans
d) study of the Company's capital budgeting procedure.

The results of this review were presented at the PMM in June and are discussed in the following chapters. It was described how there is significant potential for using robots in Trebor but that there are equally significant obstacles existing at present which were preventing the realisation of this potential and hindering innovation in the Company in general. It was argued that the removal or lowering of these obstacles must be the next step.

These recommendations were considered by the technical and production directors and the following action plan agreed:

1. Wider communication of the learning points which came out of robot project via factory management teams, U.K. engineering meeting and Technical Review.
2. Wider dissemination of robotics expertise within the Company.
3. Development of a technology strategy.
4. Work on reducing obstacles before attempting to implement the second application.

3.5. Summary

Although the Trebor case-study followed in outline the Rogers-Shoemaker model of the adoption of innovations, it has been shown that the detail of the process was highly complex, involving many diversions from the planned route. Despite this, the time taken from conception to operation of the first robot at 19 months was about average for U.K. robot application projects [179].

The complexity of the adoption process arose from the three-dimensional context in which it took place. That is, the technical problems had financial and organisational dimensions which were crucial to their solution and which could not be managed within the framework of a single discipline; be it engineering, accounting or management.

The following chapters analyse the case-study in detail, considering in particular the linkages between the three disciplines, with the aim of developing a framework for the overall robot adoption/implementation process.

CHAPTER FOUR

INTERACTIVE PROCESSES IN ROBOT ADOPTION

4.1 Introduction

It has been described how this research provides new insights into the adoption of new technology via its participative role in the adoption process itself. This chapter reports upon the results of this approach and to do so uses a novel method of presenting the data from the case-study. In order to describe both the technical and non-technical influences upon the adoption process within a common framework which includes the time element, a form of project diary is used (see Appendix E). This allows the technical and non-technical events to be analysed in the context of the changing project environment in order to test the hypothesis that the interaction between the technical, organisational and financial aspects of robot adoption is the key to understanding the complexity of factors involved. In particular, reporting the researcher's personal view of the project provides new insight into managing new technology adoption, a perspective which the literature, on project championing for example, has identified as a key area.

> "... among the questions felt to be most important for future research were the following: What motivates project champions?... What are the key personality issues involved with product champions? Are they the same as those of general managers? Do they employ similar skills?" (180)

The analysis of the championing sub-process in section 4.5 goes some way to answering these questions.

The diary provided a means by which an overall view of the complete implementation process could be gained and allowed the interaction between the various parallel dimensions of the problem to be studied. This led to the identification of four sub-processes of robot adoption: engineering, technology transfer, learning and entrepreneurial processes which are used to provide a framework for integrating the separate, specialist disciplines reviewed in chapter two. These are discussed in the following sections.

4.2 The Engineering Process

In October 1982 the Project Team agreed a plan and timescale for achieving the second project aim: the implementation of the first robot system on a production operation (see figure 4.2.1.) It was expected that the implementation process would follow a step-by-step methodology, similar to most engineering projects, where the major difficulties would lie in the development of the robotic system itself. The literature suggested that this would be the case and that skills in production engineering and robotics would be paramount. The Trebor plan was therefore based upon these premises and reflected a highly mechanistic, technical approach to the problem. The author also felt comfortable with this emphasis as it was in tune with his training as an engineer and his understanding of the engineer's role in manufacturing industry, i.e., providing solutions to technical problems, involving the co-ordination of resources and planning of work.

The actual route taken during the three year project differed substantially from this original plan (see figures 4.2.2. and 4.2.3. and the summary of the engineering process below). Although all the objectives were achieved (even slightly ahead of schedule), both the path taken and the emphasis of the work involved were widely different from the researcher's expectations. Firstly, the implementation process did not follow a sequential path but involved repeating some steps, taking paths which led in the end to blind alleys and having to retrace back; the development of the second robot application being a good example of this. Secondly, three activities in the plan took substantially longer than expected:

1. The selection and design of the first application - planned to take three months it actually took six.

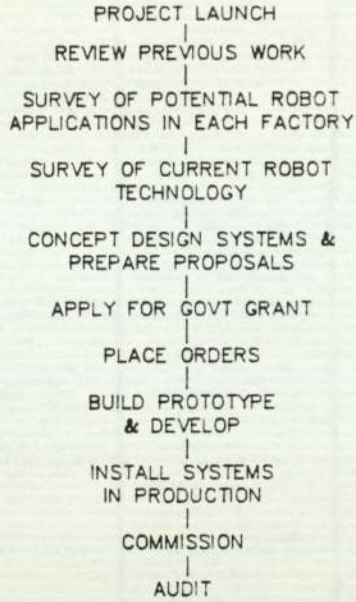


Figure 4.2.1 Project Method Planned in October 1982

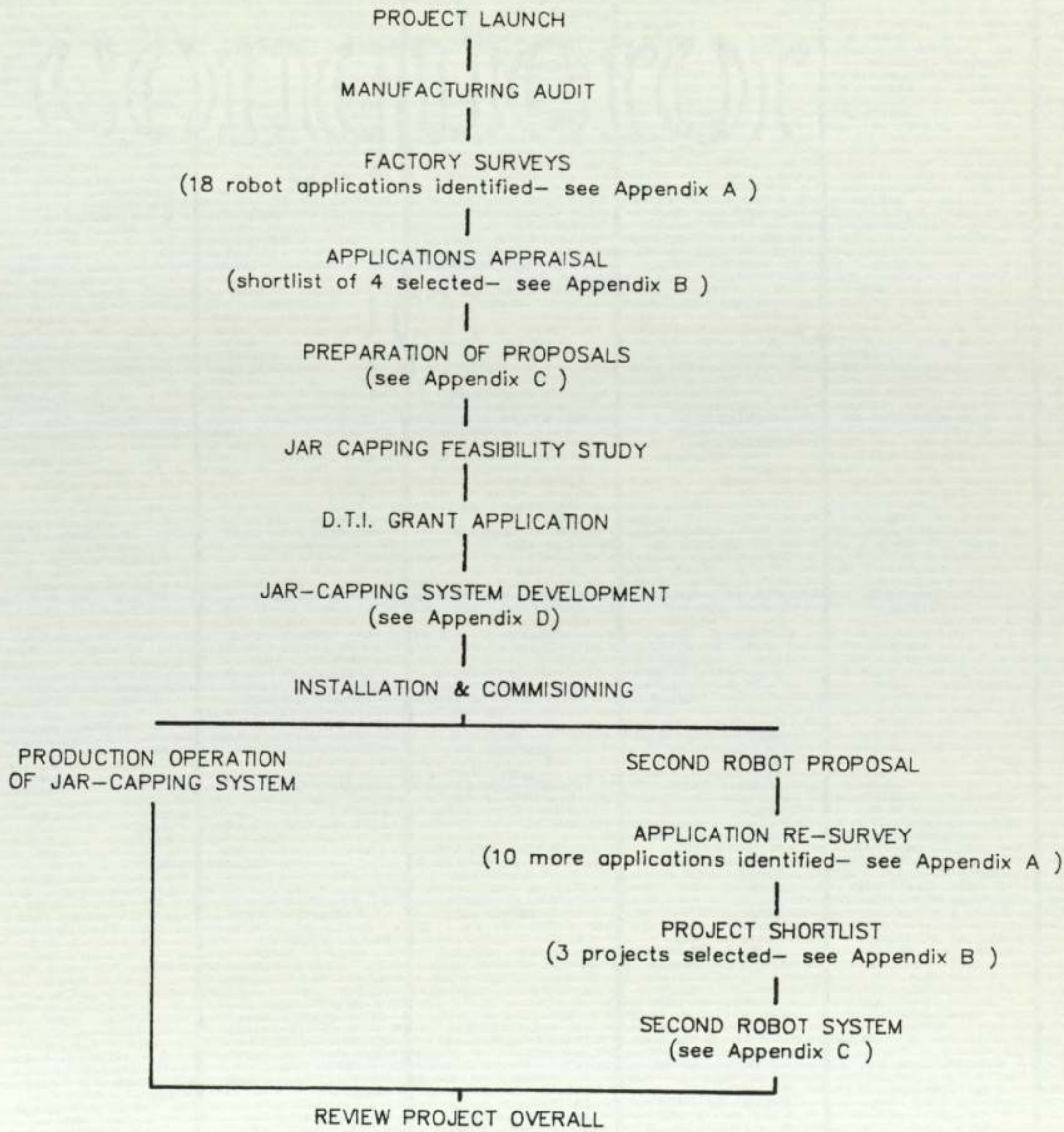


Figure 4.2.2 Actual Project Method Followed

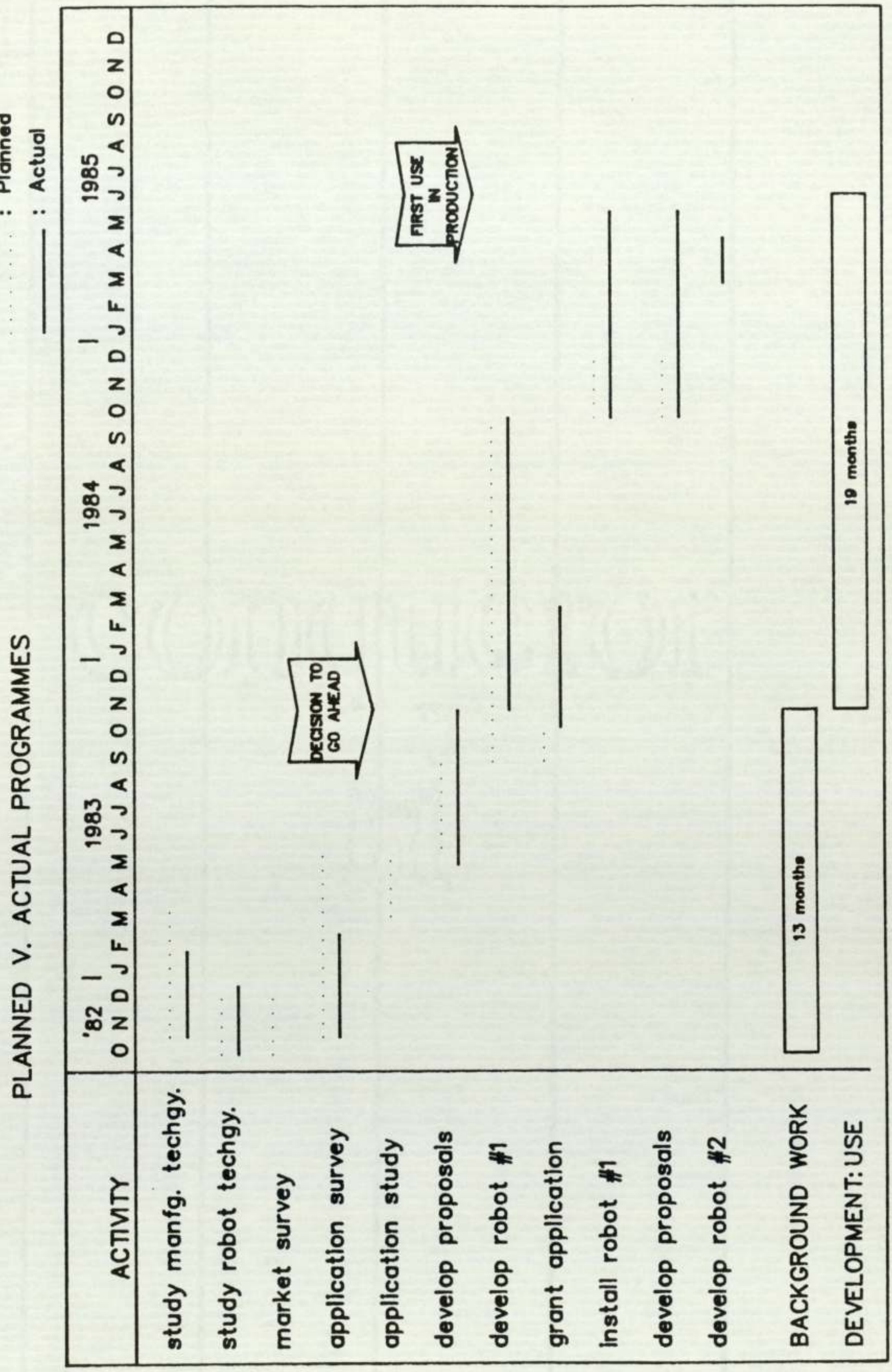


Figure 4.2.3 Planned v. Actual Project Programmes

The Engineering Process in the Robot Project

1.	set project objectives, planned project in outline	1982 September
2.	study of current manufacturing technologies, policies procedures, desk survey of current robot technology and system suppliers; reviewed literature on robot applications engineering food industry, packaging	October November 1983
3.	factory robot application survey; collection of data on potential projects, problem areas and needs	January February
4.	reviewed literature on robot project appraisal	April
5.	agreed project specifications, designed four systems, costed and prepared proposals	August September
6.	concept design, feasibility study of jar capping project	October
7.	development of jar capping system; design, construction and test	1984 February
8.	installed and commissioned jar system	September
(9)		
10.	resurveyed factories for robot applications	1985 January
11.	evaluated applications, designed three systems, costed and prepared proposals	February March
12.	agreed detailed specification for hopper project, redesign to meet specification change	April
(13)		
(14)		

N.B. The figures on the left-hand side refer to the page numbers in the project diary (see Appendix E).

2. The commissioning of the robot system to production use: planned three months, actual eight months.
3. The selection and design of the second application, planned to take four months, actual eight months

Examination of these three items suggest that there were common factors present in all three cases. They all involved the crystallization of the robot adoption process into concrete action, which required co-ordination between Production and Technical Divisions and the sharing of knowledge and expertise between them to solve technical problems. Analysis of the case-study shows that in each case there were non-technical influences which affected this sharing process. Often the parameters of the technical problem under consideration were changed because of these non-technical influences, for example in the design of the hopper loading application.

It can be concluded from this that it is necessary to consider the core technical problems - the engineering process - within the wider context of these other influences upon it, namely the co-ordination of resources and the sharing and ownership of expertise and information.

4.3 The Robotics Learning Process

It has been reported by a number of authors that two areas of expertise need to be brought together to introduce industrial robotics into a new industrial sector or application area: expertise in robotics and expertise in the company's own manufacturing processes and way of doing things. As the latter already exists, although distributed throughout the organisation, the way in which the new robotics expertise is acquired by the Company is of great importance.

In fact, a major conclusion of the Aston study into the diffusion of industrial robot technology within the UK was that at the level of the individual firm, robot adoption is an organisational learning process, whereby the "time to learn" is the delaying factor in speed of adoption and the management of expertise and know-how resources is the crucial factor in effective implementation (ref. Fleck [181]). This conclusion is borne out by the Trebor case-study, as it was clear that the fact that expertise had to be pooled from separate sources had an important influence on the engineering process. In order to understand this interaction between the ownership of expertise and the ability to solve the technical aspects of robot adoption more clearly, the way in which expertise in robots was developed within Trebor, how it diffused through the organisation and how (if at all) it was managed was studied over the three year project between 1982 and 1985. A clear 'Trebor/Robots' learning process could be identified from this study, which is summarised below in relation to the engineering process defined in section 4.2.

<u>The Robotics Learning Process in the Trebor Project.</u>

(1)		1982
2.	familiarisation with the technologies, policies and procedures used in Trebor's factories	October November.
3.	presentation of report summarising robot application survey	1983 April
4.	Colchester engineers attend Automan exhibition	May
(5)		
6.	presentations to Colchester workforce; engineers visit robot suppliers	October
		1984
7.	meetings with ESM workgroups	April
8.	operator training transfer of development engineer to Maidstone	October
9.	discussion of second robot proposal with production and technical directors	November December
10.	meeting with new product development team on robots in food processing	1985 January
(11)		

(12)

13. training of operators, maintenance fitters — April May

14. presentation of conclusions from project review to production management meeting, understanding of problems associated with technological innovation. — June

The development of robotics expertise within Trebor is summarised in the form of a graph below, which describes the rate at which three levels of expertise were developed (figure 4.3.1). It shows that a clear learning process existed, being s-shaped with turning points in late 1982 and late 1984, corresponding to the launch of the robotics project and installation of the first robot at Colchester. The graph also highlights that the development of expertise in robot applications engineering did not keep pace with the development of the lower levels of expertise; operation and knowledge of robotics. The engineering expertise curve is much flatter, suggesting that not enough engineers in the Company had acquired robotics development expertise by the end of the project.

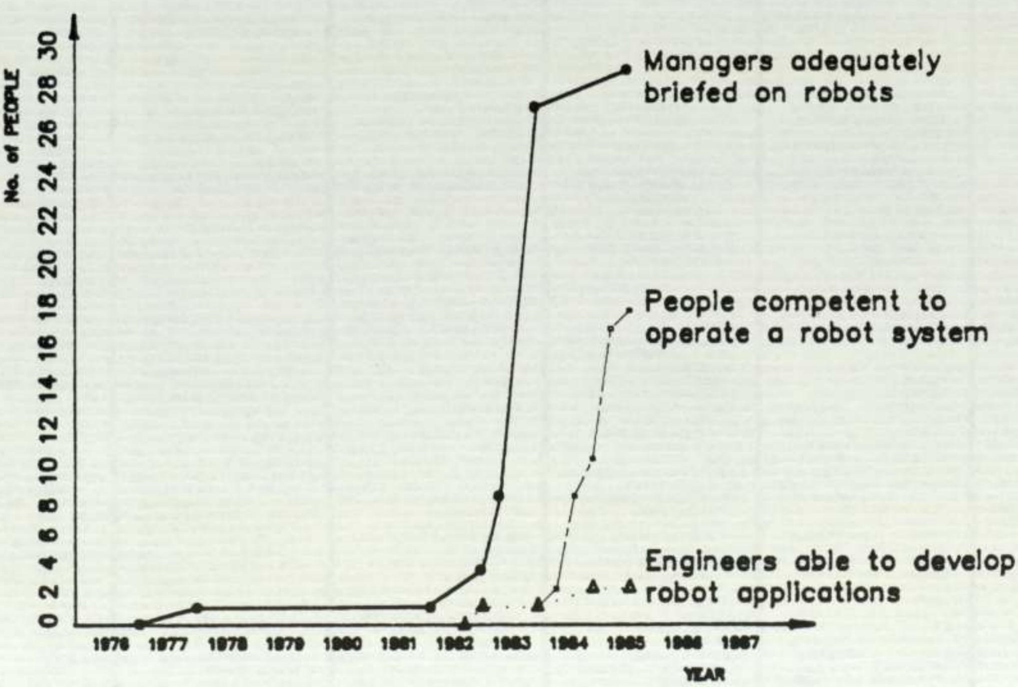


Figure 4.3.1 Graph of Trebor's Learning Process in Robotics

The analysis of the Trebor case study also suggests that the location of the individuals who had acquired a level of competence in robotics within the organisational structure strongly influenced the engineering process. For example -

- a factory manager who had previous experience in robotics in his previous job, actively supported the proposal to implement a robot system at factory management meetings.

- the transfer of the first Trebor engineer to gain experience in robot application engineering to Maidstone factory greatly increased that factory's commitment and ability to implement subsequent robots.

Of course the acquisition of robotics expertise within Trebor is the result of individuals within the organisation individually achieving a level of competence associated with their involvement and interest in the technology and its adoption. Their resistance to the change - which can be translated as commitment to overcoming obstacles such as technical problems - is linked to their uncertainty whether or not it threatens their interests, or doubt whether they will be able to cope. This is clearly affected by where they are on the learning curve as individuals. Once the installation of the first robot at Colchester had been completed, a number of people who had been indifferent or negative in attitude previously, became openly enthusiastic and committed once they had got to grips with the operation or maintenance of the robot for themselves.

Three key factors within the learning process can be identified from this analysis.

1) the importance of developing a synthesis of expertise between the local knowledge of the Company's manufacturing processes, policies and procedures etc. and the robotics know-how;
2) the existence of a positive feedback loop between skill and experience with the new technology, confidence and commitment to its use and willingness to overcome problems and make it work.

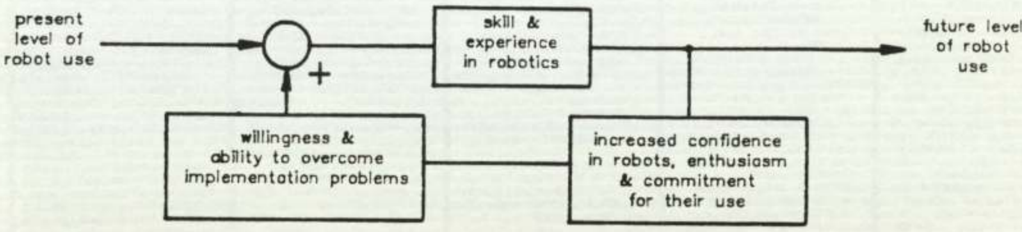


Figure 4.3.2 Feedback Loop in the Robotics Learning Process

3) the existence of a corollary of the above points in that there is a link between ownership of the skills and information relating to robots and resistance to their introduction; the often quoted "not invented here syndrome".

4.4 The Technology Transfer Process

The diffusion of technological innovations and more recently the process of technology transfer have been substantially researched for a wide number of industries and technologies showing how the diffusion of innovations follows a bell-shaped curve (figure 4.4.1.) [182]. The diffusion of industrial robots in the U.K. (figure 4.4.2) has also corresponded to the early part of this distribution as new ideas and developments gained by adopters in one industrial sector or application area are transferred to users in other areas and sectors. This particularly occurs from users in well developed, early applications such as car spot-welding, to pioneers in later areas such as the food industry. Thus the Trebor project is an example of such a technology transfer.

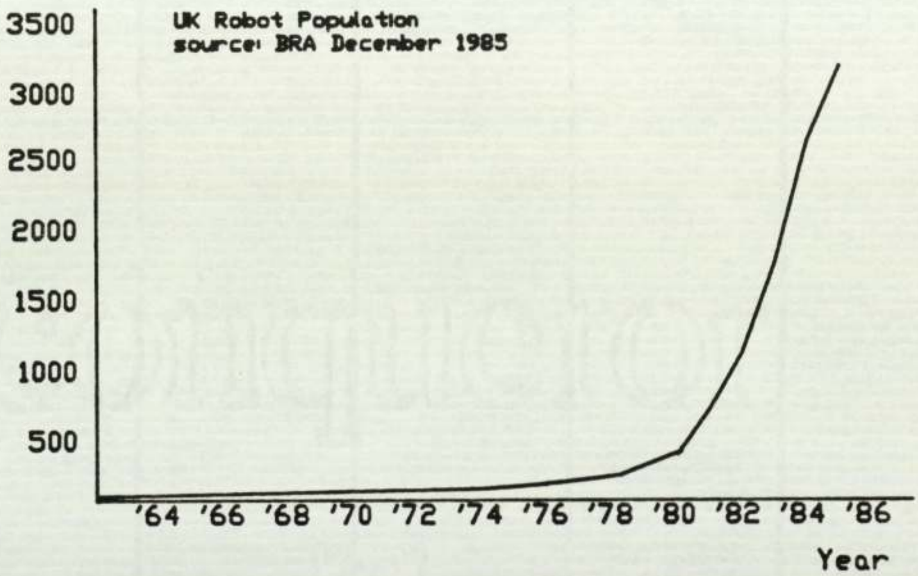


Figure 4.4.2 Graph of the Diffusion of Industrial Robots in the U.K.

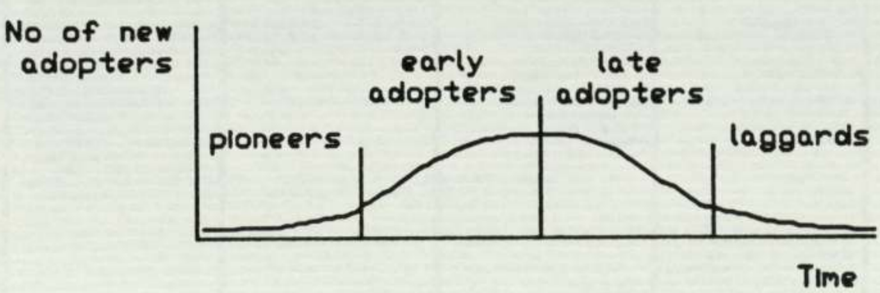


Figure 4.4.1 Graph of the Diffusion of Innovations

The technology transfer process in the Trebor project was analysed from the case-study and project diary and is summarised below.

The Technology Transfer Process in the Trebor Project.

1.	transfer of a technologist from a pioneering industry with robot application experience - Government and University acting as technology brokers.	1982 September
2.	first contact with robot suppliers and the robotics community	October November
(3)		
(4)		
5.	discussed system solutions with robot suppliers knowledge of Trebor's specific needs to spread to suppliers.	August September
6.	feasibility trials on jar capping by Dainichi-Sykes, influenced by government action	October 1984
8.	worked with robot suppliers on design of second robot system	September October
(9)		
(10)		
11.	liaison with robot suppliers, proposals for shortlisted applications	1985 February March
12.	liaison with suppliers for detailed quotations,suppliers withdrawing support due to lack of commitment	April
(13)		
14.	discussion with suppliers after project review identified area where technology needs improving	May June

This analysis suggests that in the Trebor case two technology transfer processes occured. At the start of the project the recruitment of the author with previous experience of robotics in a sector which was at the late-majority stage of diffusion (the car industry) helped to open up a new pioneer in a new industrial sector (food manufacture). Trebor was an early-adopter in robots overall, but a pioneer in its own industrial sector. This is an example of a variant of the technology transfer process, which has been previously reported by Burns[183] as transferring the technologist. It is interesting that at the time Trebor was setting up the project, it did not regard previous experience in robotics as a pre-requisite for the person it was recruiting to carry out the project. Had the recruit not had such experience a different form of technology transfer would have occured, perhaps from the robot suppliers or further education establishments.

The second process was that which occured throughout the project between Trebor and the robotics industry. As Trebor was a pioneer adopter in a new industrial sector, the applications considered were significantly different from those, for example, in the car industry (see chapter 6). As robotics is an applications-driven technology - i.e. the equipment designs evolve to meet the requirements of the new applications as they open up - then at any point in the diffusion path current robot designs are suitable for the well developed applications areas but not the areas just at the pioneer stage. In the early 1980's therefore, most robots were designed for use in automotive or metal-working industries for welding or materials-handling applications; not packing boxes of sweets. Therefore Trebor was involved in the design evolution process of the robot designs themselves. Transfer of information occurs between the user company and the supplier companies and a joint understanding develops as to what the user's special needs are, what the current level of technology can achieve and how development should progress in the future to bring the two together, given that there is sufficient market potential for the developments.

There is a growing realisation in the robotics community of the importance of this technology transfer process and this has led robot suppliers to change their marketing strategies over the past six years from supplying robots as 'universal' machine-tools to supplying turnkey robotic systems, emphasising their role as automation partners[184] with end-user companies. The implication of this change for Trebor and similar companies is that they have a proactive - not passive - role to play in the development of robot technology which must be planned for and managed through a clear technology strategy. This theme is essential to this thesis.

4.5 The Entrepreneurial Process

A major theme in the literature on innovation reviewed in chapter two was that of "key individual" explanations of innovative success. The processes of sponsorship and backing of innovative projects within organisations is most usually referred to as project or product "championing", and is quoted as being of vital importance.

Analysis of the Trebor case study showed that certain key individuals played important roles in promoting and supporting the robotics project and so a three part analysis of this area, and its effect on the overall project was carried out. This included firstly, a study of the way the project was championed within the Company. Secondly, an assessment of the project environment as it changed over the three year period and thirdly, a description of the championing process from the point of view of the author, who participated directly in the robotics project and carried out the action-research study. Finally, the entrepreneurial process, and its influence upon the project is discussed.

Analysis I: Mechanics of the Championing Process.

1.	established joint IHD - Trebor project team	1982 September
(2)		
3.	team supported introduction of outsider into the company, contact made with individuals in Production who were more committed to the project - these people gave support at the factory management meetings presentation of results of study to PMM - asking for commitment to first installation	
4.	meetings with factory management teams to discuss applications identified and to agree a ranking of preferred projects	1983 April June
5.	negotiation over proposals - design changes, pressure from University to decide on first project speeded up decision	August September
6.	preparation and negotiation of grant application, established jar capping project team, joint steering group, decided to do project in-house: pressure from DTI to consider longer term issues, future applications.	October 1984 February
7.	preparation of detailed proposal for robot palletiser development engineer moves to Maidstone factory discussion with production & technical directors re. robot project - discussed second application tried to rebuild bridges with Colchester factory, support from project team.	November
10.	discussion with factory management teams, selection of shortlist of 3 projects	1985 January February
11.	discussion with factory management teams, presentation of proposals to production management meeting operators, maintenance people support first project at Colchester. project group at Maidstone progress second application, joint responsibility	March
14.	reviewed work to date; investigated capital budgeting procedures; interviewed key people, presented conclusions at production management meeting and recommended action plan	May June

Analysis II: <u>The Project Environment between September 1982 and June 1985</u>

uncertainty, loss of technical director	end 1982
recent innovation - micros in Production backlash against R & D - no technical policy production director - temporarily responsible for Technical	
Doubt over relevance of robots for Trebor & need for project, indifferent commitment to the change	1983
Real commitment to project from Colchester but doubtful of R & D's ability	September 1983
New technical and production directors appointed Robot project very low priority for Colchester loss of commitment - problem gone away General improvement of relations between Technical and Production	1984
Backlash against second robot proposal	December 1984
Positive commitment at Maidstone, otherwise	1985
indifferent or negative at Chesterfield, Colchester	January
commitment improved once system started to be used	April

Analysis III: <u>The Author's Perspective on the Project.</u>

New-boy feeling, set of beliefs based on previous experience - wary - aware things are happening but cannot grasp their significance for the project. (September 1982)

Good progress made - gaining information mainly - not changing or questioning anything; can see problems clearly but not their importance - "can see the rotting trees in the wood". (February 1983)

Growing awareness of real problem situation, new experience - its a challenge - very high commitment to making project a success. (June 1983)

Project slowing down, coming up against resistance -don't clearly understand why, feeling isolated - everyone else on team thinks things are okay. (July 1983)

Search for new approaches - ask for input - still positive challenge to overcome obstacles and try new ideas - good fun. Real passion for the project - strong feeling of ownership - success tied up with personal feelings - goal orientated - No. 1 priority.(August 1983)

Fed up with banging my head against the wall of indifference - frustration - disillusion - consider "letting them get on with it" but realise I've got to keep on. See myself with two separate identities, as and as not a Trebor person - freer to act, overcome problems - new commitment, strong ownership, identifying with project - protective, its my baby - sweated blood to get here. (September 1983)

High points of commitment, joint team, project back on track. (March 1984)

Project progressing well - get itchy feet, going too well almost, feeling of losing marginal status - difficulty looking at problem from outsiders perspective. Engrossed in detail of project.(June 1984)

Problems come up - not sorted out - being let down by other people not as committed as myself (again lost perspective). (June 1984)

Get very frustrated at not being able to control external influences - deteriorating relationship - lose my head, just leave them to it - lash out - run away - difficult to control and direct this passion - No 1 priority to me but nowhere near that for a lot of other poeple - frustration at being unable to influence them leads to this bubbling over - depression and causing conflict. (November 1984)

Strong results orientation rather than relationship, increased frustration at no progress when really the Company wasn't bothered - nobody pushing - it all came from project team - energy came from doing something you believed in - nothing to do with Company norms - other people - can put you out on a limb. (December 1984)

Lost control of project - release of pent up frustration - cop out - wanted revenge - very deflated at being seen as consultant and not doing all the 'real engineering' - consider resigning - fresh start - new project - expect it to be different - new commitment pushed back out of Company, try and gain perspective on problem. (January 1985)

Same old problems arise - just no energy to fight it - running out of fight -because still don't understand them. (April 1985)

Step back - look at problem - understanding of whole picture leads to new commitment - feeling should have done this at beginning. (May 1985)

Re-launch but strongly hang on to marginal status - key to progress and to broader approach.(June 1985)

Discussion of the Entrepreneurial Process

The preceding analysis (II) shows that the environment within which the robotics project was carried out was not particularly conducive to its progress. It was begun whilst the effects of another manufacturing innovation - microprocessor control systems - were still being experienced, and when its main sponsor and technical director had just left the Company. During its life the Company went through substantial reorganisation and change of strategic direction. Trebor Group Limited was restructured into five separate operating companies and substantial changes occured in key management teams - including the appointment of new technical and production directors. The Company's oldest factory was closed down, putting great pressure on the remaining three; worldwide recession and Trebor's only moderately increasing share of a declining market meant that for some time return on capital was unsatisfactory, leaving very little resource for fixed asset expenditure.

Such things are however, common-place in industrial life; often they are much worse than this[185]. They do illustrate though the harsh circumstances in which any technological innovation such as the introduction of robotics has to survive before it can begin to help to improve the competitiveness of its adopting company. They also underline the very 'real-world' basis of this thesis.

The objectives of the Trebor project were achieved despite this changing environment because it had a momentum of its own which carried it on and kept it going. This momentum came from a network of individuals who provided a source of continuity and impetus which was maintained throughout the project. In close agreement with much of the literature the analysis (I) of the mechanics of the championing process showed that four groups of people were influential in promoting, either directly or indirectly, the robotics project within the Company:

i) The Technical managers on the project supervisory team

ii) The University academic supervisors

iii) Members of each of the three factory management teams

iv) The development engineer/research student

A role which has received substantial attention of late in the literature is that of the "executive champion", defined as a high level manager within the organisation who:

> "... provides sponsorship and impetus for the innovation; has direct or indirect influence over the resource allocation process; uses this power to channel resources to the new innovation thereby absorbing most, but usually not all, the risk of the project."(186)

Following the departure of the technical director at the beginning of the project this role was clearly not present in the Trebor case, and so it is pertinent to discuss how its absence affected the project.

The significance of this became apparent later on in the project when difficulties arose in the liaison between Production and Technical. The lack of a 'sponsor' supporting the project on the board of the Company meant that the technical team had to use persuasion rather than power to achieve the project objectives. It is argued in the literature that such a participative approach to new technology adoption is the most appropriate in the long term rather than a 'commanding' or 'marketing' approach which leads to either conflict or later disillusionment respectively [187]. The evidence of the Trebor case suggests that a participative approach works well if both parties involved have roughly equivalent influence and power. Championing from a position of low power using a participative approach is likely to lead to extended negotiations and an overall high cost implementation. The literature also reports that the executive champion is needed to absorb most of the risk of the project, to give the project champions the space in which to operate.

> "The executive and project champions ideally work in unison, as a partnership - the one proposing, the other disposing". (188)

Maidique also reports that one of the functions of the executive-champion is to give the project "impetus". In other words to apply pressure where needed, to underline the importance of timescales, to promote a sense of urgency and to maintain the morale of the project team through difficult periods, providing back-up and support where necessary. In the Trebor project this function was carried out, by two groups: the University supervisory team and the R & D managers.

Firstly, the University provided a 'reference point' for the author which he could regularly return to, to discuss problems, obtain help and advice and most importantly regain his perspective on the 'overall picture' away from the detailed problems of the Company. This opportunity to step back occassionally, greatly boosted the author's energy and commitment to the project.

Secondly, the R & D managers sponsored the researcher within the Company, helping to rebuild bridges he had damaged at one point and providing support in a similar manner to the University link. In addition the R & D services manager was the only thread linking the conception phase of the project to the subsequent collaborative venture, being the only person who had been present throughout all stages of the project. This was very important in maintaining clear goals and viewing developments in the longer term perspective. In the absence of an executive champion, the R & D managers and the University link, i.e., the PhD supervisory team, acted as a surrogate, providing the extra impetus and morale-boosting which the literature reports is a key influence upon the adoption process.

Thus the mechanics of the promotion of the robotics project correspond well with the innovation championing literature. However, in terms of the nature of the process itself -what it was like to be involved in 'championing' the implementation of robot technology - the Trebor case study contrasts with the previous work in this area.

Championing, as the word suggests, is presented in the literature as a heroic process carried out by rugged individuals battling against the odds. The analysis of the process from the author's viewpoint suggests that it is rarely heroic and clear cut, more often the route is foggy and ill-defined and some of the less noble of human traits crop up at times; such as his feelings of anger, arrogance and obstinacy. There is though a common theme of passion; the power and impetus behind the project come from commitment and strong belief in the work and this passion may be felt as high points of exhilaration and excitement from the pace and novelty of the innovation, but it also manifests as frustration, depression and anger as shown by the project diary (Appendix E). Thus the process is closely linked to the personalities of the people involved and their working relationships. This in itself is a key point in the context of Trebor's 'culture'. The Company emphasises an ethos of 'working together' which stresses the importance of interpersonal relationships, communication and joint ownership. It is a paternalistic atmosphere, not a 'hard' company where people do not raise their voices, where 'steamroller' types are discouraged and open conflict very unusual. (In fact the author found this change of culture a real shock after the car industry where overt conflict was commonplace).

Kanter has decribed the management of change within organisations in terms of entrepreneurship, Pinchot [189] has even coined the word "intrapreneurship" to describe the process by which individuals may carry out innovative new ventures within the supporting structure and resources of the established company. Entrepreneurial management, rather than project championing, sums up the skills and process by which innovative projects may be progressed within the confines of the optimising procedures for controlling the routine activities of an established company. Thus the way in which the robotics project was sponsored and driven within Trebor can be described as an entrepreneurial process, involving as it did the assessment and implementation for the first time of a new technology and way of working for the Company.

The importance of the entrepreneurial process to the implementation of robotics in Trebor is underlined by the fact that all three of the major delays were accompanied by a falling off in entrepreneurial effort, and an overconcentration on just the technical issues. For example, once the jar capping project was underway, effort switched to the development of the system and much less effort was spent on maintaining the push and co-ordination of the project; the informal links established during the appraisal stage were replaced by a formal project organisation which was expected to promote the co-ordination of work. This meant that early warnings of problems were not picked up informally and festered into major problems later in the project. Other incidents underline how crucial maintaining the entrepreneurial effort throughout the project was -when it waned things went wrong.

However, there were also disadvantages to the way in which the robot project was managed 'entrepreneurially' within the Company. The root of this was the separateness of the project. Innovation 'despite the organisation' meant that when changes occured in the Company which required equivalent changes in the direction or emphasis of the project - the elasticity of the linkages between them meant that this did not happen quickly enough. For example, when the business strategy the Company was following changed in 1984 there was an important change in emphasis of capital expenditure towards investing to generate sales rather than reducing costs. Although this was important to the robot project the significance of this was not grasped by the author until May 1985. People also felt uneasy about the project because it was not part of the ongoing business of the Company - it felt a little uncontrolled - on its own, separate from everything else that was going on. This had the effect in some cases of actually increasing the resistance to the change, not only was the technology new but the way it was introduced was also straining the adaptability of individuals and the organisation. The separateness of an entrepreneurial project and the need for high levels of autonomy and space on the part of the entrepreneurs tests the ability of the formal hierarchy to bend to accommodate it. Despite these important limitations this research confirms the key importance of an entrepreneurial approach to managing manufacturing innovation. The challenge for management is to be able to harness this source of power, and to direct it in the most useful way.

4.6 The Four Processes Combined

The preceding sections have clearly demonstrated the existence of four sub-processes which influenced the Trebor robotics project:

- the engineering process, involving the planning of events and co-ordination of resources in order to achieve the specific project objectives;
- the learning process, whereby the Company developed expertise in the new technology and experience of using it in its own particular siutation, achieving a synthesis of know-how between robotics and confectionery manufacture;

- the technology-transfer process, involving the sharing and transfer of information and people which occurs as robot-technology diffuses into new industries and new application areas;
- the entrepreneurial process, whereby the project is actively sponsored by an informal network of key individuals within the Company.

Certain key events which occured during the project, such as the transfer of one of the engineers who had worked on the robot capping project to Maidstone factory, also demonstrated that the four processes interfered with each other. In addition this interference sometimes had a positive result - such as the above example, but on other occasions was definitely negative. This effect can be likened to the interference phenomenon in wave physics where the superimposition of two or more waveforms produces a resultant waveform with quite different characteristics. Thus in the Trebor project, sometimes these sub-processes worked together - other times in conflict, resulting in a deep 'trough' in the progress of the work.

Figure 4.6.1 shows the four sub-processes together and highlights these interactions between them. It shows that attempting to manage technological change by controlling only the technical issues is similar to attempting to control an interference waveform by varying only one of its constituents; the result can be influenced but not controlled.

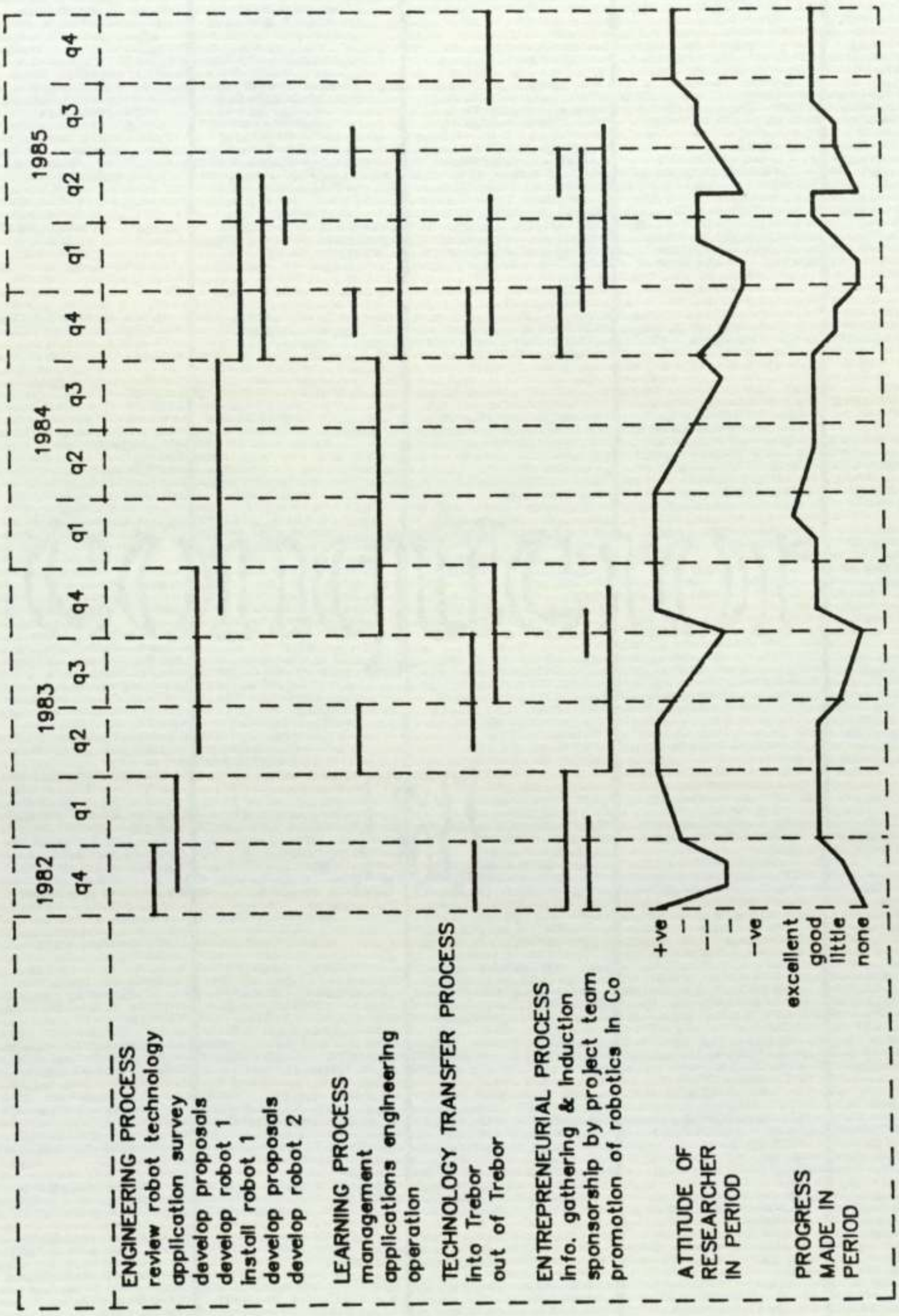


Figure 4.6.1 Four Sub-processes of Robot Adoption

CHAPTER FIVE

ORGANISATIONAL INFLUENCES ON THE

IMPLEMENTATION PROCESS

5.1 Introduction

It has been shown how the actual route taken during the project differed substantially from the original plan set in October 1982. A number of key factors were identified as causing this divergence, of which two were the resistance to the introduction of the technology by its potential end-users: the factories, and the unsatisfactory working relationship between the Production and Technical functions. This chapter examines these problems in the context of previous work, and provides guidelines for reducing their effect on future projects.

5.2 Resistance to Change

The literature on resistance to technological change within organisations makes two very important points:

i) Resistance to change is a phenomenon common to all activities where people feel their own interests are threatened in some way (ref. for example Child [190]).

ii) The implementation of technical change within an organisation is a political process (ref. for example Greenhalgh [191]).

These points suggested the need to consider first of all how and why people at Trebor felt threatened by the proposed systems and secondly to regard the implementation of the project as a political process, in the sense that it involves campaigning, negotiating and bargaining between the people involved in the change. Each of the three Trebor factories were jointly working with Technical Division in 1983 to design robotic systems for a shortlist of four previously identified applications. At each factory the following groups were involved in the design process or were influenced by it:

- the factory works-management team, which included the general works manager, production manager, works engineer, personnel manager etc;

- the manager of the production process concerned;

- the factory development engineering team liaising with Technical on the project;
- the process operators who worked on the production process concerned;
- the maintenance technicians who would eventually maintain the new system.

Figure 5.2.1 summarises how each group was affected by the proposed system and the means by which they could influence the design process. This figure clearly shows how the technology was not neutral but affected different people in ways depending upon their position and responsibilities. It was found that although there was a close correspondence between the level of resistance from a particular group and the degree to which their particular interests were threatened, the process of decisionmaking within the group was also relevant; consensus and the role of opinion-leaders were found to play an important part. This was especially true in the case of the factory management teams. In the one case where a member of a management team had previous experience in robotics and was convinced of its applicability in Trebor, his 'championing' of the project internally within his factory positively influenced the general commitment to the project and reinforcement of the design process. His enthusiasm for robots lends credence to the view that "commitment to particular bodies of expertise underlie management attitudes

GROUP	INTERESTS ENHANCED	INTERESTS THREATENED	ABILITY TO INFLUENCE DESIGN
general works manager	demonstrates the company's faith in the factory	uses capital allocation which could be used elsewhere in production	indirectly by reinforcing project team, commitment to the project
production manager		priorities in other areas loss of production	indirectly through commitment to the project
line manager	fulfills an existing need	reliability of production extra work & hassle loss of control	directly through specification of problem, commitment to solution
development engineering team	acquire new skills technical interest	not-invented-here loss of control other priorities	directly through specification of system, commitment to overcoming problems
process operators	reduce unpleasant tasks	job security	directly through workgroup meetings, although with little power
maintenance engineering team	acquire new skills technical interest		directly through specification of the system

Figure 5.2.1 Matrix of Groups Concerned with the Introduction of Robots within a Trebor Factory

during adoption", it also goes some way to explaining the refusal of some managers to believe that robots were at all relevant to confectionery manufacture:

> "the particular set of skills and knowledge embodied in an individual ... represents an enormous amount of time and effort to which he is de-facto committed (and which) shape his perception at a subtle level in such a way that he may find it difficult to recognise the relevance and importance of other newer bodies of thought." (192)

However, figure 5.2.1 suggests that even without the 'refusal-to-believe' problem, there are still fundamental conflicts of interest associated with introducing robot technology into the manufacturing situation. Consideration of these conflicts is key to understanding resistance to change in Trebor. For example, it was found that resistance to the proposals from process operators was not present in the Trebor case. Figure 5.2.1 suggests that the fact that the introduction of robots would have no effect on manning-levels in the forseeable future and that all the projects improved unpleasant manual tasks would explain this. If either of these two factors had not been present it is likely that shopfloor resistance would have been more prevalent; this may well be a problem with future systems. The main area of resistance was therefore at middle and junior management level.

For the production line managers, concern centred around the relative advantages to production of the robotic system and their confidence that it would work. The Company's recent adoption of microprocessor control systems had heightened their awareness of the problems which accompany new technology introduction. Negotiation over these areas depended upon the result of a financial analysis and justification (see chapter 6) and assurances that the system would be thoroughly proved before installation. The causes of resistance from the Production function within the factories were therefore fairly clear cut. Overcoming resistance in this area depended upon setting agreed strategic aims for adopting the technology in the first place (see chapter four) and effectively managing the installation of the system. The co-operation of Production in adopting new technologies depends upon production people feeling they can rely upon the timescales and reliability estimates that Technical give them. Only a track-record of success will develop this feeling of confidence.

The third group involved were the engineering teams assigned to the work at each factory. Resistance in this area was related to four main causes, of some complexity, which directly influenced the implementation process. Firstly, the development teams at each factory were involved in extensive process development work during this period. This work involved either the production of a new branded line or increased manufacturing capacity, both of which were of higher priority than speculative cost-saving projects such as robotics. Thus other production priorities and a shortage of resources led to increased pressure on the engineering teams which became manifest as a lack of willingness to devote time to the robotics project. This problem has been previously identified in the literature [193], its solution lies in planning ahead to smooth out peaks in workload, the use of increased resources, or the acceptance that lower priority projects will be delayed and explicit allowance made for this. Secondly, the interests of the engineering team were threatened by the fact that the robot part of the jar line was being developed by a Technical team. This caused great resistance, primarily because they felt they had little control over the project which they eventually would be responsible for. As well as this feeling of a loss of control there was implicit resistance to something "not-invented-here" and to this "whizz kid" being brought in to do the project:

> "It is no good the project champion being outside the factory ... the need originates from us - we own and run the project ... we are not a client to R & D - R & D is a contractor to us.
>
> People felt jealous that you were going to get a PhD out of all this, and they were just doing their job - they hadn't got a PhD for all the work they had done over the years - there was definitely a feeling of 'why help him?'..."
>
> (Interview with factory engineering manager 5.2.85.)

The remaining group involved in the implementation process were the general works managers of each of the three factories. The key issue here was that of capital budgeting. Each factory has a fixed budget for the current year's expenditure on capital equipment, under this capital rationing situation it is necessary to decide which combination of available projects makes the best use of the limited resources. Naturally speculative long term projects such as robotics are not viewed very favourably in this situation. In order to relieve this restriction, action was taken during the design of the second project in December 1984. A separate capital account was set up by the Production Management Meeting to pay for the project, so that each factory contributed one third from their capex budgets. This change did significantly affect attitudes, not just at general works manager level but throughout the factory hierarchy. It made the strategic, learning aspects of the investment more explicit; people could understand the reasoning behind the decision and commitment was increased as a result.

Thus resistance to the robot project came from a number of different areas, and was caused by people believing that their interests were being threatened in some way. As any change to established practice will always benefit some people and be to the disadvantage of others, some resistance is always likely to accompany robot implementation. However, its severity will depend upon the degree of change involved and the way the implementation process is managed. It must be recognised that achieving successful change requires significant time, if only to allow for the length of time that a negotiated participative approach to implementation takes.

5.3 Integration Between Production and Technical Divisions

It has been shown how important communication and co-operation between Technical and Production was to the robotics project, reinforcing previous research that had identified interdepartmental integration as a strong influence on innovative ability [(194)]. Two aspects of integration were relevant to the adoption of robotics in Trebor. As well as the integration of Production and Technical, the integration of the innovative project within the Company was highlighted as a key issue.

> "a paradox in the organisation of innovation derives from the need for the innovators to form a self-contained group of their own with considerable autonomy and the requirement that this very same group be not cut off poltically and in terms of shared understanding from the main sections of the organisation upon which the refinement, production and launching of the innovation depends." (195).

The analysis of the case study in chapter four showed that poor integration had an important influence upon the technical aspects of the project because many problems required joint input of expertise and information for their solution. However, unsatisfactory communication and co-operation prevented this at certain points in the work. The following comments illustrate this. Prior to the first robot application, the Production Division's viewpoint was:

> "R & D is just another sub-contractor to the factories and will be treated as such"
>
> (engineering manager 11/83)

> ".. the factories have had enough of new technology from R & D which has failed to live up to its promise".
>
> (factory manager 12/84)

> "I don't see why the Company has to bring in a whizz kid expert when robots are just another machine we could have handled ourselves".
>
> (development engineer 4/83)

<u>The Technical View</u>

> ".. the factories aren't interested in anything which they can't do for themselves. As far as they're concerned - if its not invented here it doesn't exist".
>
> (R & D engineer 7/83)

These attitudes changed as the first robot application project was implemented during 1983/84.

	Colchester factory	R & D Team
Late '83	Little confidence in R & D's ability to carry out the project successfully, preferred an outside supplier	Accepted this attitude as a result of problems with previous projects
Feb '84	Unhappy with R & D's attitude that "they were doing it all"	Regarded this as hypocritical when compared with the factory's 'sub-contractors' view of R &D
Mid '84	No feeling of ownership of the project	Unhappy with factory's lack of effort and commitment
Late '84	Breakdown in working relationship arose from discussion of proposed second robot application.	
Early '85	Discussion of problems and efforts of individuals led to improved working relationship but no change in the underlying causes of the problems - hence antipathy remained.	

Causes of Poor Integration

Six characteristics of the robotics project were identified which had been previously reported in the literature as causing poor integration;

1. widely different time horizons between work in Production and Technical.
2. divergence of the culture of Technical Department away from the core business.
3. strong disciplinary barriers caused by training and experience.
4. a mismatch between ownership of the problem and ownership of information relating to it.
5. the way conflicts between the functions are resolved.
6. the non routine nature of the innovative project.

The literature on organisational integration emphasises the importance of environmentally determined attributes of the different parts of the company. It is reported that as different departments of the organisation interact with different external environments this leads to differences within the organisation itself, particularly as there is:

> ".. a close fit in the high performing organisations between the attributes of each unit and the demands of its relevant part of the environment." (196)

Thus not only is the work carried out in Production and Technical quite different, but also the people will have developed a particular way of working and set of beliefs as a result. This was confirmed in the Aston Study of robot diffusion which found that people's intellectual commitments which arose from their lifelong experience and training critically affected their attitude to robot technology adoption. Research has shown that line people are more likely to identify themselves with the company as opposed to staff people who are likely to identify more closely with their professional group. Some companies have recognised this as a real barrier to developing a coherent company identity - for example at Cadbury's:

> "At our main chocolate factory ... we had a printing establishment (which) was a pretty efficient operation ... the people working in that printing department see themselves as printers not as chocolate manufacturers, so that their loyalties ... are outside the business. (By divesting the Company of the printing works) ... Those you have left on the site will be people who are held together by the fact that they are in the business of manufacturing chocolate."(197)

Cadbury's have also applied this strategy to their Technical function:

> "At the .. confectionery factories we had staffs of people who were capable of handling any schemes for putting in new machinery ... while retaining a core of technical expertise... we now contract with others to do this work "

In 1985 Trebor took steps to improve the integration of Technical's engineering function into the core business, by emphasising their role as a service to production:

> "To provide an engineering resource to the Production Division that will enable Production to take on projects centrally that:-
>
> i) The factories aren't resourced for
> ii) The factories don't have experience for
> i.e. Company/Production projects of a long term benefit to Trebor UK goals"

(Technical (Engineering) 3 year plan 13.5.85)

whereas previously it was:

> "(to) ... support current and foreseeable business needs with project and research work to understand underlying principles ... sufficiently in advance of factory engineering development.

... responsibility to ensure that the possibilities available to us through current technology are widely known.

(Technical Policy 23.3.81)

This change of emphasis caused feelings of uncertainty and insecurity for the personnel in Technical however, as they had developed within an environment of greater autonomy and with a greater development orientation.

In addition to the environmental aspects of the integration problem a second major influence was the dynamics of the collaborative process itself; in particular the way conflict between the two functions was resolved. Lorsch [198] cites the pattern of behaviour used to resolve conflict as a primary factor in achieving integration. His evidence indicates that

> "working in a problem-solving mode to get the various viewpoints out on the table and work through to the best overall solution... will be most effective.. rather than smoothing over, avoiding conflict or letting a party with greater power force a solution on another,"

He also reports that a mismatch between the

> "distribution of real influence and the knowledge and ability to contribute to decisions reduces the effectiveness by which conflicts are resolved."

This work has clear relevance to the Trebor case. In the robotics project, most of the knowledge and expertise in robotics was held by Technical, but the knowledge of the manufacturing processes and the control over the joint project was held by Production. Conflicts during the robot project tended to be generally avoided, as for example in the delays over the completion of the Colchester jar line. This led to feelings of frustration and impotence on the part of the Technical team and a dwindling of Production commitment to the project. Lorsch links these factors to the 'culture' of the organisation and this again is borne out by Trebor, where there is great emphasis within the Company upon personal relationships; 'conflict' is not welcomed, the Company has an explicit 'Trebor Way' of working which reinforces a culture of co-operation and "working together". Thus this case-study suggests that there is a need to place more emphasis upon working together to jointly face up to and solve problems rather than co-operating to the extent that conflict and the problems that cause them are avoided and left to remain.

The third major cause of poor integration has been shown by the case-study to be the innovative process itself. By definition 'innovation' refers to getting something non-routine and unusual done - therefore it is likely to conflict with the practices and procedures of an estabished company designed to optimise the normal, routine activities which make up its organisation. For example, the preceding analysis of the entrepreneurial process emphasised the need for marginal status and the separateness of the project, clearly acting against the joint ownership and co-operation which are also prerequisites of successful robot adoption. There is here a dilemma between the need for a synthesis of knowledge between the Technical and Production people that is needed to implement robots and the need for the adoption process to be separate from the normal procedures of the company. It is this dilemma which makes the introduction of robots such a substantial managerial as well as technical challenge. The other causes of differentiation are more general, relating to the structure and culture of the company overall. However, this factor is central to the robot adoption process itself. It explains why poor integration between the robotics project team and the factories became more apparent at certain points in the project - in each case it was where good integration was needed to achieve the synthesis of expertise necessary to develop the robot applications. At other stages in the project this need was not as important. Thus this suggests that attention needs to be particularly focused on the inputs to the robot development process within robot adoption in order to smooth the implementation process. This point is developed further in chapter seven.

5.4 Summary

It has been shown how the implementation of robotics strained the adaptability of individuals and the organisation to cope with it within the more routine operational activities involved in the day-to-day running of the Company.

Resistance to change is shown to be an unavoidable corollary of the manufacturing innovation process which requires a sensitive, but determined management approach - aware that the 'time to change' is a significant element in the overall implementation programme. Developing a company culture where people are able to air their objections openly so that they can be discussed in a problem solving manner is key to smoothing the implementation process.

Equally, as the project strains the adaptability of people and the organisation it will act to increase any underlying differences that exist. This is particularly crucial in robot adoption because of the synthesis of expertise that is required to solve the technical implementation problems. Joint ownership and commitment therefore must be achieved, focusing very closely on the stages in the project where the synthesis is most important: system design and development.

CHAPTER SIX

FINANCIAL ASPECTS OF INTRODUCING ROBOTICS

6.1 Introduction

The previous chapters identified two areas in which the financial aspects of the robot implementation process were particularly important, and where it was found that existing techniques for coping with them were inadequate. These were the appraisal of the robot application proposals, and the capital investment decision-making process used by Trebor to allocate funds for projects such as robotics. These techniques are reviewed in this chapter together with an analysis of their effect upon the robotics project.

Three areas of weakness are identified: the use of payback appraisal techniques, the assessment of robot applications as discrete projects and the absence of any forward planning of capital expenditure beyond two years.

An alternative method of feasibility analysis is also presented, however it is stressed that the short-term localised appraisal of robot applications is inappropriate without a framework which also considers the longer term, strategic issues relating to the implementation of robot technology.

6.2 Trebor's Capital Budgeting Process

The robotics project was financed via the Company's normal capital budgeting procedure which is linked to the three year business planning process (figure 6.2.1). The key elements of this procedure are:-

* A 3 year business plan specifying return on capital targets set by Trebor UK board.

* The Production Division's capital expenditure requirements to meet the business plan for the following two years specified by PMM.

* Firm production capital expenditure budget agreed by Trebor UK board.

* Spending priorities set by PMM within the capex budget.

* Spending controlled by budget reviews and authorisation limits.

* Projects below £100K capital appraised using payback; above £100K, discounted cash flow. Internal rate of return is used based upon a discount rate of 18%.

The starting point of the budgeting process is the setting of the Company three-year plan each year, which balances the needs of individual departments within the framework of the return on capital target and business forecast.

During 1982-84 Trebor was experiencing a period of little growth in sales volume and was therefore pursuing a strategy of cost reduction. However, during 1984/5 the business strategy was changed and a policy of going-for-growth implemented. Consequently the 1985-87 business plan had the primary objective of increasing the return on capital employed of Trebor UK Limited by 44% over this three year period. This policy was based upon a strategy of substantially increasing sales volume whilst keeping operating costs at their 1984 levels. The company's capital expenditure also changed in line with this plan, emphasising investment to generate sales volume, rather than to improve productivity. For example the 1986/7 Production Division capex budget was allocated:

-	new production lines/increased capacity	50%
-	essential maintenance/new facilities	10%
-	"shopping list" of projects prioritised by PMM from total spending requirement	40%*
	TOTAL	100%

* Production division's requirements substantially exceeded the capex budget.

As Trebor's capital budgeting procedure was found to have a significant influence upon the robotics project, use was made of Pike's[199] assessment framework and the results of his study of the capital budgeting practices of UK firms. Appendix F summarises the information for Trebor's expenditure for each category listed by Pike and compares it with a) firms with a capital expenditure budget of less than £5m, and b) firms manufacturing consumer non-durable products.

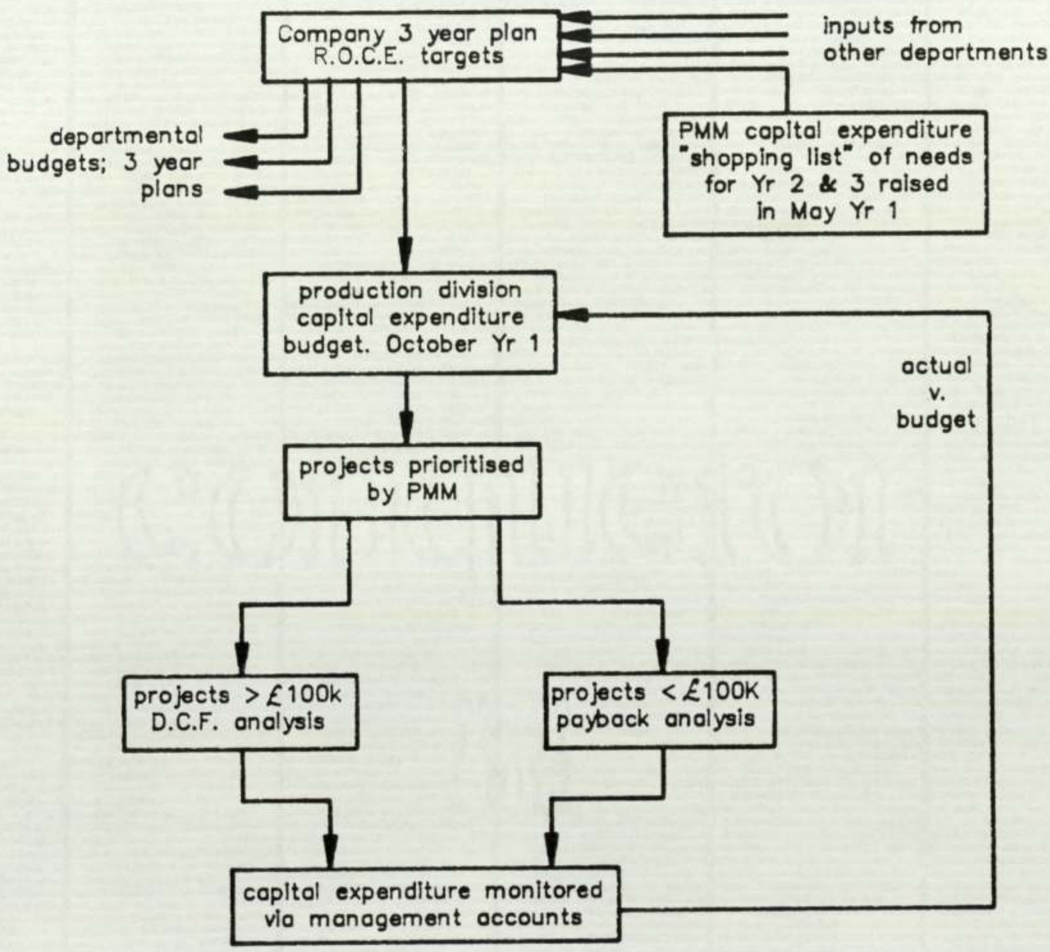


Figure 6.2.1 Trebor's Capital Budgeting Procedure

Trebor's practices differed from industrial norms (that is where it was different to more than 50% of the surveyed firms) in only two items out of the seven major areas listed.

These were:

a) Trebor's 3 year planning cycle; 5 years is widely regarded as a necessary time horizon for planning capital investment, (82% of industrial sector)

b) The lack of a requirement in Trebor for post-completion audits (61%)

Nevertheless they were found to be of crucial importance. Thus the key points of the capital budgeting process relevant to the robotics project were:

a) Assessment of individual robot applications as discrete projects requiring their own justification.

b) A capital expenditure planning horizon of two years.

c) Appraisal of projects using payback analysis, using a hurdle rate of three years.

6.3 The Financial Appraisal of the Robot Applications

The survey of Trebor's manufacturing processes carried out during this project identified twenty-eight work-areas where robots could be used at their current level of development. Nine of these applications were investigated in detail and an outline design study prepared, including a financial appraisal based on assessment of payback. The results showed that the majority of projects failed to meet the Company's hurdle rate of payback within three years (see Appendix E). A comparison with alternative methods to the robot based solutions also highlighted the apparently poor cost-effectiveness of these robots applications. For example, in the case of the Chesterfield carton palletising application CC013, robot based palletising does not compare very favourably in financial terms with the existing manual method.

Manual method:

2 operators per shift: £13,000 per annum direct labour overhead single shift working.

Robot method:

robot palletising system: £14,000 per annum depreciation and maintenance costs.

Although these figures are sensitive to the characteristics of the particular application, the comparison is representative of the general trend: the direct cost advantage of robots over manual methods was found to be marginal at best.

The capital cost of a robot system includes the peripheral equipment necessary to interface the robot elements with the existing manufacturing process. Because the main applications for robots in Trebor lay in automating those parts of the manufacturing process which could not be automated using conventional machinery, these peripheral equipment costs were on average more than two thirds of the total system cost. This compares with the figure of 50% reported in the literature and by the robot-system suppliers, thus in the Trebor applications the proportion is substantially higher than normal. For example in the previous case of the Chesterfield palletising project they were 64% of the cost of the complete system. Moreover, it was found that in large part these costs only arose because of the constraints brought about by the nature of the existing manufacturing process. It is likely that any improvement in the cost effectiveness of robots will come from a reduction of the peripheral costs rather than the prime cost of the robot systems themselves. This point is further discussed in chapter seven where it is shown that there is a link between the cost of the peripheral equipment needed and the approach taken to the implementation process overall.

Although the majority of robot applications considered did not meet the Company's three year payback hurdle it was recognised by Trebor management that there were important benefits to be considered in the investment decision which were not quantified within the payback calculation. In the case of the first application the learning benefits were of over-riding importance, but additional relevant issues were the elimination of an unpleasant manual operation, improvement of a longstanding quality problem, and reduced risk of product violation. All important issues, but all difficult to quantify in cash terms. In the case of the second application these intangible, qualitative issues were just as prevalent but management were now expecting an attractive return from the project, i.e payback within three years. It became clear that this appraisal method did not cope well with the robot projects because these factors, rather than being side issues, were critical to their justification.

There has always been a need to include qualitative factors in capital budgeting decisions. However, their importance relative to the more quantifiable direct cost factors has not been significant enough to warrant their explicit analysis in the investment appraisal process, existing practice instead relied upon management judgement establishing the correct balance in the consideration of quantitative and qualitative factors. However, with the increasing use of advanced manfuacturing technologies and their associated impacts on the fundamental productivity relationships and product cost structure of the firm (ref. Gold[(200)]) the adequacy of this informal approach has been called into question (ref. for example Seed [(201)], Van Blois [(202)]). Various alternative techniques for robot feasibility analysis have been suggested, which stress either thorough analysis of all the relevant factors within a discounted cashflow framework, on the basis that it <u>is</u>

possible to quantify these qualitative factors in cash flow terms (ref. Primrose and Leonard [203]); or which focus on the long term planning and strategic aspects of the robotics investment decision (ref. Van Blois [204]).

In the Trebor case, the problem was one of convincing management that the indirect or intangible benefits, which they recognised as existing and important were substantial enough in a situation of very tight capital rationing to warrant the investment. There was an implicit bias on the part of factory management that capital investments should provide significant savings in direct costs, and due to the difficulty in reducing direct materials they were looking primarily for direct labour cost savings. This bias does not agree with stated Company policy, however at the time these discussions were taking place in 1983/84 Trebor was in a period of little growth and inadequate profits. As such, there was pressure on gaining increased contribution from a fairly static sales volume and in these circumstances there was little opportunity to spread fixed costs,[205] leading to a natural emphasis on variables[206] - particularly labour. This bias can therefore be said to reflect the particular financial situation that Trebor was experiencing at that time, and the business strategy it was following.

The task, therefore, was one of persuasion, both of the advantages of the robot installation and of the need to broaden the investment appraisal basis, in an atmosphere where in general people were wanting to be convinced. Thus the requirements of any new technique were that it should quantify all relevant factors affecting the merit of the proposal, that it should be easily understood and communicated and that it should be founded upon a sound theoretical basis. A review of techniques proposed in the literature showed that none fulfilled all these criteria adequately, in most cases because their complexity prevented their use as an aid to communication. However, the field of cost benefit analysis was also examined and found to offer significant potential, although by this time a positive decision had been reached on the second robot installation using the conventional analysis method. Despite this a new method was experimented with, based upon a very simple form of cost benefit analysis.

An Alternative Robot Feasibility Analysis Technique

The new method uses a very simplified form of cost benefit analysis to quantify and make explicit, managers' implicit assessments of the relative values of the various costs and benefits relevant to the robot application under consideration. The project is assessed using an appraisal sheet which lists the possible costs and savings in accordance with Trebor's Production and Personnel policies. Each item, both quantifiable and non quantifiable in cash terms is then rated on a scale of 1 to 10 by the person or team carrying out the appraisal. This rating is a measure of the team's assessment of the relative importance of this benefit or cost to the overall viability of the project. (i.e. 1: not at all important to 10: the most important cost or benefit). Next, the items which are quantifiable in cash terms, for example direct labour cost, are used to derive an equivalent cash value for all the indirect, quantitative or intangible factors, in proportion to the rating assessment.

For example, consider a project which has only one cost: capital cost of the equipment £50K and only two benefits: it reduces direct labour cost by £5K per year, and it eliminates an unpleasant manual task. The appraisal would be as follows:

ITEM	RATING	REAL CASH	EQUIVALENT VALUE
Costs			
Capital		£50,000	
Benefits			
direct labour	4	£ 5,000	
health & safety	8		£10,000
Total	12 - i.e. a ratio of 2:1		

$$\text{Payback} = \frac{\text{(Real and equivalent) costs}}{\text{(Real and equivalent) cost savings}}$$

$$= \frac{£50,000}{£5,000 + £10,000} = 3.3 \text{ years}$$

Thus the payback figure now includes a measure of all relevant factors in a clear and concise way, which makes explicit the manager's own assessments of the importance of the normally unquantified elements. This analysis showed that for the nine projects considered, the direct cost savings were only about one third of the total benefits package (figure 6.3.1), confirming that Trebor's appraisal method fails to quantify the majority of the factors relevant to the decision to invest in a robot system. Calculation of the (real and equivalent value) payback of the nine projects revealed a significant improvement across the board giving an average payback of 2.2 years as against 7.1 years previously (see figure 6.3.2 and Appendix E). This technique is presented here as an example of one way in which intangible factors in the analysis can be made more concrete and easier to compare, without complex, detailed investigations which in reality companies are unlikely to use. Employed with respect to its limitations it is an effective tool, particularly for comparisons between similar projects.

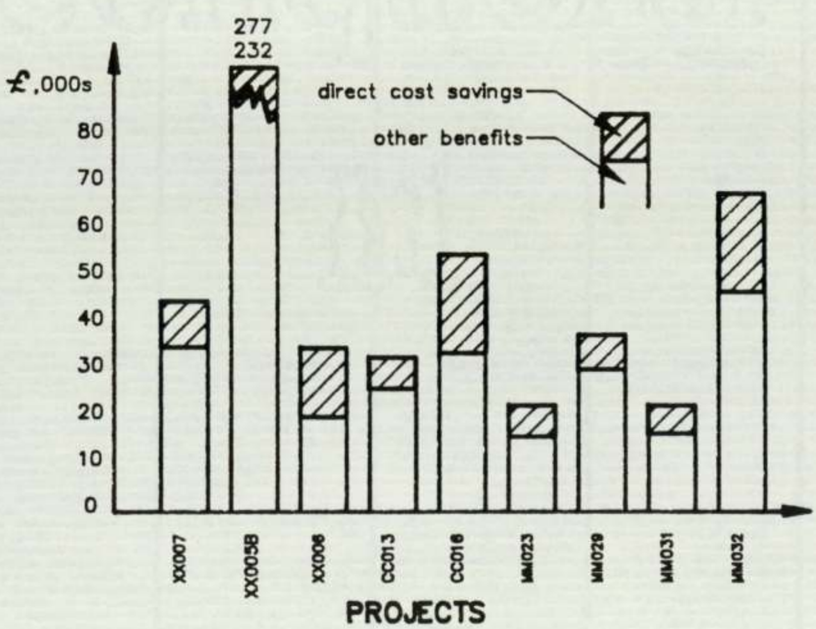


Figure 6.3.1 Breakdown of the Benefits of the Proposed Robot-Applications by Type of Cost Saving.

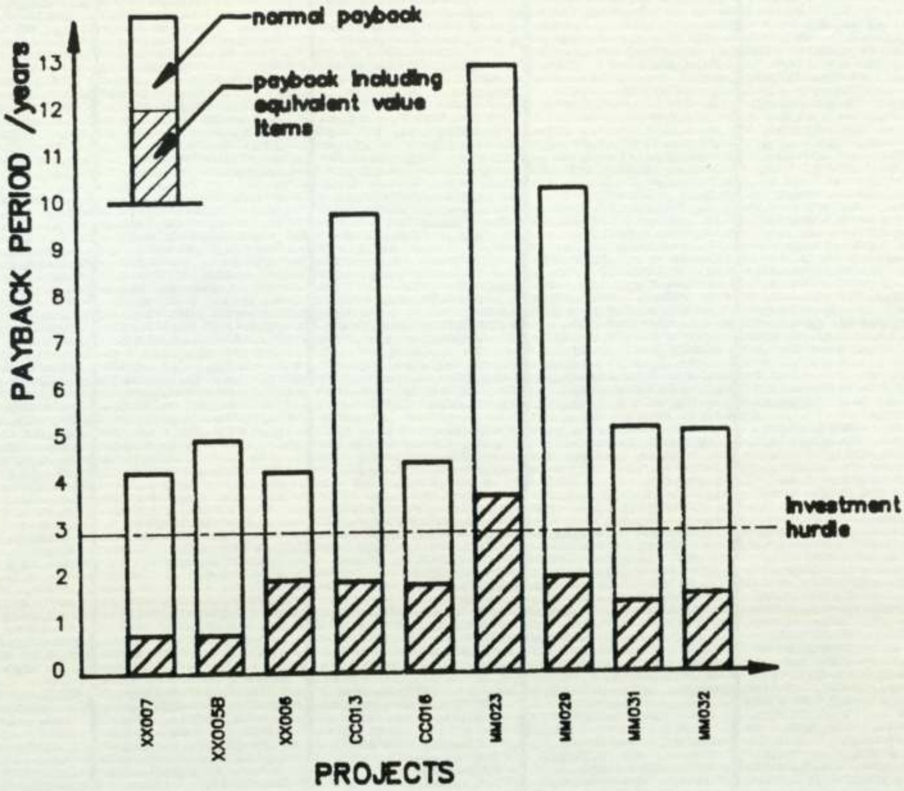


Figure 6.3.2 Graph of Payback Periods for the Robot Applications Studied in Detail.

6.4 The Strategic Aspects of Industrial Robot Technology

It has been described how the emphasis of the project, and indeed this research changed slowly over the three year period, away from its initial concentration on managing the technical aspects of robot implementation and towards trying to understand and to cope with the broader aspects of the adoption process. The previous section has considered how Trebor assessed the robot applications as capital investments and the difficulties which were experienced in doing this. However, during the latter half of the project it became clear that there was an additional dimension to the investment decision which was not receiving sufficient attention: the longer term competitive and strategic aspects of using robot technology. The preceding discussion has centred around the assessment of the viability of robot systems at the operational level, i.e. focusing on the cost of a robot system to perform given tasks or processes - often in comparison to conventional methods. This operational focus was the normal, established method used by Trebor for all but the most extensive manufacturing investment decisions. It also matched the approach taken by the robot system suppliers in developing turnkey solutions for user companies and the earlier literature on robot implementation [207].

This focus on the localised, short term operational aspects of the investment decision was called into question by the results which emerged from the study of the longer term potential and implications of robots for Trebor. This showed that the major impact of robots would not be in providing productivity and safety improvements arising from the automation of currently manual tasks as had been expected, but instead its impact would be in the strategic competitive opportunities that would be offered in the longer term. When combined with the changes that the use of robotics would impose upon the way Trebor manages production highlighted by the experience of the first project, it became clear that the adoption of robot technology was not an operational decision but a strategic one, and that the use of localised assessments of operational viability was wholly inappropriate. This conclusion was reinforced by certain key papers published at the time which also emphasised the importance of considering the strategic aspects of robotics. These reported that robotics had strategic impacts upon the adopting Company in three key areas:

* The use of robotics technology changes the fundamental economic structure of the business (ref. Gold [208], Clarke and Cecil-Wright [209]).

* Implementing robotics programmes requires sustained effort over a number of years (ref. Thompson [210]).

* Robotics offers new business strategy options, namely: capacity matching to the product life cycle; vertical integration into distribution and supply, removing the need for inventory decoupling within the manufacturing process to achieve a stronger competitive position through more flexible, predictable manufacture.

Payback appraisal in particular was criticised by a number of authors. Clarke and Cecil-Wright citing its widespread use as a limiting factor on the diffusion of robots in the UK. Primrose and Leonard (211) reported how their analysis of payback appraisal revealed that a three year payback hurdle corresponds to an internal rate of return of 31% after tax. This compares with a base rate of 12% in July 1985 and Trebor's return on capital of 14% in 1984. In this context payback within three years is clearly an overly severe hurdle rate. Holland (212) recommended that

> "in any project designed to achieve a payback against a time frame, do not use any equipment which is not genuinely developed. To become involved in the development of a device on which such a project depends is to court disaster".

Without doubt to be a pioneer adopter of robots in a new application area or industrial sector requires substantial development work.

The common conclusion of the literature was that

> "robot justification (is) radically different from the traditional financial justification methodology ... which tends to focus on the short-term question of 'what will it do for me over the next six months to three years?' When dealing with robots, however, the question ought to be, 'What should be the strategic direction for the organisation?'"(213).

De Vries has argued from his own experience that British Industry is particularly bad at taking into account these strategic aspects:

> "Britain will never catch up with Germany (in the use of robots)... the problem is a different attitude towards investment. In Germany, industry carries out overall financing of facilities, thereby ensuring that investment in new plant is continual rather than a stop-go injection of money into parts of the factory." (214).

Therefore Trebor's method of assessing the viability of the robot applications contrasts with the literature in three important areas:

1) The use of payback analysis. Prior research has shown its inadequacy for this type of investment decision.

2) Assessment of the robot applications as discrete projects. This fails to consider the wider strategic aspects of using this technology which can only be analysed from the total system perspective as argued by De Vries.

3) Planning of capital expenditure limited to two years ahead. Such a short planning horizon has been shown to be inadequate to cope with the long-term process of implementation which accompanies the introduction of new manufacturing technology. Two years is also shown to be unusually short for this industrial sector.

6.5 Summary

This chapter has reviewed the capital budgeting procedure used by Trebor and the financial aspects of the robot project. Generally Trebor's methods are in line with similar UK companies with the exception of the absence of a capital expenditure plan beyond two years and the carrying out of post completion audits on important projects.

The majority of robot applications did not meet the company's investment hurdle of three years because of

a) the comparatively high cost of the robot systems, which was shown to be due in large part to the unusually high level of ancillary equipment needed.

and

b) the inadequacy of payback appraisal in accounting for the qualitative factors in the robot investment decision. An alternative method of appraisal was presented as a possible solution to this problem.

Finally, it was argued that the nature of robotics suggests that localised short-term assessments of profitability are inappropriate and that a total perspective of the overall manufacturing process in the long term is also required in order that the strategic aspects of the investment can be properly judged.

CHAPTER SEVEN

ROBOT SYSTEMS ENGINEERING

7.1 Introduction

The Trebor case-study highlighted four key points concerning the implementation of industrial robot technology in food manufacturing:

a) The importance of non-technical influences upon the adoption/implementation process.

b) The poor performance: cost ratio of the robot applications in comparison with conventional methods of operation.

c) The comparatively large floor-areas required by robot based systems.

d) The recurrent difficulties which accompanied the interlinking of the robot systems with the existing manufacturing processes.

This chapter considers these points in detail and identifies the causes behind them. An analysis of the robot applications identified by the factory surveys is used to investigate the major design problems associated with implementing robots in Trebor. A novel parameter for assessing robot-system design is presented, that of productive workspace, and this is used to review the existing industrial robot technology in terms of Trebor's needs. From this analysis, two major factors are shown to be crucial to the further adoption of robotics:

a) changes to robot manipulator designs to meet the food industry's special needs, and

b) the adoption of a total-systems approach to robot manufacturing system design and implementation.

7.2 Analysis of the Trebor Robot Applications

The twenty-eight robot applications identified by the survey of the three Trebor factories are analysed below in terms of four parameters:

i) Payload (figure 7.2.1)

ii) Cycle-time (figure 7.2.2)

iii) Horizontal reach required (figure 7.2.3)

iv) Vertical reach required (figure 7.2.3)

A number of conclusions can be drawn from these figures.

a) Cycle times are generally less than 10s, with a large proportion in the 1.5 -3s band. These times are very fast for robots and suggest operating speeds 100-300% faster than those currently available.

b) Loads carried fall into two major groups: 10-25Kg and 0-4Kg, with the majority of loads in the 0-2Kg band. Although these figures are well within current capabilities they are not available with the speed/reach characteristics required by Trebor.

c) Horizontal and vertical reach fall into two groups as well:

0.1 - 0.2m vertical
R0.7 - R1.0m horizontal

1.6 - 2.0m vertical reach
R2.0 - R2.5m horizontal reach

These groups correspond to the load grouping (fig.7.2.1) and suggest two main types of robot are needed to fulfill Trebor's requirements:

	Type A for small items	Type B for large items
Max load/Kg	4	25
Horizontal reach/m	R1	R2.5
Vertical reach/m	0.2	2
Maximum speed/ms^{-1}	3	2

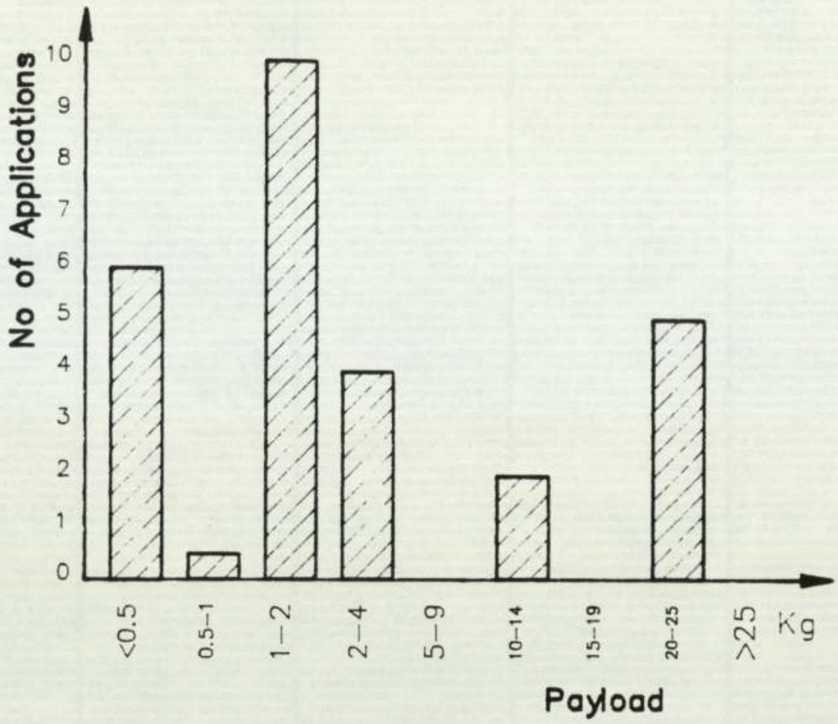


Figure 7.2.1 Analysis of Aplications by Payload

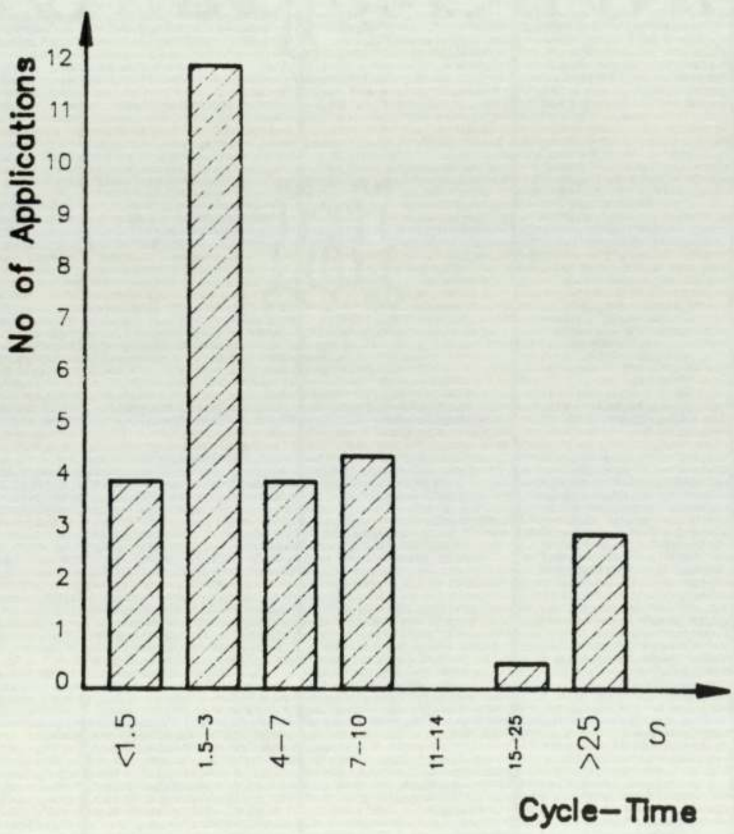


Figure 7.2.2 Analysis by Cycle Time

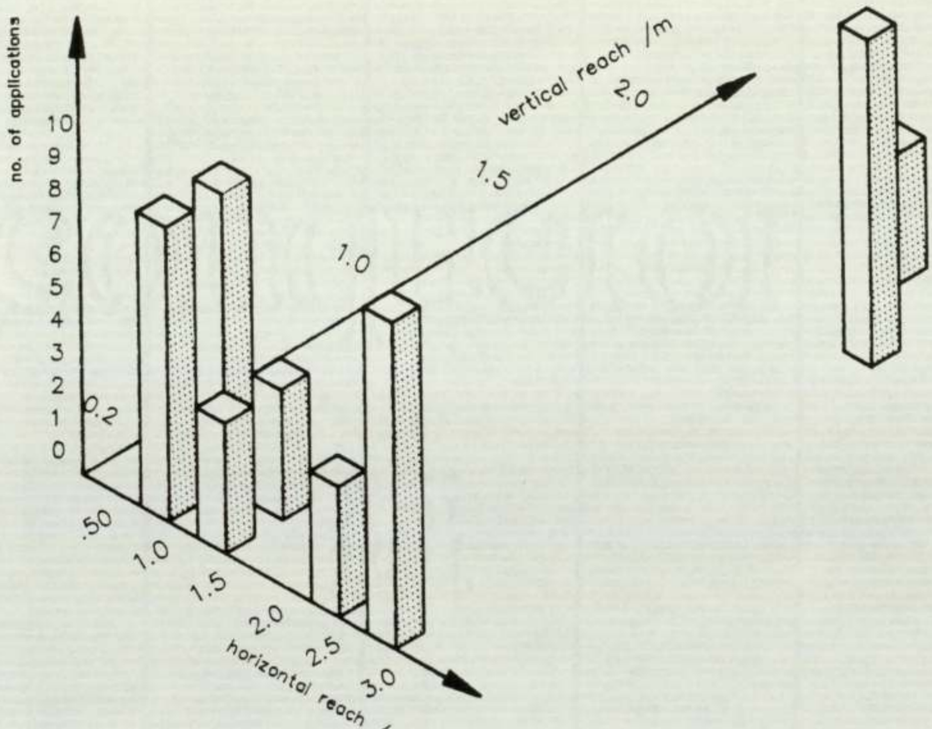


Figure 7.2.3 Analysis by Horizontal and Vertical Reach

7.3 The Major Design Problems

The major technical problems in designing suitable robot systems for the Trebor applications were firstly, the large floor areas required by the robot based solutions, and secondly interlinking the robot systems with the existing manufacturing process.

The Floorspace Problem

The most frequently encountered problem in designing robot-based manufacturing systems was the large amounts of floorspace required. In fact, more projects were appraised as not feasible on the grounds of the excessive floorspace needed than for any other reason. This result was surprising as both the literature and the robot suppliers' marketing material cites compactness and space efficiency as a major advantage of robot technology. However, the problem was common to all three factories and across the range of applications studied. Although there was a shortage of factory floorspace at the time which meant that this criterion was more important to the implementation decision than perhaps it should have been, nevertheless, factory managers commented on a number of occasions that the robot systems took up too much space for what they did. The point being that in comparison with non-robotic methods rather than in absolute terms, the robot systems were not space-efficient.

The floorspace needed by a robot based manufacturing cell is related to the robot's working area requirement, which is a function of both the task to be carried out and the configuration of the robot manipulator. The majority of tasks considered during the Trebor project were for packaging and materials handling, and the preceding analysis showed that these divided into two classes of application: type A and type B.

	Type A	Type B
Load/Kg	4	25
Horizontal Reach/m	**R1.0**	**R2.5**
Vertical Reach/m	0.2	2
Speed /ms^{-1}	3	2

Ignoring payload and operating speed for the moment, it is clear that both types of application require the most working area in the horizontal plane.

These areas are the minimum required, specified by the size of the objects which the robot is working upon, in this case small cartons and palletised loads. However, to meet these minimum dimensions a robot may have to be used with a larger reach than is needed to meet some other parameters, such as load capacity, or because the robot work-envelope is itself shaped inefficiently. For example the Cincinnati Milacron T^3-746, a state-of-the-art electric drive robot, requires a minimum of $35m^2$ floor area (horizontal reach envelope + 0.5m guarding allowance) but only provides a work area of $3.5m^2$ at a vertical reach of 2m as required by the type-B projects (figure 7.3.2.) Thus in these applications this robot provides a usable workspace which is one tenth of the floor area it occupies. This result provides evidence in support of the earlier observation that the robot systems were not space efficient in comparison with other methods.

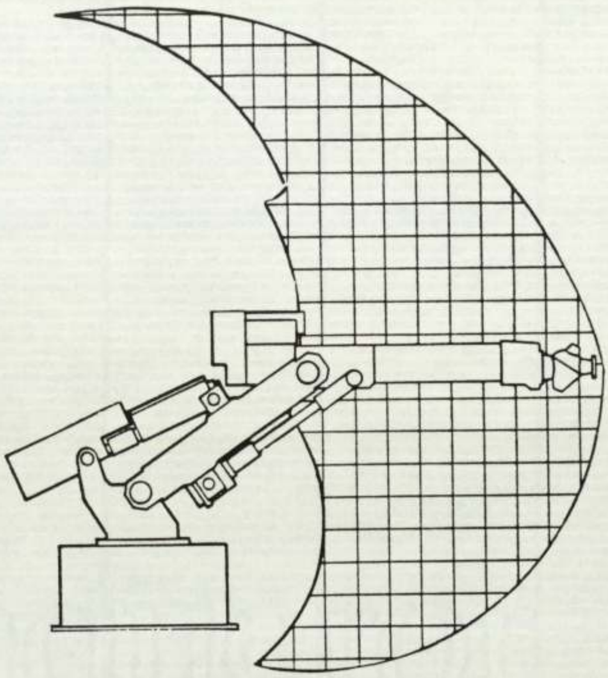


Figure 7.3.2 Reach Envelope of the T^3 746 Robot

In order to investigate this point further, a new criterion for assessing application design solutions using different robot models, was developed and used. The productive floorspace (P) is a measure of the space efficiency of the design solution under consideration.

$$P = \frac{Aw}{At} \times 100\%$$

where:
P = productive workspace
Aw = used working area
At = total floor area occupied.

Thus in the cases of the T^3-746 robot in type B applications:

$$P = \frac{3.5m^2 \times 100\%}{35m^2}$$

$$P = 10\%$$

which is clearly unsatisfactory. The cause of this low figure is that this type of robot is of revolute configuration; designed primarily for the welding of large objects with a reach envelope shaped to meet those needs. However, a major disadvantage of this type of robot configuration is that the movement of individual axes cannot be restricted in order to reduce on the unused reach for other types of application. Operation of this type of robot requires full simultaneous control of all three major axes in order to reach any point within its reach envelope, whereas a cartesian configuration robot can be restricted on one or more axes to improve the productive workspace. Thus P is related to the configuration of the robot arm:

<u>Productive Workspace for Type B Applications: R2.5m x 2m</u>

Revolute: 10% (T^3 - 746)

Gantry: 62.5%

Cartesian: 59% (BA - 2600)

P is highest for robots of the gantry-type configuration. However the disadvantage here is that the arm mechanics are mounted above the working area, and so a minimum headroom of twice the vertical reach is required, i.e. 4m. The majority of manufacturing areas at Chesterfield and Maidstone have a 3m ceiling height. This suggests that contrary to some authors (ref. for example Engleberger [(215)]) it is unlikely that universal robots will be developed that can be used in most applications, but rather that the trends towards increased specialisation of robots will continue, retaining the flexibility within specialist application areas.

This result suggests that Trebor, and companies with similar applications, should use robots with the higher P values, i.e., the gantry or pendulum type robot configurations.

Achieving Effective Integration of the Robot System

System integration was found to be the third most significant barrier to the implementation of robot applications in Trebor. Integration refers to the degree that the separate sub-units within a manufacturing process function effectively together as well as individually. Integration becomes particularly difficult to achieve when processes have been updated piecemeal, new systems being installed to interface with machinery which was not designed with this need in mind leading to communication difficulties, excessive handling equipment and tooling, and the need for buffer stocks. In the Trebor case integration problems centred around the following issues:

a) Process equipment which had not been designed to interface with automatic devices. For example, loading and unloading of the jar conveyor at Maidstone could not be automated due to the design of the tray carriers which hung from the moving conveyor (project MM 024 Appendix A)

b) Poor machine reliability. Many wrapping machines could not be run unattended for any length of time as continuous operation relied upon monitoring and adjustment by nearby operators. This could be tolerated in a manual system but not an automatic one. For example a major objection to robot palletising systems from factory management was that the unreliability of the existing overwrapping machines would have to be improved [216], a problem which they had been able to tolerate with manual palletising. There were two schools of thought on this issue, on the one hand some people were in favour of the robot systems because they would force them to solve a problem which they had "put up with for years" (ref. a factory manager February 1985) More common though was the view that the robot systems weren't justifiable because "an operator would still be needed to look after the overwrapper". (ref. factory manager December 1984)

This dichotomy of attitude towards process reliability is well described in the literature, in fact De Vries has reported that it is a highly differentiating characteristic between West German and British manufacturing industry. In contrast to the Germans he states that when considering robot technology

> "... the reliability argument carries no weight in the U.K., they are so used to having inefficient production systems" (217)

However, those companies that have installed robots have found that the fact that they had to sort out long-standing reliability problems provided major financial benefits which they hadn't been expecting.

c) Lack of an ordered environment for the robot to operate in. The classical robot application engineering problem, which has led to the demand for more 'intelligent' robots with sophisticated tactile and vision sensing to be developed. The main problem is coping with random changes in part orientation, in most cases this could be resolved by the use of jigs and position sensing (see for example jar capping cell, Appendix D) although at increased cost and at the expense of system flexibility.

These integration problems were particularly significant in the Trebor project because so many applications involved using a robot to link two existing operations in a flow-layout process. For example, project MM 023 required the robot to remove a PVC jar from a blowmoulding machine and place it on a continuously moving conveyor (Appendix A). This project suffered from all three integration problems because

a) The design of the tray hangers on the conveyor made automatic loading difficult without costly modifications.

b) The blow-moulder was an old machine, which did not consistently deflash the mouldings properly. The operator was relied upon to inspect all the jars and rectify bad ones.

c) After moulding and deflashing the jars were ejected automatically to fall randomly onto a conveyor belt. Modifications to the ejection mechanism would have been needed to retain part-orientation to allow location by the robot.

These integration problems were particularly troublesome in the Trebor case because they were largely new to the Company. Although the pace of change in confectionery markets is considerable, radical changes to the production processes are quite unusual as new product introductions are generally produced on existing equipment. Packaging machinery is usually installed on a machine replacement basis and so integration problems might be expected to be a problem here. However, packaging machines are designed as discrete, autonomous units which require little interfacing to the existing process. Trebor is therefore able to take a localised approach to new machine installation, improving parts of the manufacturing process as required, without the need for a long term plan for the overall improvement of the whole manufacturing plant. Therefore, the integration modifications required by the robot systems were regarded as excessive in many cases by the factory works-engineers, and were cited as evidence of the inappropriateness of robotics for Trebor's needs. Indeed, in comparison with norms in other industries who have adopted robot technology Trebor's systems required significantly more peripheral equipment (see chapter 6). This analysis suggests that the causes of this lie firstly in the fundamental difference between robotics technology and the existing process and packing technologies and secondly, in the approach taken by Trebor to new machinery installations.

7.4 The Design of Robot Systems to Meet Trebor's Needs

This research has shown that although there is substantial potential for employing industrial robot technology in Trebor both in the short and long term, at the moment the 'fit' between the technology and Trebor's needs is a poor one. There needs to be substantial changes from both sides before the undoubted benefits to the Company offered by robots may be achieved. This section draws together the results which have emerged from the Trebor case-study and its analysis to provide an outline specification for industrial robot systems to improve their compatibility with the Company's financial, organisational and technical needs.

Design Principles

Modularity - modular design of both the robot cells, to minimise integration costs and to allow staged implementation, and of the robot tooling to allow fast product changeover and high flexibility.

High Speed - operating speeds are needed to match manual methods of packing and handling, i.e. cycle times of 1.5 - 3s for small items, 10-15s for larger ones.

High floorspace utilisation - P greater than 60%

100% product inspection - to increase consistency of manufacture, and remove the need for manual post operation inspection.

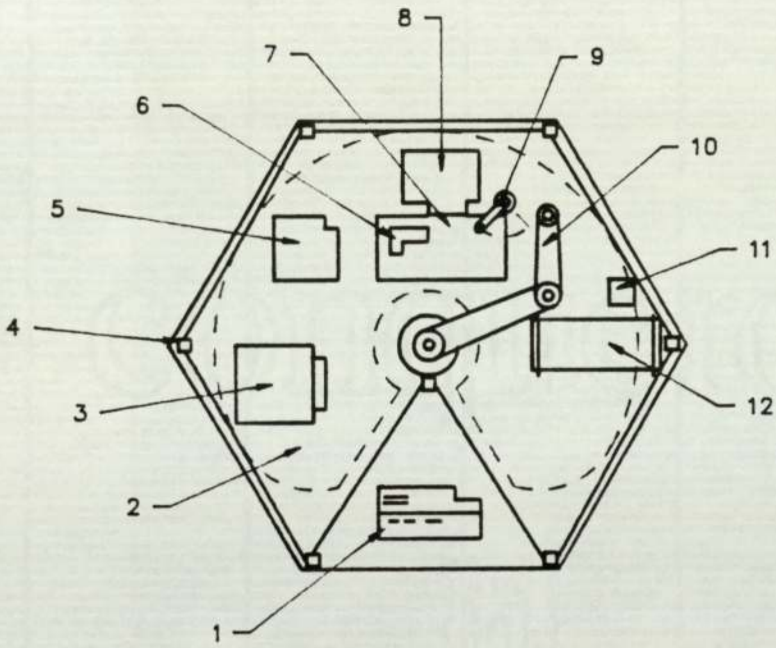
Environmental Protection to IP55 standard - of all system components to prevent ingress of water during cleaning, or airborne sugar and dust particles during use.

Standardised hardware and software - to reduce integration costs and timescales, to allow production control data-link and automated materials handling to finished stock warehouse.

Two distinct categories of system are required as described below: type A for the packaging and handling of small products at high speeds and type B for handling larger products at end-of-line stations, particularly palletising. The majority of applications are for type A and are likely to be so in the future.

Type A: Modular Robotic Handling/Packaging System

Purpose:	To automate the currently labour intensive low-volume packaging and materials handling tasks.
Background:	At the moment a large proportion of Trebor's products are packed by hand as they are low volume lines which do not justify, or would not fully utilise dedicated high-speed packaging machinery.
Potential Benefits:	Elimination of direct labour cost whilst retaining flexibility, improved quality, untended operation during nightshift.
Features:	Modular design to minimise integration costs - bolt on tooling - 'table' based design, 'robot in a box' - high speed, low inertia arm design using direct drive electric motors. Cartridge feeding of Packaging Materials. 100% inspection of output Product changeover in less than 15 minutes



SYSTEM MODULES

1 computer control linked via busbar to cell periphery
2 tooling table
3 folded carton cassette
4 cell guarding & busbar
5 product cartridge
6 product inspection unit
7 carton erection jig
8 pack-inserts cassette
9 pick & place arm
10 scara direct drive robot
11 ink-jet printer
12 outfeed conveyor

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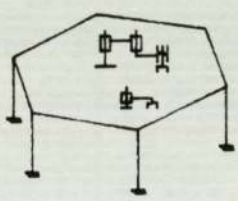


Hexagonal cell-shape maximises productive workspace & reduces integration problems; allows 2-D production lines to be built in honeycomb fashion.

All tooling modules bolt directly onto tooling table & plug into the I/O busbar which is fitted within the cell guarding

As the tooling table is fixed w.r.t. the robot datum, modular tooling and portable software may be used.

Figure 7.4.2 Type A Robot

Type B: End of Line Robotic Handling/Palletising System

Purpose:	To automate the end-of-line and inter-line packaging and handling operations; integrating currently separate processes and closing the loop to finished product storage.
Background:	All end-of-line operations are currently carried out manually due to Trebor's flexibility and inspection requirements. Many are unpleasant and repetitive.
Potential Benefits:	Reduced direct labour cost, improved working conditions, improved quality, untended operation during night shifts, flexibility to meet changes in product/pack - new combinations.
Features:	Gantry configuration to maximise productive workspace. 100% inspection of output Production data input to central computer control Quick-change tooling Modular design interfacing to production line and materials handling equipment.

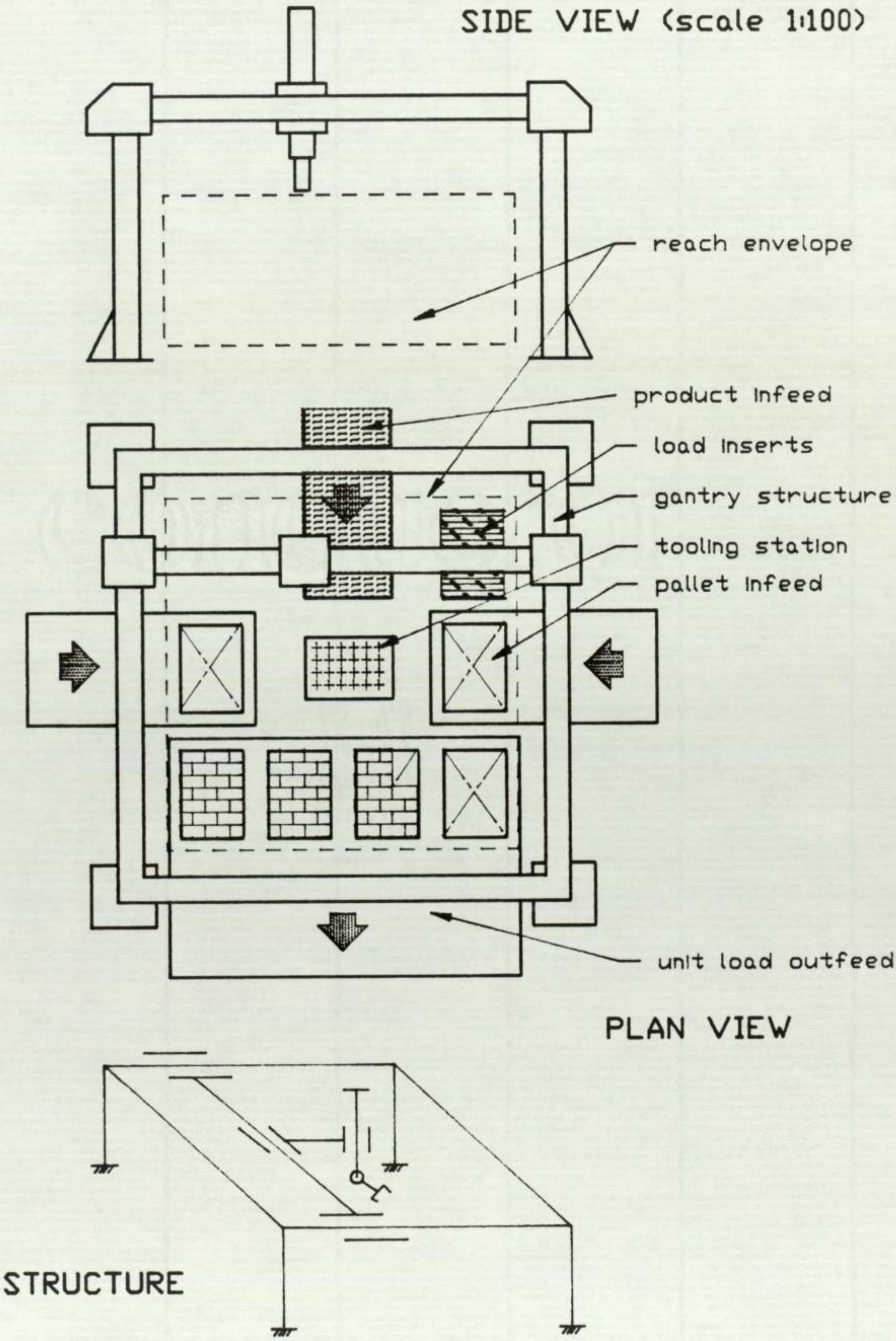


Figure 7.4.3 Type B Robot

7.5 Analysis of the Design Method

The majority of the design studies carried out in the Trebor project involved the use of a robot system to link separate work stations within a production line. These stand-alone systems, retrofitted into the existing manufacturing process were found to be much more difficult to design than the applications where a fresh start was possible - as for example in the case of the jar capping system. In particular, overcoming the integration problems at the interfaces between the robot system and the surrounding process was far easier in the case of the new lines because both the robot and non-robot parts of the system could be designed together, avoiding the orientation, communication and layout problems described above. However, in the case of retrofitted systems a recurrent obstacle was the need to make substantial changes to the existing process equipment to enable a robot based solution to be used. As well as these integration problems, these linking type applications suffer from three other drawbacks:

a) Retrofitting leads to the 'robotisation' of the manual task at the expense of considering more radical approaches, possibly through the adoption of more elegant or simple means. The emphasis on robots as "mechanical people-replacers" has fuelled this problem and led to research into the development of humanlike capabilities. The demand for more intelligent robots has also been a result of this. The flaw in this approach to robot development was highlighted by Seering in 1984.[218]

> "Humans were designed to throw stones, pick berries and climb trees. Survival based upon one's ability to place a bearing on a shaft has played almost no role in the evolutionary process . . . machines modelled after humans have all the inherent weaknesses of humans in performing manufacturing tasks..."

His point is equally applicable to industrial robot applications modelled in the same way.

b) Linking type applications emphasise the robot as an autonomous unit rather than as just a machine integrated within the manufacturing process. This centres attraction on the robot, increasing labour sensitivity and resistance, and reducing effective management of the overall system it is to be linked with. This error was specifically made in the development of Trebor's first robot installation at Colchester. Great trouble was taken with the management of the robot cell's development and installation, but the new jar line it was to be linked with was not managed so closely. As a result the robot was installed six months before the rest of the line was completed (see also chapter four).

c) Using an industrial robot within a dedicated process results in poor utilisation of the programmable facilities provided by the computer control system. This redundancy is reflected in the significant number of companies who have substituted low-cost "pick and place" devices after first using sophisticated robot systems (16% of companies surveyed in the Aston Study). [219]

Despite these disadvantages, linking applications are still an ideal first step in introducing robot technology to a firm. Their low cost and low complexity make them ideal as learning projects with the aim of gaining experience and expertise with the technology. However, there is a danger that companies do not progress from them, choosing instead to implement similar systems in this isolated "piecemeal" fashion to improve the productivity of localised cost-centres. This is a characteristic which clearly distinguishes between British and Japanese user companies. The Japanese approach is more total-system orientated in line with their thorough overall approach to production engineering. Rather than focussing on a particular task for robotisation they consider the manufacturing process as a whole. For example, the Nippondenso system for the assembly of automobile fuel gauges[220]. Here the sophistication lies in the overall system rather than the individual robotic devices, which in this case are very simple and would not classify as robots at all in the Western sense. Despite the low flexibility of the component devices, the overall manufacturing process is very flexible indeed, being able to cope with 40 different types of gauge. The striking aspect of Naruki's paper, which reports on the Nippondenso line, is the clarity of purpose and determination with which the task of automation was undertaken. Many authors have reported how Japanese productivity cannot be simply explained in terms of technological advantage - their production technology is no more advanced than the West's - it seems likely that their approach lies at the heart of their success.

Alternative ways of designing robot applications to the linking type have also evolved from work on flexible manufacturing systems for component machining. (ref. for example Vuzelov [221], Bjorke [222]). The principle concepts here have been: firstly the layout of equipment in the form of cells along the lines of group technology [223] principles (fig. 7.5.1); secondly the idea of modularity at the cell level; and thirdly the integration of these autonomous cells within a direct numerical control (D.N.C.) hierarchy (fig. 7.5.2)

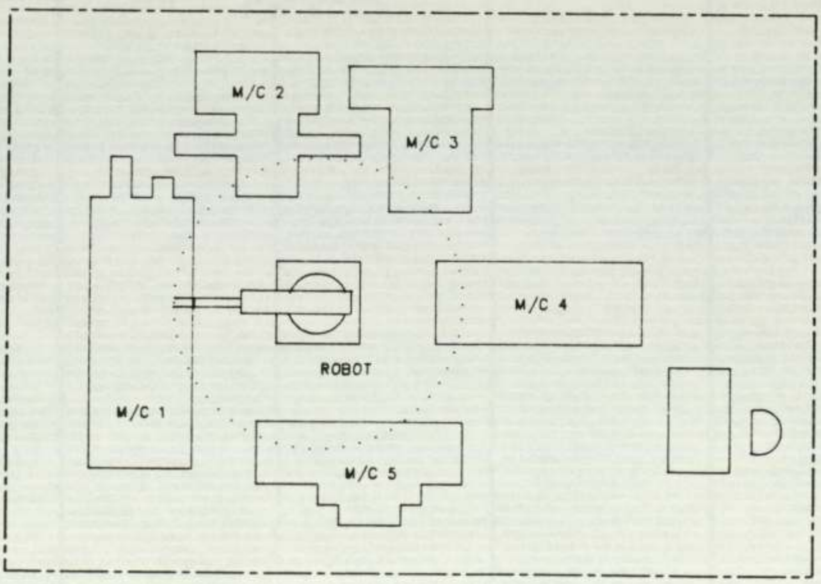


Figure 7.5.1 'Cell' Layout of Machinery

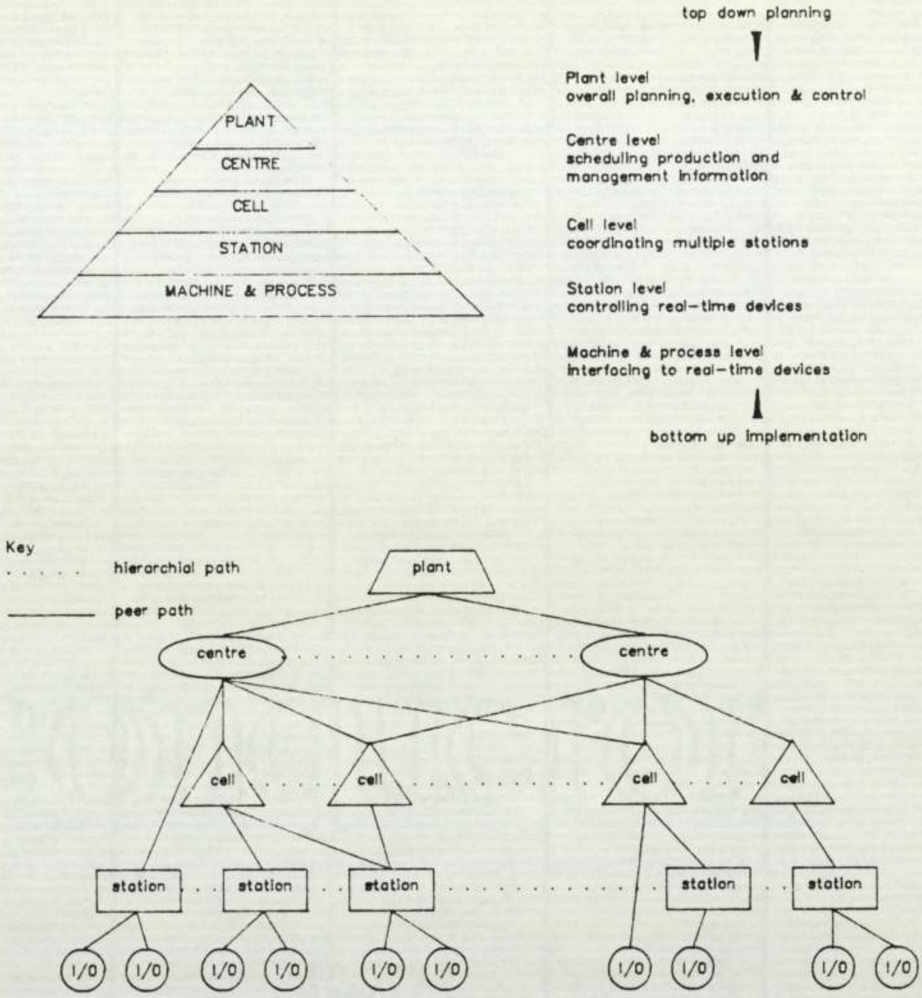


Figure 7.5.2 A D.N.C. Hierarchy of Machinery Cells

These machining cells share two major characteristics with the Japanese electronic assembly applications described above:

a) The manufacturing process has been designed as a whole rather than piecemeal - i.e. a top-down design approach has been adopted.

b) The individual robot cells have been desgined to operate as sub-units within the overall manufacturing process, such that flexibility is inherent in the sub-unit and not just the component robot devices.

This total system approach is reported to offer the following benefits:

- reduction of prime cost
- shortening of system design, planning and installation lead time
- increased capability for small batch manufacture
- gradual introduction of sub-units to match learning-curve
- application of standard hardware and software
- high reliability [224].

Thus the question arises whether this total-system approach is appropriate in the Trebor case. Prior research has shown that numerous technical advantages are gained from using it, however this thesis has demonstrated the equal importance of the financial and organisational aspects of the implementation process. The case-study and its analysis have enabled a number of conclusions to be drawn in these areas which are very relevant to this question.

In the organisational area, the following points have emerged:

- Organisational resistance will always accompany significant change within a firm, although its impact can be mitigated by clear planning which places the change in context, and which recognises the time that change takes.
- The learning curve is a limiting factor upon the rate of change, it is important to build on the knowledge gained, to use it and develop it within the organisation, realising that its importance is as significant as the technology itself. The link between learning to use the technology and resistance to change is a clear and important one.
- Matching the technology to its social environment is key to improving the quality of work and to productivity. In the Trebor case this increasingly means work-group organisation, tending away from line to cell layout of production systems.
- The introduction of robotics and flexible automation, as a manufacturing

innovation involves the processes of entrepreneurship, championing and negotiation within the organisation. This is shown to be helped by an approach which tackles the problem as a whole - rather than splitting it up and dividing responsibility. This is also important in managing the project so as to ensure that all aspects are progressing together.

In addition, the following conclusions have been arrived at in relation to the financial dimension of the implementation of robotics:

- It is necessary to take a long term view of the financial implications of adopting robotics as a continuous process rather than as a series of discrete projects.
- The importance of the strategic aspects of robotics and the need to take a total perspective of the manufacturing process as a whole in order to judge them and to be able to link the use of robotics in terms of the business aims of the company. This highlights the importance of manufacturing as a competitive weapon.

Consideration of these conclusions from the three main aspects of the problem together, highlights the themes which are common to them all. Two items are common denominators of the three dimensions of the robot adoption/implementation problem:

* <u>a longer-term planning orientation</u> reduces design and implementation costs, organisational resistance to change and provides a balanced framework for financial evaluation.
* <u>adopting an integrated approach to the process as a 'whole'</u> is the common philosphy for the design method, project management method and a financial appraisal method which are both mutually compatible and appropriate.

It is concluded from this research that the above two points are the key principles behind the successful adoption of industrial robot technology by manufacturing organisations.

7.6 Summary

This chapter has considered the major technical problems associated with the implementation of robotics at Trebor. It has been shown from an analysis of the parameters of the Trebor robot-applications, and the use of a new criterion, productive workspace, that the technical problems encountered derive from two key causes:

a) the inadequacies of current industrial robot technology in terms of Trebor's needs and
b) the approach adopted for system design and implementation.

Study of these two points from a multi-disciplined perspective led to the development of outline specifications for robot systems which meet Trebor's requirements and to the description of a robot-application design approach which is appropriate in this context.

Comparison of these conclusions in the technical area with the earlier organisational and financial analysis of the case-study highlighted two principles common to all three areas:

* long term planning
* integrated management of the robot-adoption process

suggesting that a common framework which links the previously separate dimensions of the problem does exist.

CHAPTER EIGHT

DISCUSSION

AND

CONCLUSIONS

8.1 Introduction

This chapter discusses the methodology that was followed in the Trebor project and the conclusions that arose from it in the context of the relevant literature. Finally, these conclusions and the experience of the case-study are synthesised into a set of guidelines for the management of future robot implementation projects.

8.2 Discussion

It was reported in chapter seven that despite the complexity of the many factors affecting the robot adoption process, this research has indicated the existence of a common binding philosophy between the previously separate disciplines involved in the task. Particularly it has shown that a longer-term planning orientation within the company and an integrated approach to implementation are crucial to the successful introduction of robots.

These conclusions thus complement earlier research which found that the following three factors are generally most determinant of successful robot adoption:

a) the existence of previous experience with automation

b) the availability of appropriate electronic and programming skills

c) the poor working conditions of the manual task before robotisation [225].

Whereas the above points can be said to be preconditions for successful adoption, this research has identified the techniques by which the adoption process should be managed. Previous authors have studied robot adoption from the socio-technical perspective, stressing the need for a good 'fit' between the technology and the company's organisational and labour environments, in that the "introduction of robots must reflect a congruent production strategy in which all relevant factors fit together".[226] The naivety of these recommendations reflects the retrospective nature of the research on which it is based, and the authors' lack of experience of manufacturing industry. The contribution to knowledge provided by this thesis lies in its study of the dynamic adoption process in practice, from the perspective of a participant within it.

This research confirms Bessant's [227] work in the wider area of manufacturing innovation generally where he reports the need for effective planning. However, his design-space model of new technology adoption was not found useful other than as a description of the boundaries of the problem. Equally Zermeno-Gonzalez's[228] model of robot adoption, whilst specifying the various factors involved, gave no useful guidance on how they affect the implementation process in a dynamic way, nor guidance as to how they could be managed. The most useful model of the adoption process was in fact found to be one of the earliest and simplest: Rogers and Shoemaker's[229] schematic was an adequate description of the stages of the process and was used as a basis for the description of the case-study. Subsequent models, whilst they are more thorough and comprehensive were found to be of little practical use; the adoption process is so complex and variable that highly descriptive models are self-defeating. It is more important to highlight the key factors and generalise the stages in the process at the expense of comprehensiveness in order to present a useful management tool. Thus the technical school's description of robot implementation as a sequential structured process was found to be of value, despite the fact that the Trebor case-study showed that such descriptions are far from complete. As a skeleton-framework of the stages that must be gone through, not necessarily in the order presented and certainly not as methodically, the technical approach to implementation is a useful benchmark.

This research also underlined the limitations of an overly mechanistic approach to technological change. It leads to an under-estimation of the importance and the influence of the less objective, less well-defined aspects of the adoption/implementation process and to an over-reliance on the formal procedures and structure of the company, when it is the 'informal organisation' which is the key to managing innovation successfully. This confirms Kanter's[230] argument that an organic or informal environment within the company allows innovation to flourish and the 'entrepreneurs' carrying out the change to see the process as a whole, rather than it being divided or cut-off by the existing formal structure. The collaborative nature of this project, and its marginal status half outside the firm gave freer rein to the innovation process. However when this flexible approach was superceded by formal structure - such as the Colchester project team - problems arose through poor communication and a lack of shared ownership of the problem. The formal structure, when grafted onto the project, brought with it the existing interdepartmental conflict and prejudices. People were forced to "wear their hats" as production manager or engineering manager rather than as members of a project team. Thus organising for robot adoption means developing a flexible approach - not splitting tasks down into specialised roles or burdening the project with the existing procedures of the company. Rather it means working through the informal organisation, seeing the problem as a whole and separate from day-to-day considerations, being flexible in using whatever skills and resources are available within the company and sharing ownership of the problem as a whole rather than allocating parts of it to different individuals.

The Trebor case-study also highlighted the limitations of the highly mechanistic approaches to robot application analysis and system design development, such as presented by Warnecke and Schraft[231] for example. It was found that as expertise was developed in considering robot technology in the Trebor manufacturing situation, an overly mechanistic approach constrained the development process rather than helping it. A more loosely structured study was found to be more effective as it reduced the tendency to over concentrate on the robotics system as an isolated unit, rather than as an integrated part of the overall manufacturing process. The need to effectively integrate the robot systems also crucially influenced the design method used for developing the system solutions. The total-system approach advocated by Parnaby[232], Vuzelov[233] and others was found to be considerably more effective than those that focused on the robot systems in isolation. In fact the particular characteristics of the Trebor situation meant that a broad perspective was of great importance: the nature of the existing manfucaturing technologies, the slow rate of change in the industry and the Company's approach to production engineering were all found to be significant obstacles to the implementation of robots. It was concluded that wider adoption of robots within the industry would require significant changes in both robot technology development and the production engineering approach employed. The reasons for this were shown to be linked to the nature of the robot-application design problem - involving as it does a web of chained design parameters which make an integrated design approach indispensable; the total systems approach is shown to be in concert with the multi-disciplined influences on the robot adoption process.

By definition almost, manufacturing innovation involves the accomplishment of something unusual and non-routine by the Company, which therefore requires extra effort. Even if it only a small, incremental change it will be going against the finely tuned mechanisms which are designed to reduce variance and to optimise the status-quo. This thesis confirms previous research which has linked the presence of key individuals to the provision of this extra effort behind the innovation. However, it also provides new insight into the nature of the process, particularly project championing. In identifying the role of passion in driving the project,it has shown how the entrepreneurs or champions within the Company can be a negative as well as positive influence. There were both advantages and disadvantages to the way the Trebor project was 'entrepreneurially' managed, clear examples were identified where it was a negative influence upon the implementation process - bringing some harsh reality into the overly romantic literature in this area.

The most striking aspect of the financial dimension of the problem highlighted by this research is the stark contrast between the tidy, highly structured financial methodologies presented in the literature, and the ill-defined, untidy reality of the adoption process in practice; there seemed to be little in common between them. A rigid solution-approach to a variable problem is likely to be inappropriate and this research shows that indeed it is. Two rather conflicting hypotheses presented in the literature were a) that the implementation of robots is hampered by inadequate accounting methods and b) by the poor understanding and use of the existing methods by the engineers responsible for implementation projects. This research suggests that both are partly true. The accounting techniques are inadequate, even the accountancy literature recognises this, but their inappropriate use obviously worsens the problem. This research indicates that the whole method of investment decision-making employed by the Company is the most important issue: its time horizons and its priorities, and the ability of the engineers to be able to influence the investment decision, rather than simply a question of understanding accountancy. The problem is one of access by the technical people to the decision-making process and to the information relevant to the decision itself. This research found that it was above all a lack of information, particularly relevant to the business strategy of the company, that was the problem. It suggests that focussing upon the decision methodology is inappropriate when the problem is one of access to information, participation in the decision process and understanding of the wider context of the problem.

The adoption and successful implementation of industrial robot technology is a complex and difficult technical problem, for which engineers should be best equipped to manage. Although this research has demonstrated the central importance of the technical aspects of the problem it has also shown how the technical issues are directly influenced by equally important organisational and financial dimensions of the innovation process. The development of robot-application proposals in the Trebor project is an example of this. The preparation of schemes for the proposed robot automation projects was found to be a crucially important part of the overall implementation process. Two aspects of the application proposal documents were relevant here: the technical and the negotiational, which were dependent upon and related to each other. First and foremost the application proposal arose from an analysis of the workplace and task data and an outline design, to form the basis of the technical specification for the eventual system. Therefore the operational performance and success of the system depended upon getting the specification and hence the proposal right. But, not just right in a technical sense, right from the point of view of the intended users/operators/managers of the system, and right from the point of view of the needs and aims of the Company, matching the overall business strategy. Thus the application proposal document had three parallel roles: as a specification, as a basis for financial analysis and as a basis for negotiation between the acting, using and directing groups involved in the project.

This presents significant problems for the traditionally orientated engineer, because he is either poorly equipped to deal with these non-technical issues, or as often is the case, tends to dismiss them as unimportant, as not 'real engineering'. This research suggests that the people managing robot implementation projects must take a broad approach which incorporates the management of these crucial non-technical issues, and more importantly embrace them within their own concerns. This suggests a change in emphasis of the role of engineers within organisations, away from being purely a resource to the company for providing solutions to technical problems and towards being the driving force for change - for getting the 'right things' done. This means a pro-active rather than reactive role. Engineers must widen their scope to embrace the organisational and financial aspects of technical problems, to understand the wider context and constraints which the firm is operating in, and the strategy it is following. They must internalise this knowledge and then use it effectively to mobilise resources and provide appropriate solutions to the company's needs.

It was described in chapter five how some form of technology transfer has to occur when a company adopts a new manufacturing innovation for the first time, because specialist expertise in the new technology has to be acquired by the firm. This means that either current employees have to go outside the company to acquire this expertise, or people who already have such knowledge have to be brought in. Whichever route is taken the aim is the same: to develop a synthesis of expertise within the company between robotics knowhow and knowledge of the existing manufacturing situation that it is to be used within. Developing a synthesis of robotics and 'local' expertise has been shown to provide the "critical mass" in the robot-adoption "reaction" (figure 8.2.1). This explains why the major difficulties in introducing robots occur at the development and trial-adoption stages; it is here that the crystallisation of this synthesis of expertise is first put to the test; having a direct influence upon the project team's ability to design successful system solutions, upon people's commitment and ownership of the innovation and in maintaining the project's accord with the business and financial plans that the company is following. Thus it is a thread which runs through all three dimensions of the problem. This conclusion leads to an important guideline for the management of robot adoption: the synthesis of expertise must be achieved during the investigation stage. It is also good news for companies considering robotics, they already possess half of the expertise needed and it is the more important half.

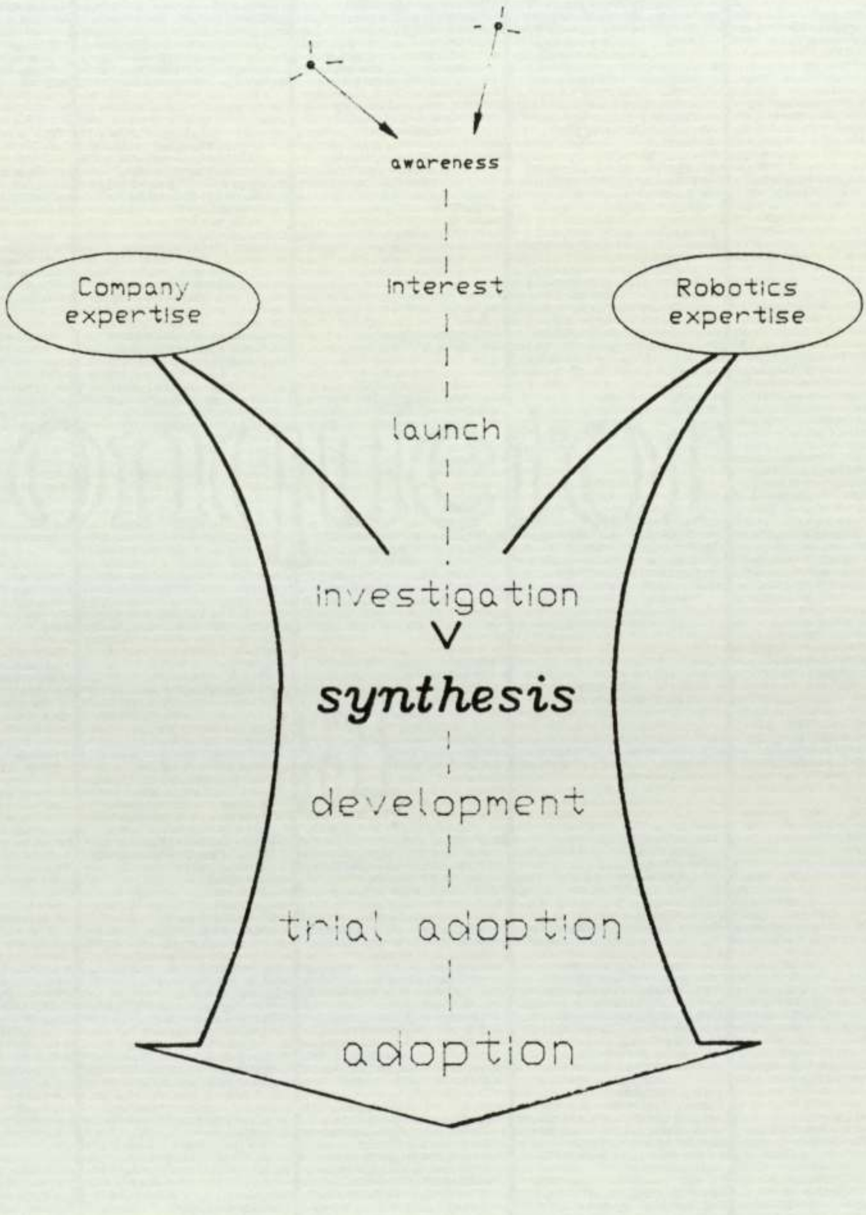


Figure 8.2.1 Development of a 'Synthesis' of Expertise During the Robot Adoption Process

It has been mentioned how there are two ways of obtaining this synthesis of expertise and whilst the objective is the same, the route for getting there is not. In the former case existing employees who have acquired a detailed understanding of the manufacturing situation, perhaps over some years, use this knowledge to assess the applicability of the new techniques. However, in the latter case, the new 'experts' who have specialist expertise in the new technology have to develop an understanding of the particular manufacturing situation from the basis of their experience of different industries. Trebor followed the latter strategy, and although there is no evidence to suggest that either route is preferable, it is vitally important that this synthesis of expertise is developed as quickly as possible. In the Trebor project an opportunity was missed to do this during the factory surveys. It would have helped to develop this synthesis if a factory engineer had also been involved in this work together with the author.This would have allowed a two-way exchange of knowledge which would have developed better factory ownership and commitment to the project and improved the author's understanding of the problem. In the same way the development of the application proposals was done separately from production people and then later discussed with them. Some of the subsequent problems which arose may have been avoided if they had participated in the actual designs themselves.

Of course the disadvantage of doing this is the cost it involves. The participative approach is a very expensive one, involving manpower from each factory as well as a central person from R & D. It is also linked to the entrepreneurial process which has been shown in this research to be a key influence. It is important that a coalition of support is built with the people involved in and affected by the change, upon which the project can then be built. In the early months of the Trebor project an over-concentration on the technical aspects of the problem meant that this coalition-building was not done, as a broad approach was not adopted until problems were faced in identifying the first application in late Summer 1983.This highlights the importance of this linkage between the application development and learning processes involved in robot adoption.

Strategic planning - the "... deliberate and conscious articulation of a direction, creating a vision of a possible future ..." has been reported in the literature to be a crucial influence on a company's ability to cope with change, including robotics. It is argued that the complexity and pace of technological change is one of the strongest influences on business and that the strength of this influence is likely to increase in the future; in the case of robotics and flexible automation, the need for strategic planning is emphasised for four reasons:

* significant use of robotics technology changes the fundamental economic structure of the business

* implementing robotics programmes requires sustained effort over a number of years

* robotics offers new business strategy options. Namely; capacity matching to the product life cycle, vertical integration into distribution and supply removing the need for inventory decoupling and exploiting technological discontinuity within the manufacturing process to achieve a stronger competitive position through more flexible, predictable manufacture.

* integration difficulties such as hard/software incompatibility can only be avoided by planning.

It may be argued that these factors are only important to companies intending to make substantial investment in robotics, and not firms like Trebor who are still at the experimentation trial - adoption stage. However, the preceding analysis of the Trebor project reported that even at this early stage, clear long term planning is vital. Seven instances of the need for it were cited:

- at the start of the project, in deciding the Company's response to this developing technology
- at the commitment stage, emphasising the learning aspects of the first robot
- at the completion of the first installation, to maintain the momentum of the project
- to 'flag' the effect that the changing business strategy was having on the emphasis of the project
- to aid liaison with outside agencies
- to reduce internal resistance to change by putting the short term problems into a long term plan which put the difficulties into perspective, and provided a joint 'vision' for "why we were doing this"
- to bring the project back into the Company, "to institutionalise the innovation" which the entrepreneurship will act to push out

The analysis in chapters four and five showed that at certain points in the project, this need for long term planning was not fulfilled, particularly following the installation of the first robot. Two main problems were experienced here, firstly an emphasis on the operational benefits of continued further adoption of robotics rather than the strategic ones, and secondly a failure to grasp the significance of an important change in the Company's business plan which affected the project. This contributed to the perception which developed in early 1985 that the project was too separate from what the rest of the Company was doing. As chapter four demonstrated, there needs to be a clear link between any technical project and the Company's business aims. This failing was due to an overemphasis on the technical aspects of the project in the early stages, which in turn led to inappropriate design solutions in the context of the Company's needs and priorities. It can be concluded that technical solutions cannot be developed in isolation of the business needs and financial framework. An understanding of these needs will enable the engineer to tailor his design and present his solution in the best light - emphasising the features which provide the benefits needed by the company at that time. This was therefore further evidence of the importance of engineers' training and briefing in the areas of accountancy and business planning.

The three year planning horizon is also of crucial impact on the Company's ability to properly consider the strategic long term issues raised by robotics. Three year planning means that at best the Company can only 'see' two years ahead. Thus one of the reasons for the lapses in the robotics project's long term planning can be attributed to the Company's capital budgeting procedures. An alternative approach to having the robotics project funded from Production division's capital investment budget, is to use a separate 'venture capital' account to reflect the higher risk and special issues involved, and to separate an entrepreneurial risk from the mechanisms aimed at optimising normal operations, a fundamental principle of innovation management.

The purpose of a technology strategy is to define how a company can most effectively use and 'develop' its knowhow resources to achieve maximum competitive advantage. (It is worth noting that three of the four processes in robot adoption identified in chapter four were knowhow dependent.) However, in the case of robots the literature reflects a dichotomy of opinion as to whether the adoption of robotics is an investment or a strategic decision. It is clear that the conflict arises from confusion as to at what level the decision should be taken. Deciding if the time is right to enter a new market, acquire another business or build a new factory are all generally regarded as strategic business decisions, dependent upon the competitive position of the company overall and managed via long range plans. However, the decision to adopt a significant new manufacturing technology is not regarded in the same way. Perhaps through a lack of understanding the decision is often relegated to an operational level, focussing on the short-term benefits that may be achieved and without any acceptance of the business risk associated with the decision. Trebor were both enlightened and progressive in their attitude towards adopting robots on a trial-adoption basis to both learn about and prove the technology in their particular manufacturing situation.

Overall this research has achieved the objectives set at the beginning of the work in September 1982. It has shown that whilst there is significant potential for using robotics both in Trebor and the food industry (at the most fundamental level long wave trends in the marketplace point to flexible automation as a key enabling technology in the future), it has identified the equally significant changes to both the technology and production engineering techniques needed if this potential is to be realised. The research study of the robot adoption process in action led to the identification of both the strengths and weaknesses of Trebor's approach to managing innovation. Evidence in support of the worth of this work can be found in that the author was asked to write a technology strategy for the Company as a result.

One of the aims of this research was to improve the currently rather poor success-rate in the use of robot technology in the UK. To this end the research conclusions have been summarised in the form of a plan of work for the management of future robot projects.

Plan of Work

for

Industrial Robot Implementation

8.3. Plan of Work

This plan of work provides guidelines for the management of robot implementation projects based on the experiences and conclusions of this research.

It consists of four parts

- a list of key project milestones
- an action plan for top management
- an action plan for the project team
- a critical path analysis of a complete robotics adoption process from investigation through to full adoption.

PROJECT MILESTONES

1 Started to actively search for more information on robotics technology and its use.

2 Decided to investigate the application of robotics to the firms manufacturing processes and the strategy to be followed in doing so.

3 Identified the potential and implications of using robots within the company and the fit with company plans.

4 Developed a synthesis of robotics and local manufacturing expertise.

5 Agreed the company's response to the opportunity offered by robotics technology.

6 Chosen first production application for robotics within the company.

7 Audited first system and reviewed project overall.

8 Decided long term plan, level and rate of implementation or decided to suspend adoption.

9 Production personnel able to effectively consider robots and use them where suitable in the manufacturing process, integrated efficiently with other manufacturing technologies.

ACTION PLAN - TOP MANAGEMENT

* Provide the raison d'etre for the implementation/adoption project, i.e. clarify the links betwen the use of robotics technology and the long-term aims of the company.

* Set up a group to manage the adoption/implementation process. Provide clear responsibility and the resources necessary. Clarify the entrepreneurial nature of the project and the importance of a broad approach.

* Protect and sponsor the project team, emphasise a 'time' orientation and that success <u>matters</u>, be aware of project drifting too far away from the core company or conversely being bogged down by 'normal' procedures/policies - maintain a balance of marginality, but maintain the project team's autonomy.

* Provide a clear "vision-of-the-future" which people can aspire to and which puts the short term difficulties into perspective.

* Be clear that the technology offers a competitive advantage to the company - i.e. understand it - beware of technological jingoism pushing the project rather than the company's needs pulling it.

ACTION PLAN - PROJECT TEAM

* Take time to understand the problem, and if a newcomer to the company - take time to understand the 'system'

* Develop support for the work at all levels in the company - this will involve 'marketing' the idea, emphasising the benefits most relevant to the groups concerned - i.e. provide focus to 'why we are doing this' -emphasise their benefits or outweigh disadvantages with a longer term view.

* Don't start the development stage of the project until sufficient: expertise, understanding and information on robotics; understanding of the problem, the important issues; support from top management, production management and production workforce; resources have been acquired.

* During the development/trial adoption stages think ahead to smooth the path for the project, protect it - don't baulk at doing what is necessary; realise that this is an innovative project and so requires extra push, so bending the rules is unavoidable. Just do it as diplomatically as possible, but be resolute.

* Involve production people in the development process.

* Reconnoitre the territories that have to be crossed in implementing the project and develop alliances with the people who occupy them.

* Towards the end of the trial adoption stage act as a gardener for the seeds of other projects, disseminate expertise and ownership to institutionalise the use of robotics within the organisation, and thus maintain the momentum established by the earlier championing and sponsorship. Support other people championing projects.

* Be sensitive to hints that problems are occuring, don't let them fester into major obstacles. Watch the radar - listen to informal network.

* Don't fall back upon the formal organisation to get things done, establish informal links early on and use and maintain them.

* Don't feel guilty if less time is being spent on the 'real engineering work' than is usual or expected. Real Engineering is about managing the situation so that the "right things" get done. The crucial broad, integrated perspective cannot be maintained if you spend all your time on the detail. The non-technical stuff is crucial - watch it closely.

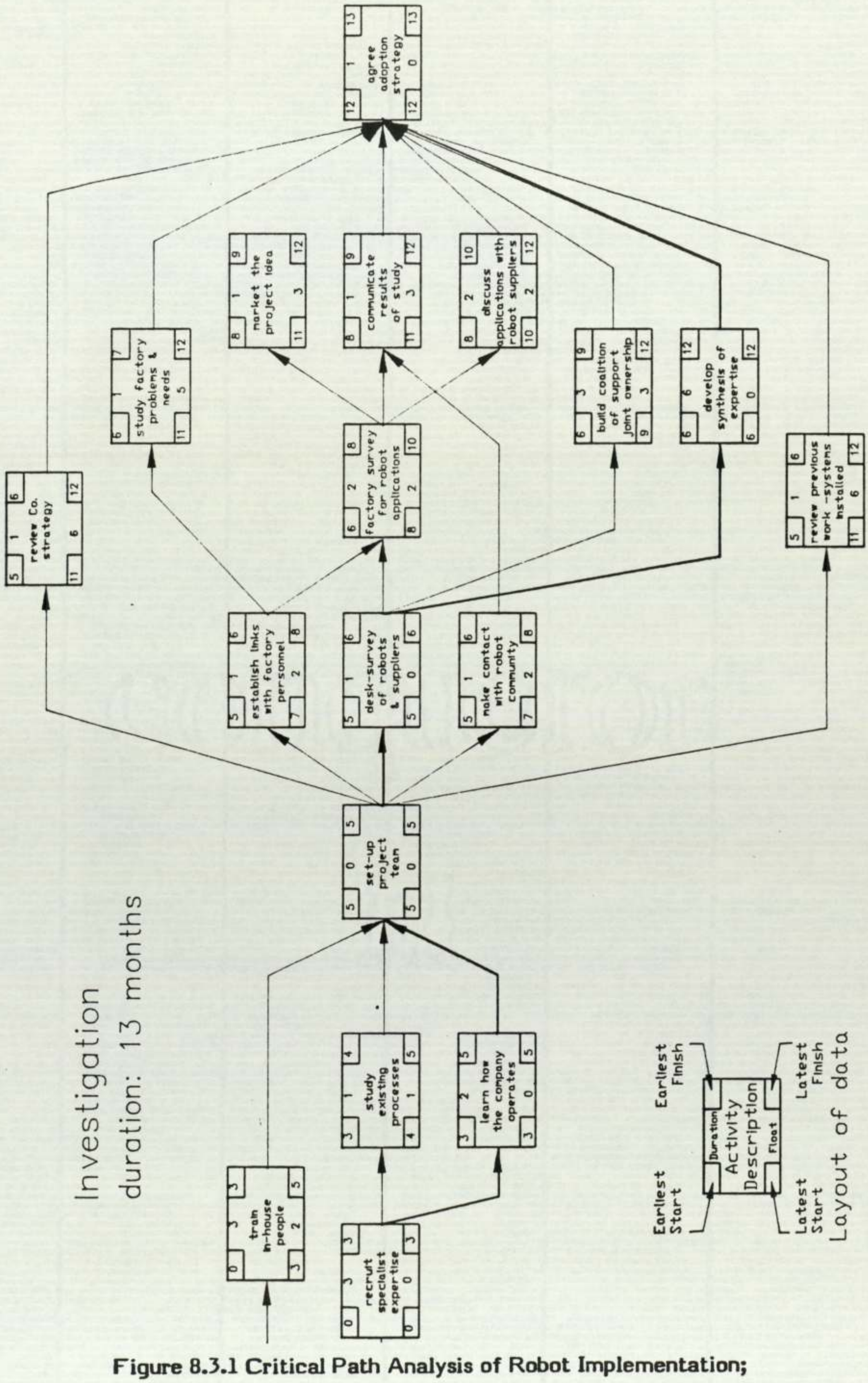


Figure 8.3.1 Critical Path Analysis of Robot Implementation;

Investigation

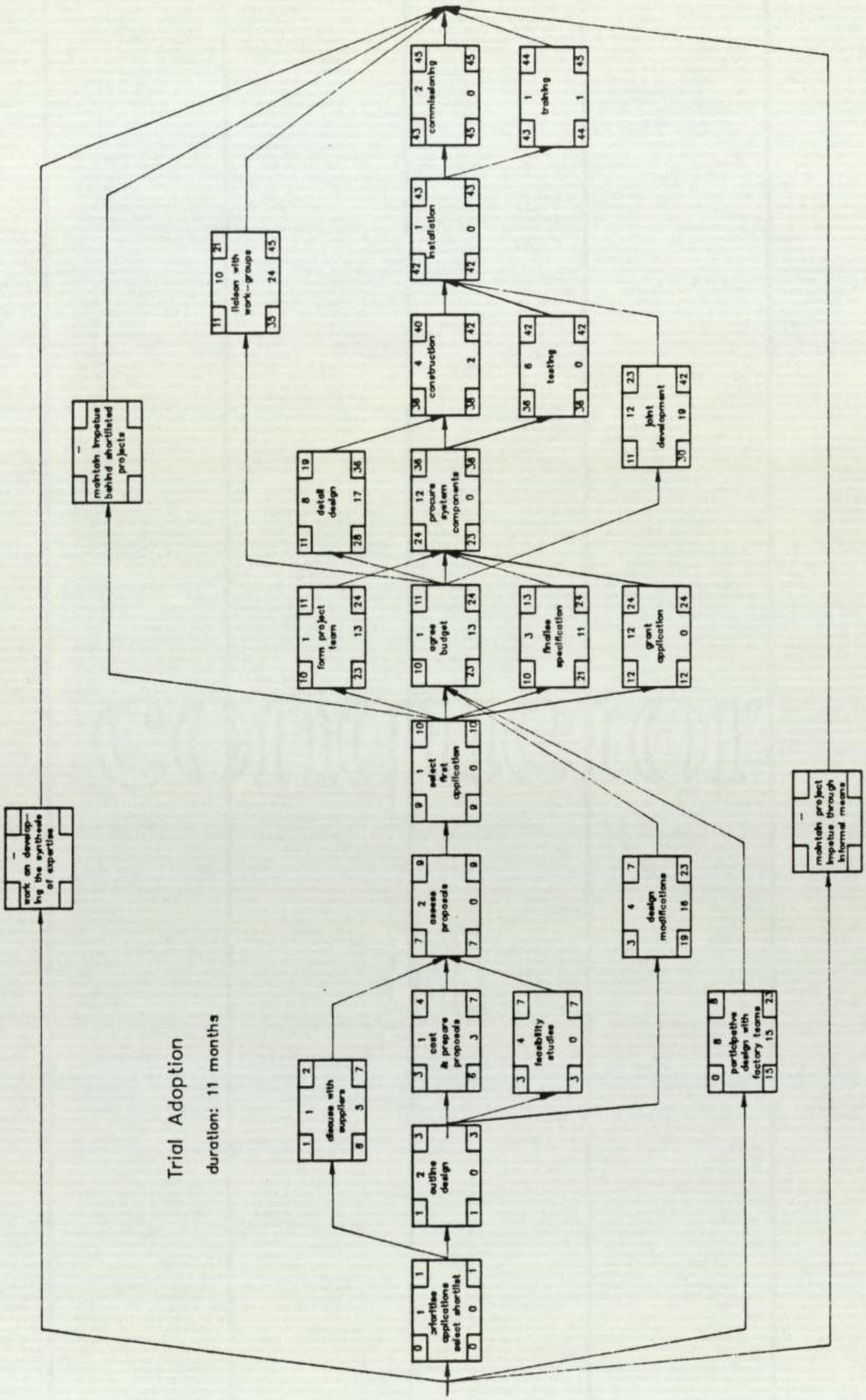


Figure 8.3.2 Critical Path Analysis of Robot Implementation; Trial Adoption

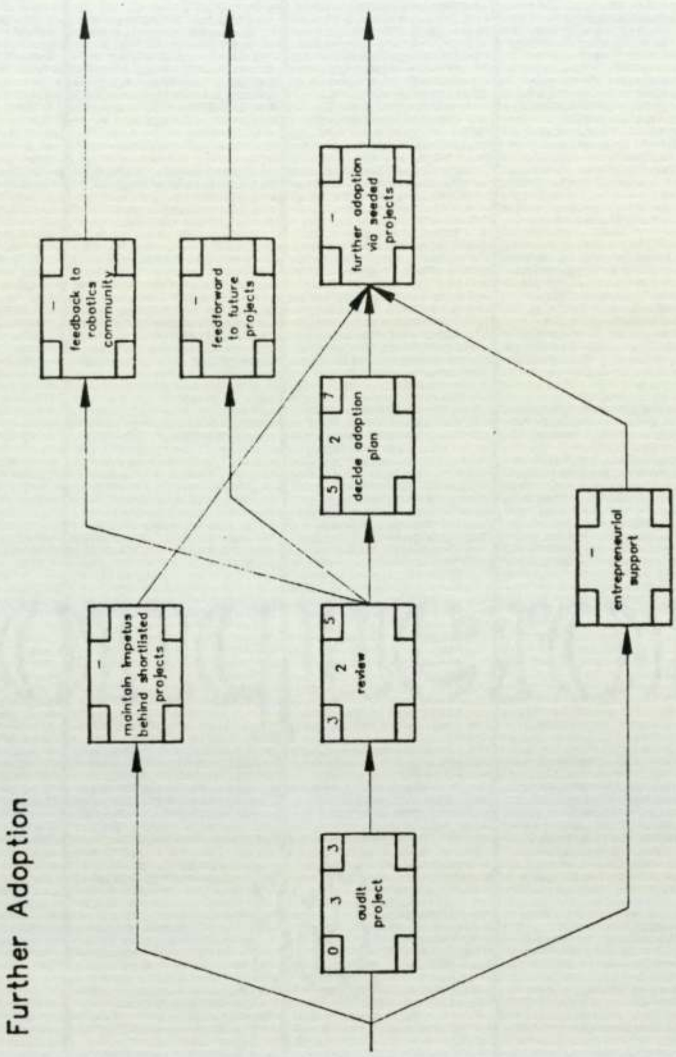


Figure 8.3.3 Critical Path Analysis of Robot Implementation; Further Adoption

8.4 Conclusions

It has been shown that robotics technology will have a significant impact on confectionery manufacturing and similar batch food-processes, particularly:

* product decoration e.g. cakes, easter eggs, chocolates
* 'assembly' of layered products, such as sandwiches pre-packed snacks and ready-meals
* product inspection and sorting
* packing and packaging operations
* end-of-line stacking and palletising
* materials-handling and warehousing.

At the present time the fit between robotics and Trebor's needs is a poor one, developments will have to occur in both the technology and Trebor's production engineering methods if the opportunity offered is to be realised. The current problems are:

* the poor space efficiency, low speed and high cost of the current generation of robot systems
* the fundamental difference between robotics technology and the 'mainstream' manufacturing technologies used in the food industry in both design and use.

The changes needed to bring the problem and the robotic solution closer together are as follows:

Robot system design principles
for food manufacture:

- modularity of tooling and component systems
- systems configured to give good floorspace utilisation
- visual inspection systems designed for very high speed inspection of simple shapes

- fast arms
- IP55 protection of all system components using food quality materials in construction
- integration into packaging and handling operations, general merging of robotics technology into food process and packaging equipment to give flexibility throughout the manufacturing process.

Production engineering principles
for employing robotics technology:

- take the whole manufacturing process as the starting point when considering process improvements
- design robot-cells to operate as sub-units within the manufacturing process such that flexibility is inherent in the sub-unit and not just the component robot devices
- establish a long term plan for the eventual modernisation of the whole process before consideration of partial improvements
- integrate the financial and organisational context of the design approach - ie take a multi-disciplined, broad approach to design.

The adoption of industrial robot technology by a company is a process of innovation which involves:

a) an engineering process: whereby the technology is investigated and evaluated, systems designed and developed to meet the comapny's special needs, and implemented on a trial basis to assess their effectiveness.

b) a technology transfer process: in that a synthesis of expertise has to be developed between the 'local' knowledge of the Company's specific manufacturing processes, and the specialist knowledge of robotics technology. Two main technology-transfer routes may be used to obtain this synthesis:

i) between the adopting company and other users

ii) between the adopting company and the robotics community, particularly the robot system vendors.

c) a learning process: whereby the implementation process is limited by the rate at which robotics expertise can be acquired and disseminated within the company. The effectiveness of the synthesis of expertise and shared ownership that is developed is a crucial influence upon the level of organisational resistance that is encountered and the ability to design effective robot applications.

d) an entreprenuerial process: the adoption of robot technology involves the Company in a process of change which must be managed separately from the activities necessary for the day-to-day running of the firm. This involves an element of entrepreneurial management to provide impetus and sponsorship for the adoption/implementation process. The championing of technological innovation is not an especially heroic process, rather it is a process of sponsored change which tests the adaptability of the organisation and individuals to cope with it, and which has negative as well as positive influences on the innovation process. Passionate belief in the project is a key source of drive behind it.

A balanced judgement of the financial viability of adopting robot technology requires:

i) a long-term view (5 years plus);

ii) consideration of the effect on the overall manufacturing process as a whole;

iii) consideration of the impact of the technology in terms of the company's business strategy and the manufacturing task, and hence the competitive advantage it could provide.

Finally, the most important conclusion from this research is that a longer-term planning orientation which links the implementation of robotics to the company's business strategy and an integrated, broad approach to managing the adoption process are crucial to successful robot use.

APPENDIX A

Appendix A

This appendix contains the data collected during the factory surveys carried out in 1983 and 1985.

This work is discussed in chapters 3.3 and 7.2.

REPORT

POTENTIAL APPLICATIONS FOR INDUSTRIAL ROBOTS IN TREBOR

PAUL R. DRAYSON
FEBRUARY 1983

Research & Development
Maidstone

SYNOPSIS

A survey was undertaken at each Trebor factory in the U.K. in order to identify possible applications for industrial robots.

A total of 18 different types of feasible applications were identified, representing approximately 100 applications in total in Trebor.

<u>CONTENTS</u>

1.0 Introduction

This report presents the results of a study carried out during December 1982 and January 1983 as part of the I.H.D. robotics project.

The purpose of the study was to identify all feasible applications for industrial robots in each factory and to gather the information required for their evaluation as future projects.

As well as a description of each type of application the report contains an explanation of the study method and summary of results.

2.0 Method

The method adopted for the survey of each factory was as follows:-

i) A first tour of the factory in order to gain a general familiarisation with the layout of the plant and understanding of the manufacturing processes employed.

ii) A detailed study of each production process, following the material flow throughout the process, identifying possible applications and recording individual task and process information.

iii) Collection of background data on each application identified.

iv) Analysis of information collected.

v) Further study of individual operations where necessary.

vi) Compilation of formal records on each application.

2.1 Study Criteria

The criteria used when carrying out the investigation and upon which the study was based can be summarised:-

i) Is the task wihin robot capability in terms of load, reach envelope and complexity.

ii) Is the task heavy, unpleasant or monotonous.

iii) Does the operation add value to the product.

iv) Is the task labour intensive.

v) Is the cycle time greater than 6 seconds.

vi) Can workpiece orientation be controlled.

vii) What visual inspection is required during the operation.

viii) What is the line output capacity and present output.

ix) What is the likely future output.

x) What is the frequency of product variation.

xi) What is the relationship of this operation to the process as a whole w.r.t. material flow and machine interfaces.

xii) What is the physical nature of the workpiece.

xiii) What level of positional accuracy is required.

xiv) How much floor space is available.

xv) Has a similar operation already been successfully automated elsewhere.

xvi) How successful is the present operating method.

3.0 Robot Applications

The information on each application is summarised as follows:-

A) A layout drawing showing a plan view of the operation at present. It includes the positions of machines and operators and the material flow through the operation.

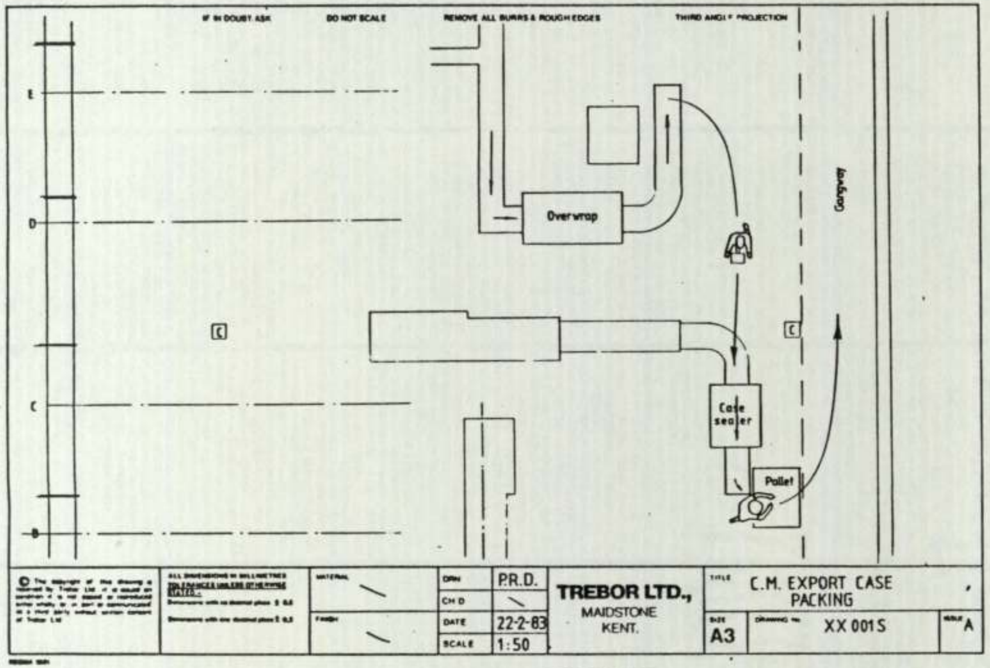
B) An application data sheet summarising the information relevant to the operation.

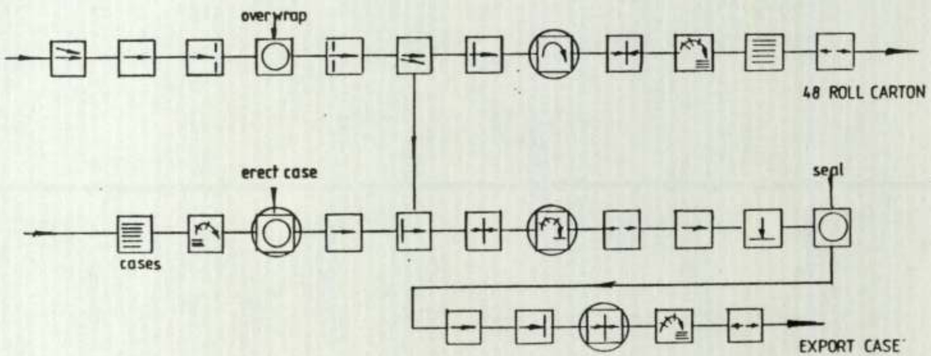
C) A process flow diagram.[1] These diagrams exactly describe the elements of the process and the relationship between them. They also facilitate subsequent analysis of the operation. (An explanation of the symbols used is given on a fold-out sheet; appendix)

3.1 Applications List

XX001	C.M. EXPORT CASE PACKING
XX002	C.M. 48 ROLL CARTON
XX003	C.M. MULTIPACK PACKING
XX004	E.S.M. PALLETISING
CC009	1p CHEW PACKING
CC010	5p CHEW PACKING
CC010	BINNING OFF FROM ROLLWRAP CONVEYOR
CC012	JAR MANUFACTURE
CC013	LOLLYBAG PACKING
CC014	JAR PACKING
CC015	LOLLIPOP CARTON PACKING
CC016	IMPERIALS CARTON PALLETISING
CC017	LOLLYADE MANUFACTURE
MM020	BON-BON BAG PACKING
MM021	BON-BON CASE PACKING
MM023	JAR MANUFACTURE
MM024	JAR FILLING MACHINE LOADING
MM026	TOFFEE & FUDGE PACKING

1 After Warnecke & Schraft 1982





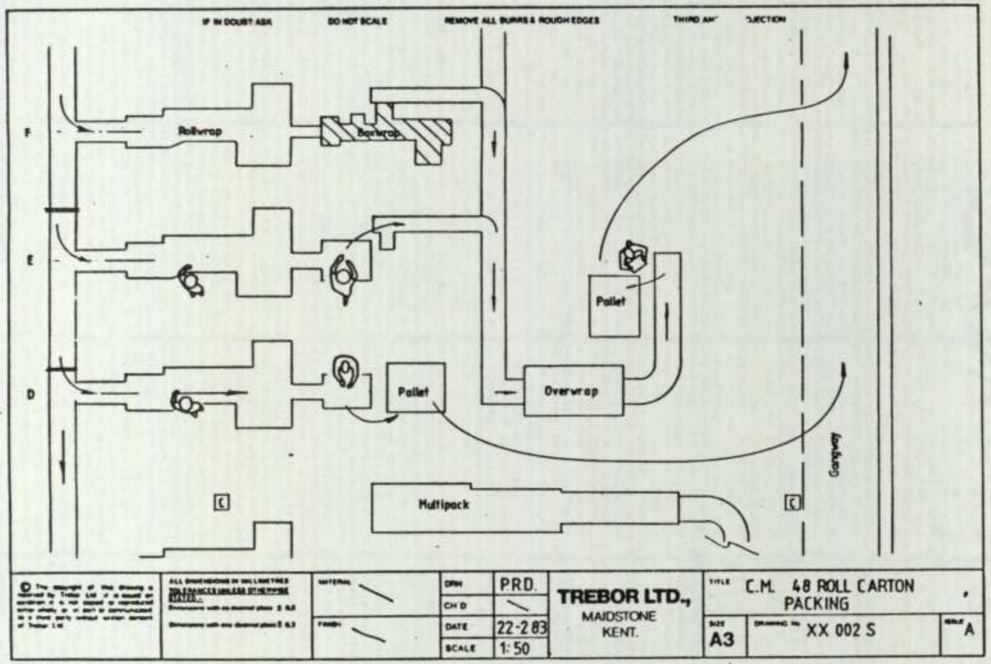
XX 002 F
XX 001 F

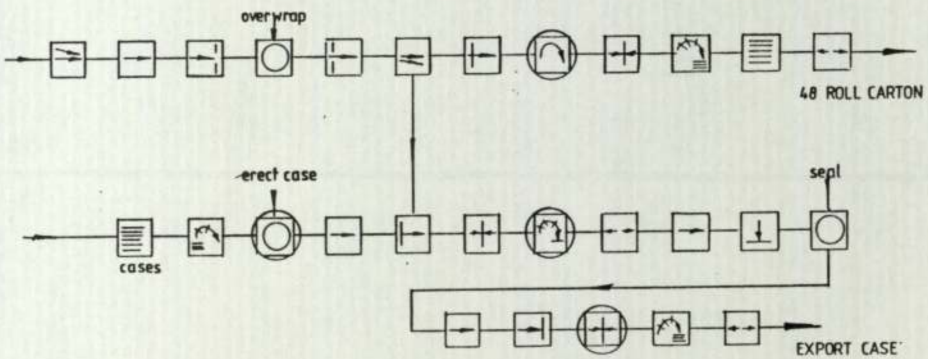
TREBOR R&D — ROBOT APPLICATION DATA SHEET — XX001

1. Application No: 001 Date: 29.11.82 By: PRD Factory: XX
2. Application Name: COMPRESSED MINT EXPORT CASE PACKING
3. Location: PRODN 1 Personnel: IAN HEARSUM
4. Description of Object: CASE OF 9 CARTONS CONTAINING 48 ROLLS
5. Dimensions: L 280 mm W 235 mm H 240 mm Weight: 11.3Kg
6. Description of Task: GET OUTER FROM STACK. PICK UP CARTON FROM CONVEYOR. INSPECT WRAP. PLACE IN OUTER. REPEAT 9 TIMES. CLOSE BOX. SEAL BOX. STACK ON PALLET
7. Occasional Variations: PLACE ASIDE BADLY WRAPPED CARTON
8. Inspection: OVERWRAP SEAL. GENERAL CONDITION OF CARTON.
9. Load/Unload Time: 2 s Positioning Accuracy: ± 2 mm
10. Operation Cycle Time: 25 s Overhead mounting possible? Y
11. How is Object Presented: FROM O'WRAP BY ROLLER CONVEYOR
    Removed: BY HAND
12. Machines to be interfaced to this operation: MARDEN-EDWARDS
13. No. of Operators this Operation: 1 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	: 1	5	5
Muscular strain	: 2	3	6
Noise	: 2	4	8
Dust, vapour	: -	3	—
Temperature	: -	3	—
Monotony	: 3	4	12
Eyestrain	: -	3	—
Prot. Clothing	: -	1	—
Oil, grease	: -	2	—
Coldroom Conds	: -	3	—
			TOTAL: 31

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: LIMITED
17. Floor Layout Drawing No: SSCH/0022 B





XX 002 F
XX 001 F

TREBOR R&D

ROBOT APPLICATION
DATA SHEET

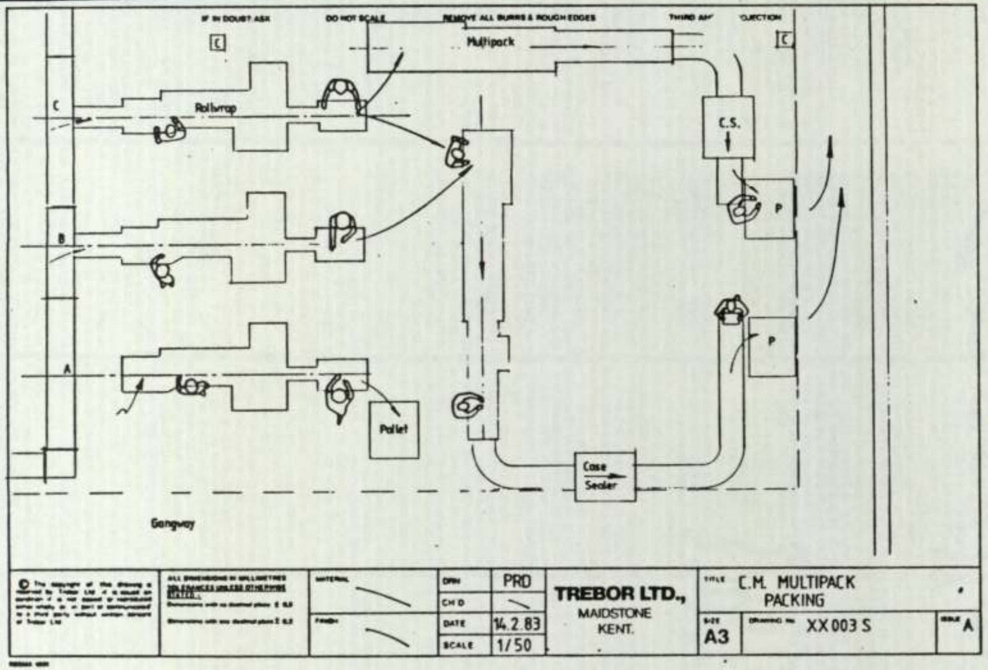
XX 002

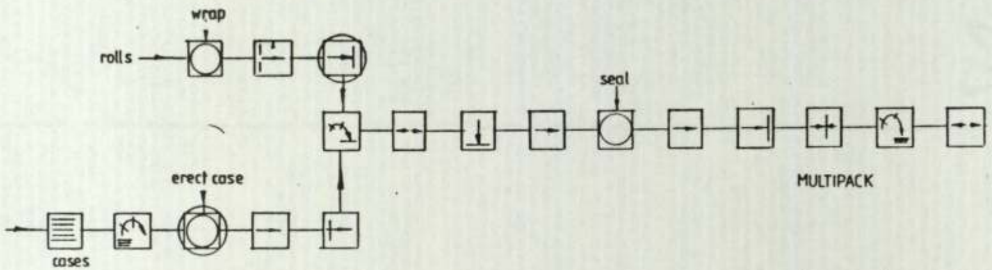
1. Application No: 002 Date: 29.11.82 By: PRD Factory: XX
2. Application Name: COMPRESSED MINT 48 ROLL CARTON PALLETISING
3. Location: PRODᴺ 1 Personnel: IAN HEARSUM
4. Description of Object: O'WRAPPED CARTON OF 48 ROLLS
5. Dimensions: L 176 mm W 82 mm H 73 mm Weight: 1.3Kg
6. Description of Task: COLLATE 2 CARTONS. CHECK WRAP STACK ON PALLET.
7. Occasional Variations: CHANGE PALLET. TEND O'WRAP M/C.
8. Inspection: O'WRAP GENERAL CONDITION OF CARTON
9. Load/Unload Time: 3 s Positioning Accuracy: ± 3 mm
10. Operation Cycle Time: 12 /min Overhead mounting possible? Y
11. How is Object Presented: FROM O'WRAP M/C BY ROLLER CONVEYOR

    Removed: BY ROLATRUC
12. Machines to be interfaced to this operation: MARDEN EDWARDS
13. No. of Operators this Operation: 1 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	2	3	6
Noise	2	4	8
Dust, vapour		3	
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
			TOTAL: 31

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: OK
17. Floor Layout Drawing No: SSCM/0022B





XX 003F

TREBOR R&D

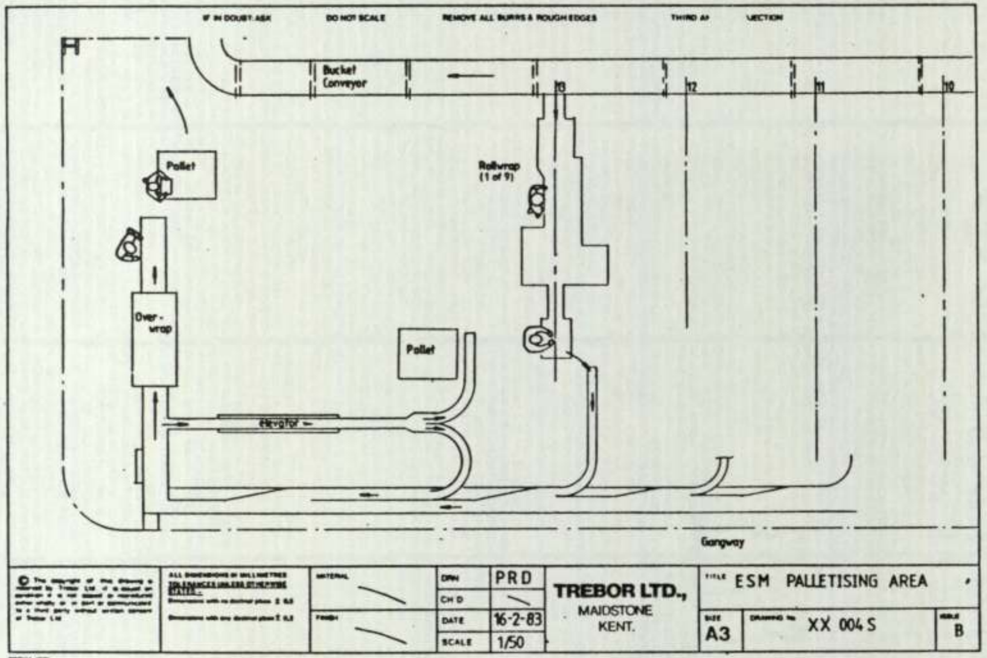
ROBOT APPLICATION DATA SHEET

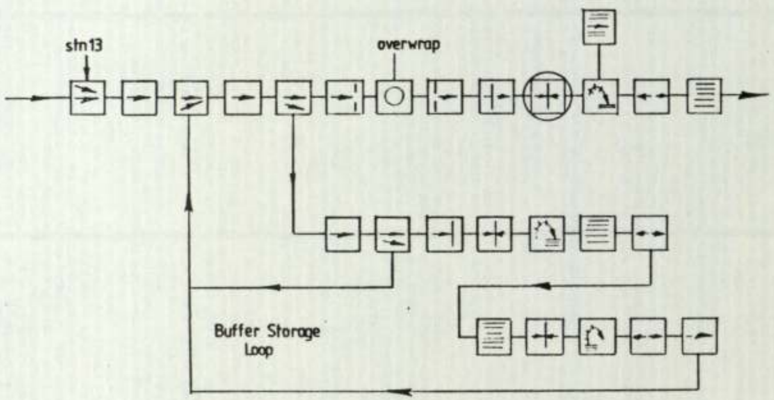
XX 003

1. Application No: 003 Date: 29.11.82 By: PRD Factory: XX
2. Application Name: COMPRESSED MINT MULTIPACK INTO OUTER
3. Location: PROD^N 1 Personnel: IAN HEARSUM
4. Description of Object: 3-5 ROLLS OF 16 SHEETS IN CELLOPHANE.
5. Dimensions: L 306 mm W 233 mm H 169 mm Weight: 1.3 Kg
6. Description of Task: FILL BOX WITH CORRECT NUMBER OF PACKS. CLOSE BOX SEAL STACK ON PALLET.
7. Occasional Variations: POOR WRAP REJECT
8. Inspection: CELLOPHANE WRAP
9. Load/Unload Time: 1.5 s Positioning Accuracy: ± 5 mm
10. Operation Cycle Time: 30 s Overhead mounting possible? Y
11. How is Object Presented: BY POWERED CONVEYOR
    Removed: ROLLER CONVEYOR
12. Machines to be interfaced to this operation: MULTIWRAP, CASE SEALER
13. No. of Operators this Operation: 3 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	2	3	6
Noise	2	4	8
Dust, vapour		3	
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
			TOTAL: 31

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: OK
17. Floor Layout Drawing No: SSCH/0022B





XX 004 F

TREBOR R&D

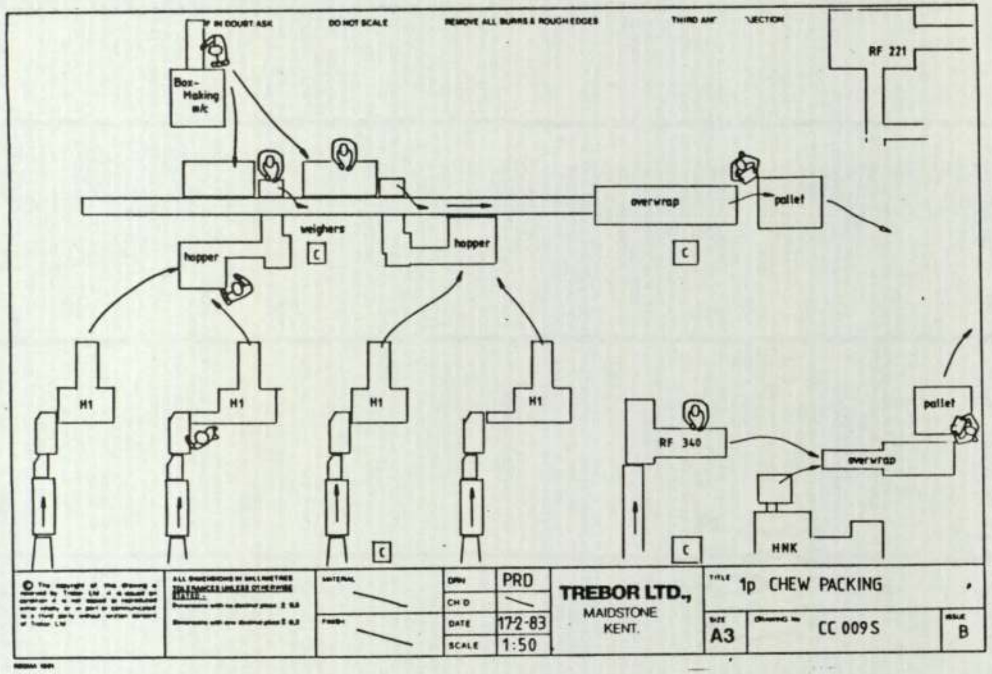
ROBOT APPLICATION
DATA SHEET

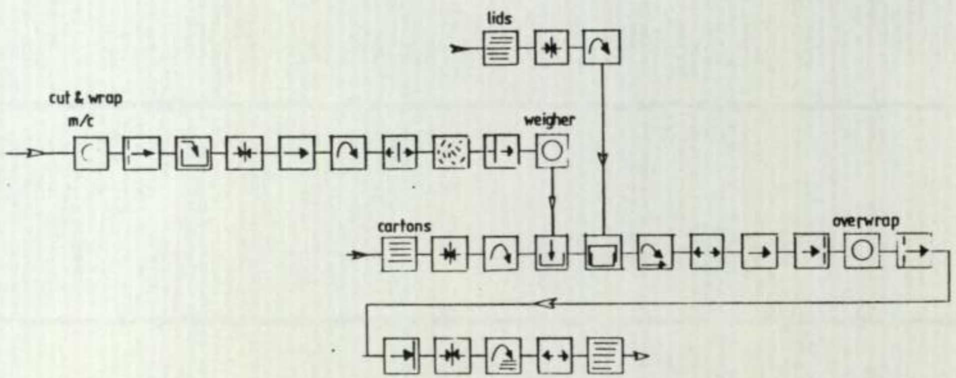
XX 004

1. Application No: 004 Date: 30.11.82 By: PRD Factory: XX
2. Application Name: PALLETISING OF E.S.M. CARTON
3. Location: PRODN 2 Personnel: IAN MACLOUD
4. Description of Object: OVERWRAPPED CARTON OF 36 ROLLS
5. Dimensions: L 218 mm W 98 mm H 89 mm Weight: 1.5Kg
6. Description of Task: PICK UP CARTON, CHECK OVERWRAP STACK ON PALLET.
7. Occasional Variations: CHANGE PALLET REJECT CARTON
8. Inspection: OVERWRAP. CONDITION OF CARTON
9. Load/Unload Time: 1.5 s Positioning Accuracy: ± 5 mm
10. Operation Cycle Time: 12ms Overhead mounting possible? Y
11. How is Object Presented: POWERED CONVEYOR
    Removed: ROLATRUC
12. Machines to be interfaced to this operation: MARDEN EDWARDS
13. No. of Operators this Operation: 2 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	2	3	6
Noise	2	4	8
Dust, vapour		3	
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
			TOTAL: 31

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: OK
17. Floor Layout Drawing No: 0006/D





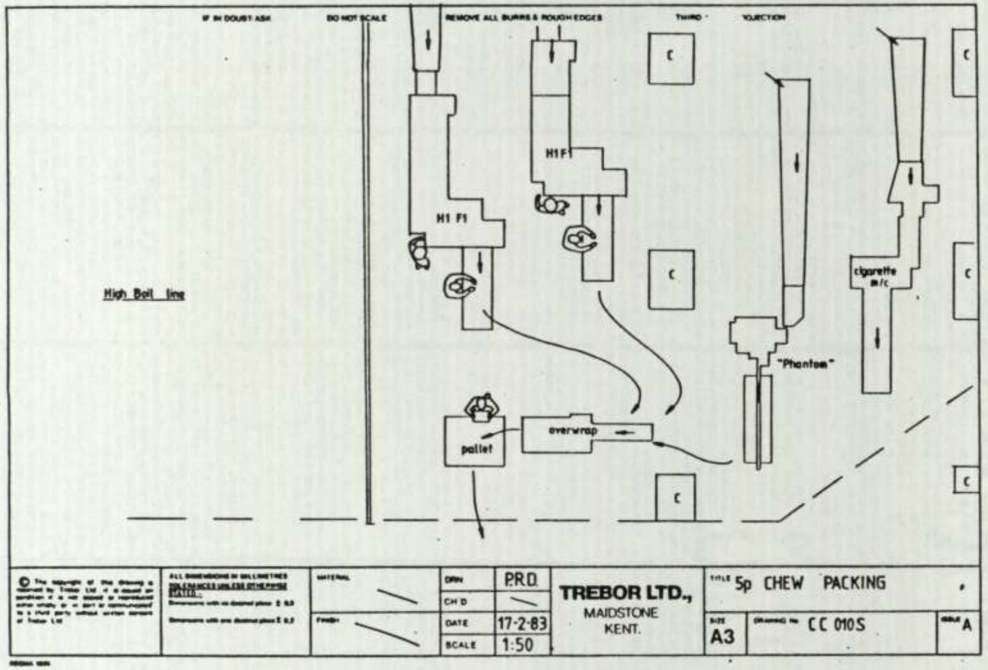
CC 009F

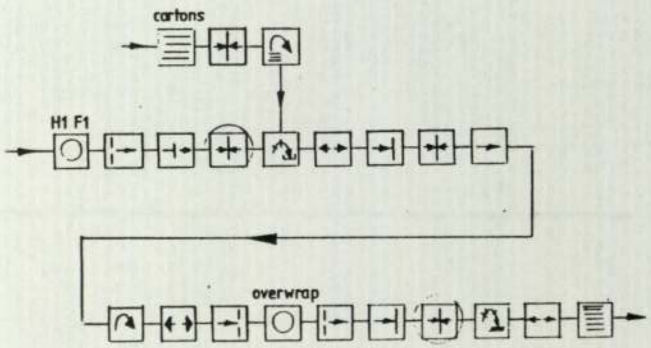
TREBOR R&D ROBOT APPLICATION DATA SHEET **CC 009**

1. Application No: 009 Date: 18.1.83 By: DRD Factory: CC
2. Application Name: 1p CHEW PACKING
3. Location: No 4 DEPT Personnel: W. BROADBENT
4. Description of Object: 1p CHEW INTO TUMBLEPACK CARTON
5. Dimensions: L 155 mm W 193 mm H 89 mm Weight: 1.5Kg
6. Description of Task: PLACE CARTON UNDER WEIGHER DROP
   ALLOW TO FILL
   PLACE LID ON CARTON
   PLACE ON CONVEYOR
7. Occasional Variations:
8. Inspection: GENERAL CONDITION OF CARTON
9. Load/Unload Time: ~ s Positioning Accuracy: ± 2 mm
10. Operation Cycle Time: 7 s Overhead mounting possible? N
11. How is Object Presented: STACK OF CARTONS ON BENCH
    Removed: POWERED CONVEYOR
12. Machines to be interfaced to this operation: WEIGHER.
13. No. of Operators this Operation: 2 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	:	5	
Muscular strain	: 1	3	3
Noise	: 2	4	8
Dust, vapour	: 1	3	3
Temperature	: 1	3	3
Monotony	: 3	4	12
Eyestrain	:	3	
Prot. Clothing	:	1	
Oil, grease	:	2	
Coldroom Conds	:	3	
			TOTAL: 29

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: GOOD
17. Floor Layout Drawing No: CCF04





CC 010F

TREBOR R&D

ROBOT APPLICATION DATA SHEET

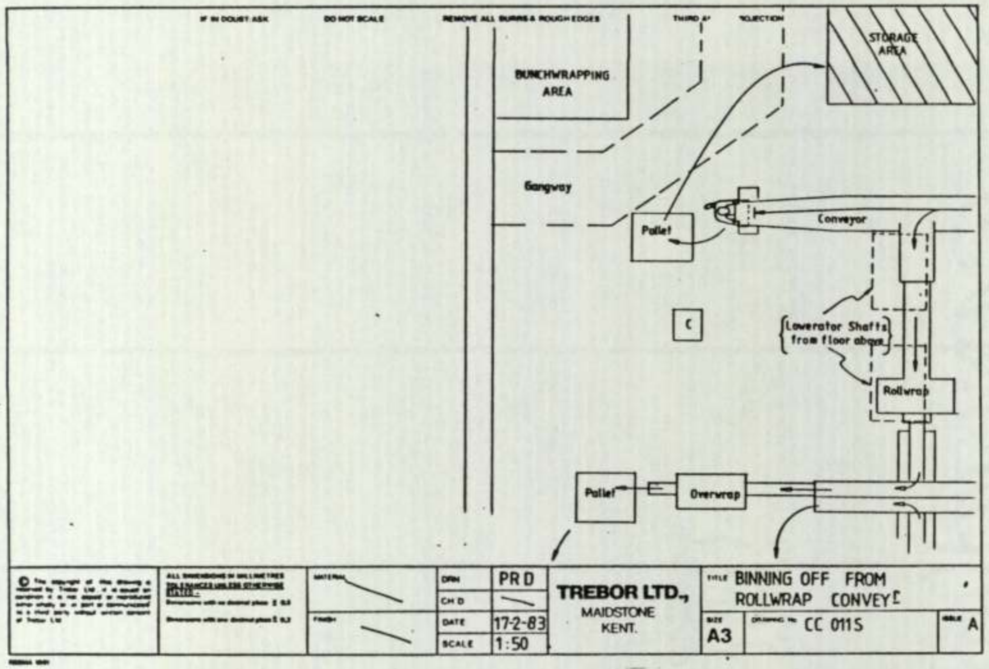
CC 010

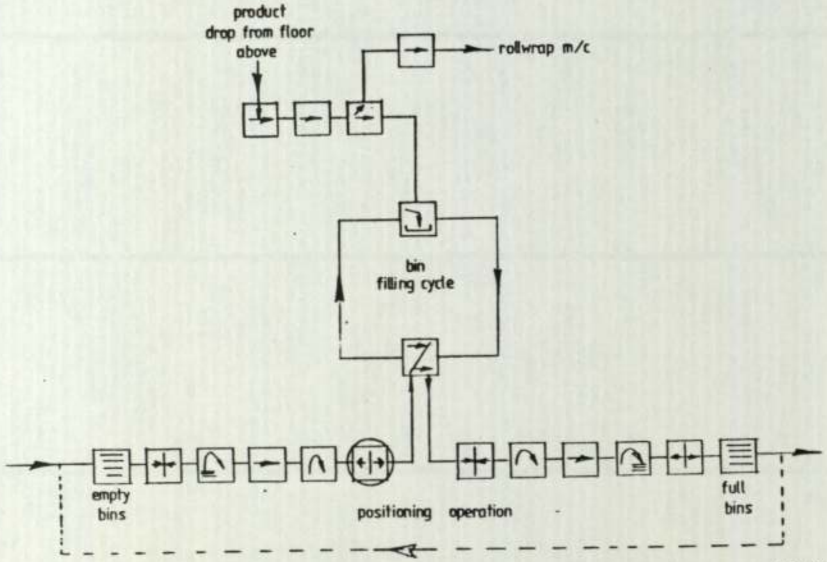
1. Application No: 010 Date: 18·1·83 By: PRD Factory: CC
2. Application Name: 5p CHEW PACKING
3. Location: No 4 DEPT Personnel: W. BROADBENT
4. Description of Object: C90/D CHEW CARTON ("SUPAS" "MONSTERS")
5. Dimensions: L 245 mm W 107 mm H 75 mm Weight: 1·5Kg
6. Description of Task: COLLATE BLOCK OF 9 PACKS IN LINE
   PICK UP FROM GUIDE
   DROP INTO BOX. REPEAT 8 TIMES
   PLACE ASIDE BOX.
7. Occasional Variations: M/C BREAKDOWN
8. Inspection: CONDITION OF WRAP OF CHEW PACKS
9. Load/Unload Time: — s Positioning Accuracy: ± 1 mm
10. Operation Cycle Time: 26 s Overhead mounting possible? N
11. How is Object Presented: ON GUIDE TRACK OF H1 F1

    Removed: BY HAND
12. Machines to be interfaced to this operation: CUT & WRAP M/C H1F1
13. No. of Operators this Operation: 3 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	2	3	6
Noise	2	4	8
Dust, vapour	1	3	3
Temperature	1	3	3
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
			TOTAL: 37

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: LIMITED
17. Floor Layout Drawing No: CCF04





CC 011 F

TREBOR R&D

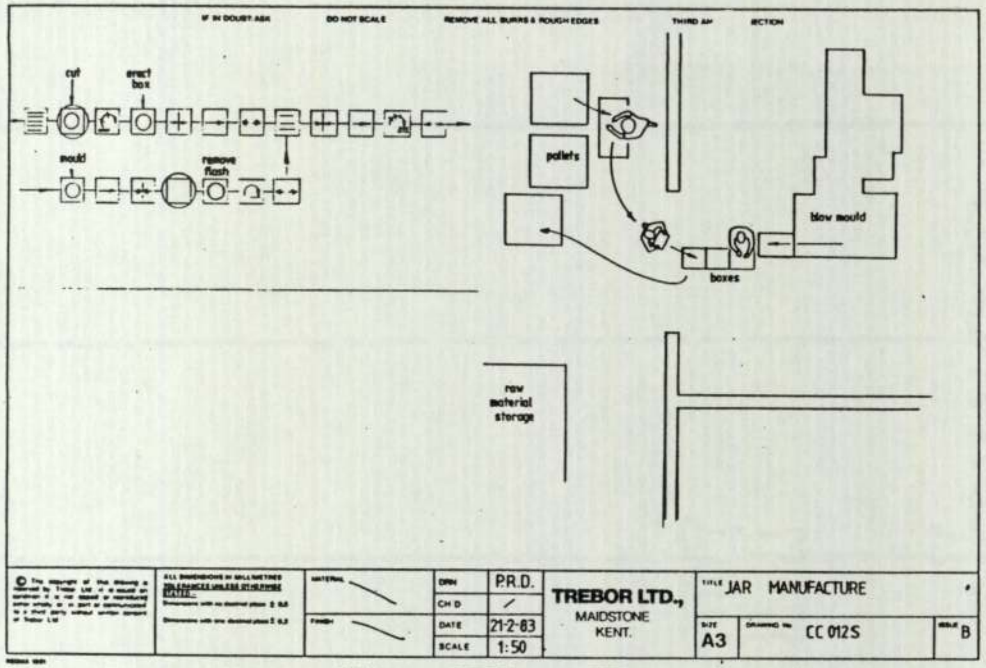
ROBOT APPLICATION DATA SHEET

CC 011

1. Application No: 011 Date: 19.1.83 By: PRD Factory: CC
2. Application Name: BINNING OFF FROM ROLLWRAP CONVEYOR
3. Location: No 5 DEPT Personnel: R. BLACKBURN L. MANAGER
4. Description of Object: LOOSE WRAPPED SWEETS
5. Dimensions: L 750 mm W 300 mm H 150 mm Weight: 20Kg
6. Description of Task: GET EMPTY BIN FROM STACK
   SLIDE UNDER CONVEYOR DISCHARGE CHUTE
   PICK UP FULL BIN
   STACK BIN ON PALLET
7. Occasional Variations: —
8. Inspection: —
9. Load/Unload Time: ✓ s Positioning Accuracy: ± 5 mm
10. Operation Cycle Time: ✓ s Overhead mounting possible? N
11. How is Object Presented: N/A
    Removed: PALLET TRUCK
12. Machines to be interfaced to this operation: CONVEYOR
13. No. of Operators this Operation: 1 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	2	5	10
Muscular strain	3	3	9
Noise	1	4	4
Dust, vapour		3	
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
			TOTAL: 35

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: FAIR
17. Floor Layout Drawing No: CCF05



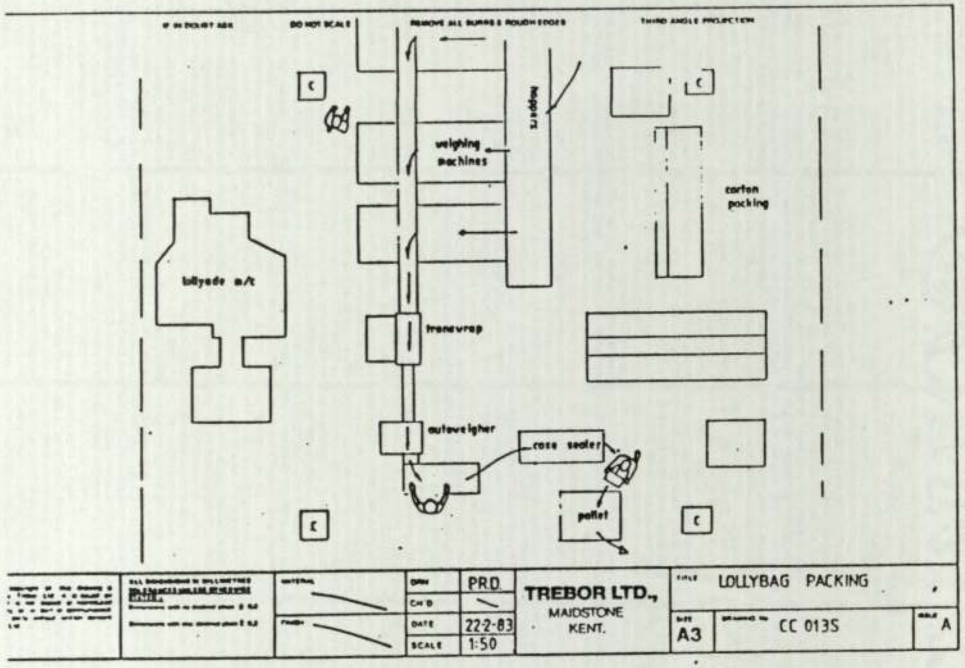
TREBOR R&D ROBOT APPLICATION DATA SHEET **CC 012**

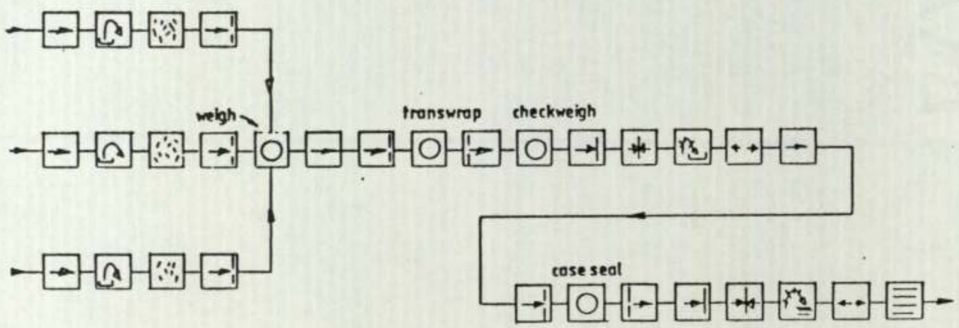
1. Application No: 012 Date: 18.1.83 By: PRD Factory: CC
2. Application Name: JAR MANUFACTURE
3. Location: No 7 DEPT Personnel: -
4. Description of Object: JAR MOULDING
5. Dimensions: L 150 mm W 115 mm H 300 mm Weight: ~ Kg
6. Description of Task: PICK UP MOULDING FROM CONVEYOR
   REMOVE EXCESS MATERIAL
   PLACE IN OUTER (6 OFF)
7. Occasional Variations: REJECT BAD MOULDING
8. Inspection: MOULDING FOR DEFECTS
9. Load/Unload Time: 6 s Positioning Accuracy: ± 2 mm
10. Operation Cycle Time: 36 s Overhead mounting possible? N
11. How is Object Presented: RANDOMLY ON CONVEYOR

    Removed: BY HAND
12. Machines to be interfaced to this operation: MOULDING M/C
13. No. of Operators this Operation: 1 - 2 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	3	3	9
Noise	3	4	12
Dust, vapour	1	3	3
Temperature	2	3	6
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing	1	1	1
Oil, grease		2	
Coldroom Conds		3	
			TOTAL: 48

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: VERY LIMITED
17. Floor Layout Drawing No: —





CC 013 F

TREBOF R&D

ROBOT APPLICATION DATA SHEET

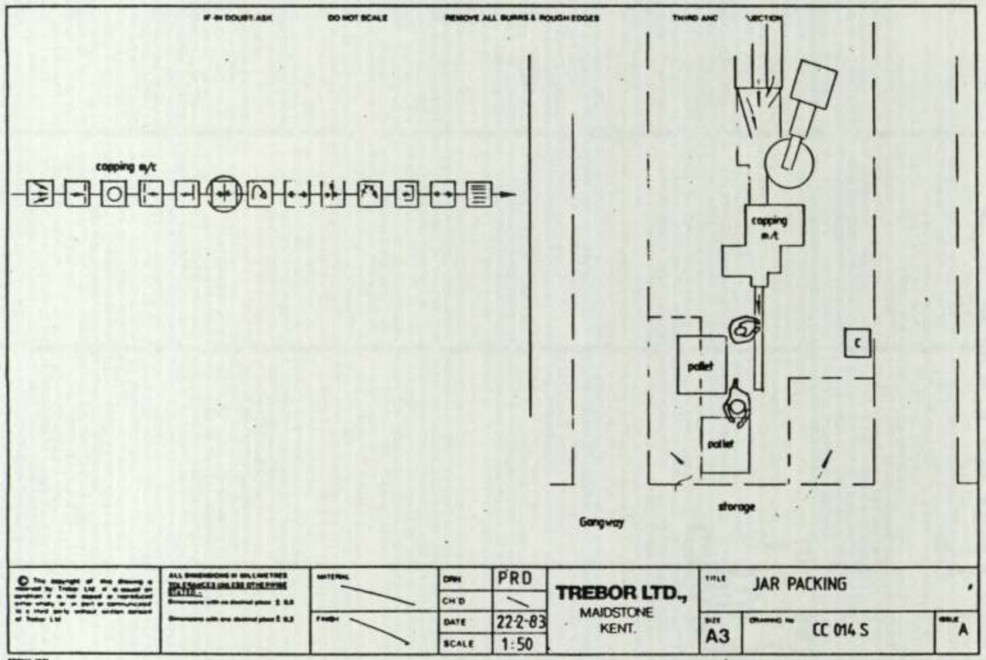
CC 013

1. Application No: 013 Date: 18.1.83 By: PRD Factory: CC
2. Application Name: LOLLY BAG PACKING
3. Location: No 3 DEPT Personnel: S. LOCKE
4. Description of Object: 10 BAGS IN OUTER U327
5. Dimensions: L 485 mm W 250 mm H 183 mm Weight: 2 Kg
6. Description of Task: PLACE OUTER ON BENCH FILL WITH 10 BAGS FROM CONVEYOR CLOSE BOX. STICK ON LABEL PLACE ASIDE
7. Occasional Variations: OPEN UNDER WEIGHT BAGS
8. Inspection: BAG REGISTRATION
9. Load/Unload Time: 1·5 s Positioning Accuracy: ± 3 mm
10. Operation Cycle Time: 30 s Overhead mounting possible? N
11. How is Object Presented: CONVEYOR FROM WEIGHER

    Removed: BY HAND
12. Machines to be interfaced to this operation: WEIGHER
13. No. of Operators this Operation: 1 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk		5	
Muscular strain	2	3	6
Noise	1	4	4
Dust, vapour		3	
Temperature	1	3	3
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
		TOTAL:	25

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: FAIR
17. Floor Layout Drawing No: CCF03



TREBOR R&D

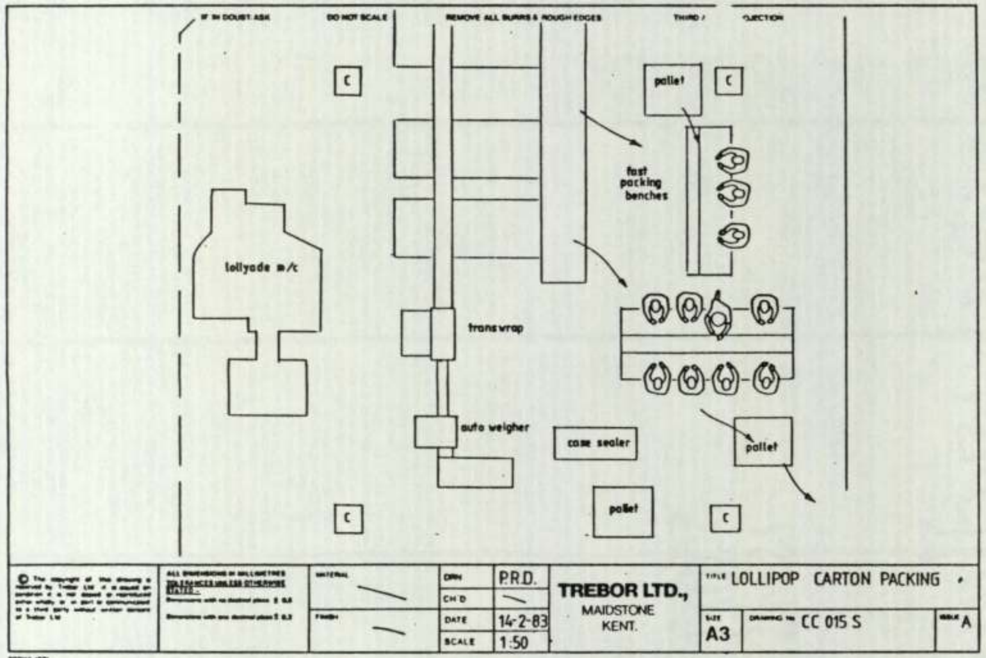
ROBOT APPLICATION DATA SHEET

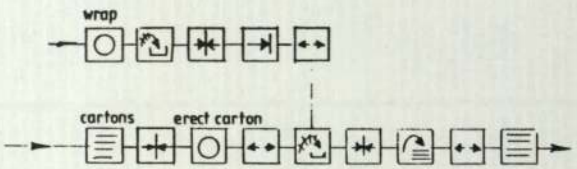
CC 014

1. Application No: 014 Date: 18.1.83 By: PRD Factory: CC
2. Application Name: JAR PACKING
3. Location: No 2 DEPT Personnel: B. WATKINSON L. MANAGER
4. Description of Object: FILLED & CAPPED JAR
5. Dimensions: L 150 mm W 115 mm H 300mm Weight: 3+Kg
6. Description of Task: COLLATE 3 JARS ON CONVEYOR
   ROTATE 90°
   PICK UP. CARRY TO PALLET
   PACK IN BOX. CLOSE BOX.
7. Occasional Variations: SQUASHED/WEAK JAR. CAP NOT ON
8. Inspection: JAR, LID, CONTENTS, LABEL
9. Load/Unload Time: 15 s Positioning Accuracy: ± 3 mm
10. Operation Cycle Time: 40s Overhead mounting possible? Y
11. How is Object Presented: IN LINE ON CONVEYOR
    Removed: PALLET. BOXES STACKED ON PALLET
12. Machines to be interfaced to this operation: CAPPING M/C, CONVEYORS
13. No. of Operators this Operation: 2 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	3	3	9
Noise	2	4	8
Dust, vapour	2	3	6
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
			TOTAL: 40

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: LIMITED
17. Floor Layout Drawing No: CCF02





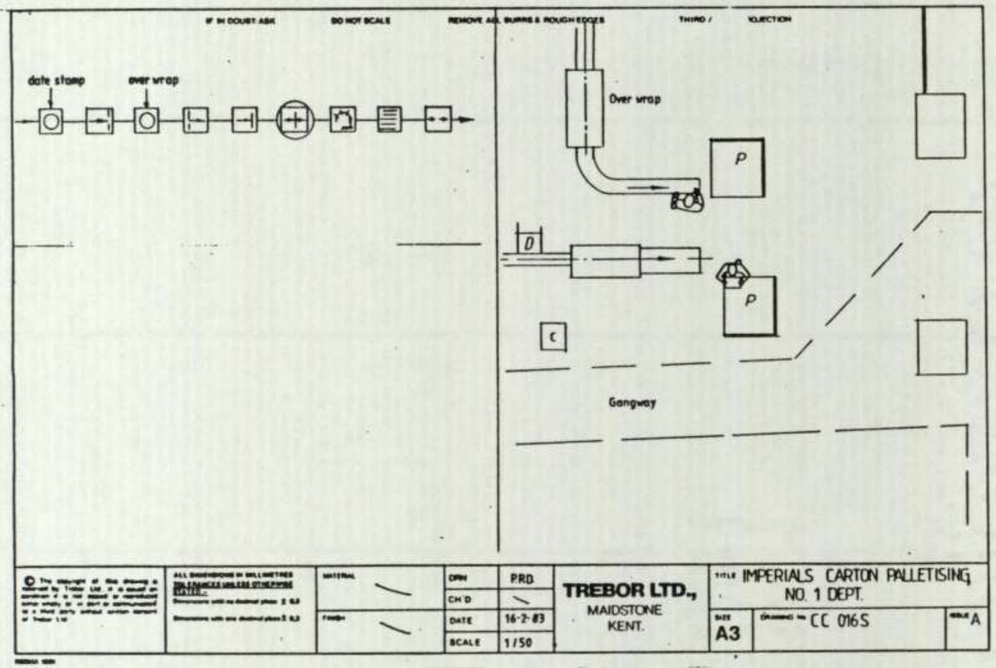
CC 015 F

TREBOR R&D — ROBOT APPLICATION DATA SHEET — CC 015

1. Application No: 015 Date: 19.1.83 By: PRD Factory: CC
2. Application Name: LOLLIPOP CARTON PACKING
3. Location: No 3 DEPT Personnel: S. ROCKE
4. Description of Object: 100 LOLLIES IN CRASHLOK CARTON C46
5. Dimensions: L 125 mm W 227 mm H 103 mm Weight: 1 Kg
6. Description of Task: PICK UP CARTON
   HAND PACK 100 LOLLIES FROM BIN
   PLACE CARTON ASIDE
7. Occasional Variations: GET CARTONS FROM STACK
8. Inspection: CONDITION OF LOLLIES
9. Load/Unload Time: — s Positioning Accuracy: ± 3 mm
10. Operation Cycle Time: 40 s Overhead mounting possible? N
11. How is Object Presented: FROM BIN
    Removed: BY HAND
12. Machines to be interfaced to this operation: —
13. No. of Operators this Operation: 16 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	:	5	
Muscular strain	: 3	3	9
Noise	: 1	4	4
Dust, vapour	:	3	
Temperature	: 2	3	6
Monotony	: 3	4	12
Eyestrain	:	3	
Prot. Clothing	:	1	
Oil, grease	:	2	
Coldroom Conds	:	3	
		TOTAL:	31

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: LIMITED
17. Floor Layout Drawing No: CCF03



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TREBOR R&D

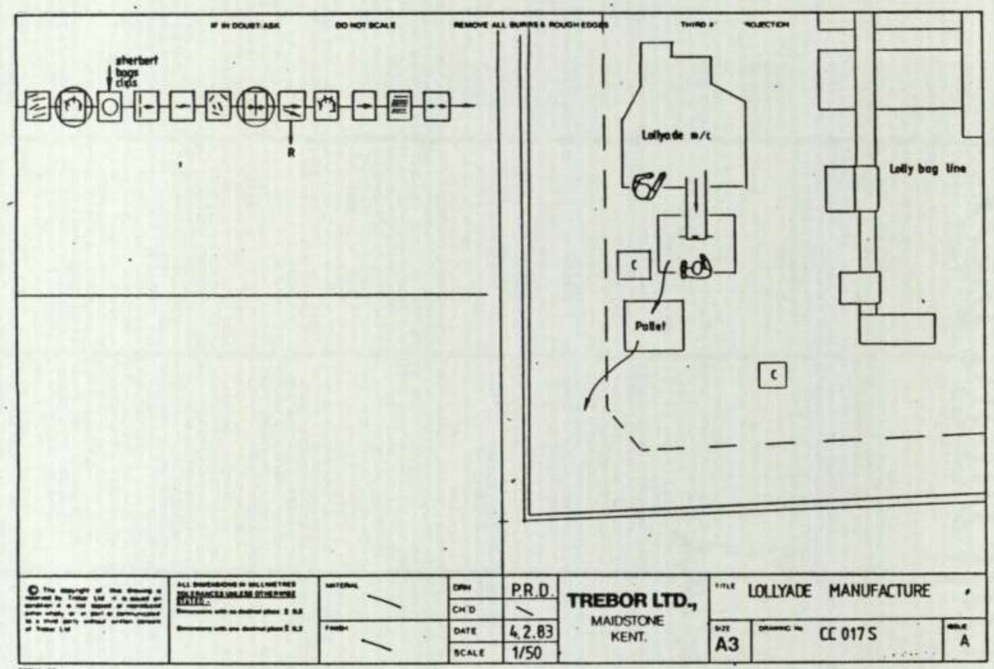
ROBOT APPLICATION DATA SHEET

CC 016

1. Application No: 016 Date: 19.1.83 By: PRD Factory: CC
2. Application Name: MINT IMPERIAL PALLETISING
3. Location: No1 DEPT Personnel: 1. PHILIPS
4. Description of Object: C234 CARTON CONTAINING 36 ROLLS
5. Dimensions: L 115 mm W 225 mm H 103 mm Weight: 1.5Kg
6. Description of Task: PICK UP CARTON FROM CONVEYOR
   CHECK OVERWRAP
   PLACE ON PALLET STACK
   264 CARTONS PER PALLET
7. Occasional Variations: GET NEW PALLET. TEND O'WRAP M/C
8. Inspection: OVERWRAP SEAL
9. Load/Unload Time: 1.5 s Positioning Accuracy: ± 2 mm
10. Operation Cycle Time: 7MINS Overhead mounting possible? N
11. How is Object Presented: ON CONVEYOR
    Removed: PALLET TRUCK
12. Machines to be interfaced to this operation: O'WRAP M/C
13. No. of Operators this Operation: 1 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	3	3	9
Noise	1	4	4
Dust, vapour	1	3	3
Temperature	1	3	3
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
			TOTAL: 36

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: LIMITED
17. Floor Layout Drawing No: CCF01



TREBOR R&D

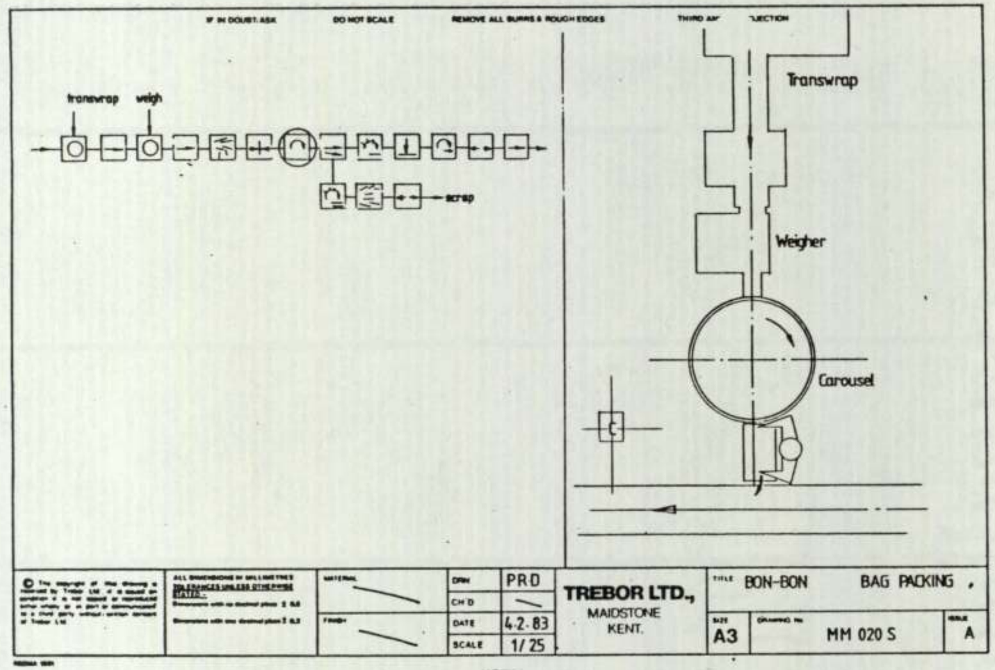
ROBOT APPLICATION DATA SHEET

CC 017

1. Application No: 017 Date: 18·1·83 By: PRD Factory: CC
2. Application Name: LOLLY ADE MANUFACTURE
3. Location: Nº 3 DEPT Personnel: S. ROCKE
4. Description of Object: C35 CARTON CONTAINING 36 BAGS
5. Dimensions: L 125 mm W 227 mm H 103 mm Weight: 1·5Kg
6. Description of Task: ERECT CARTON
   PICK UP 36 BAGS IN TURN FROM CONVEYOR
   & PACK INTO CARTON
   STACK ONTO PALLET
7. Occasional Variations: BAG NOT PROPERLY SEALED, REJECT
8. Inspection: BAG SEAL & REGISTRATION
9. Load/Unload Time: 1 s Positioning Accuracy: ± 3 mm
10. Operation Cycle Time: 40 s Overhead mounting possible? N
11. How is Object Presented: DROPS OFF CONVEYOR ONTO BENCH
    Removed: ON PALLET
12. Machines to be interfaced to this operation:
13. No. of Operators this Operation: 1 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	2	3	6
Noise	2	4	8
Dust, vapour		3	
Temperature	1	3	3
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
		TOTAL:	34

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: LIMITED
17. Floor Layout Drawing No: CCF03



TREBOR R&D

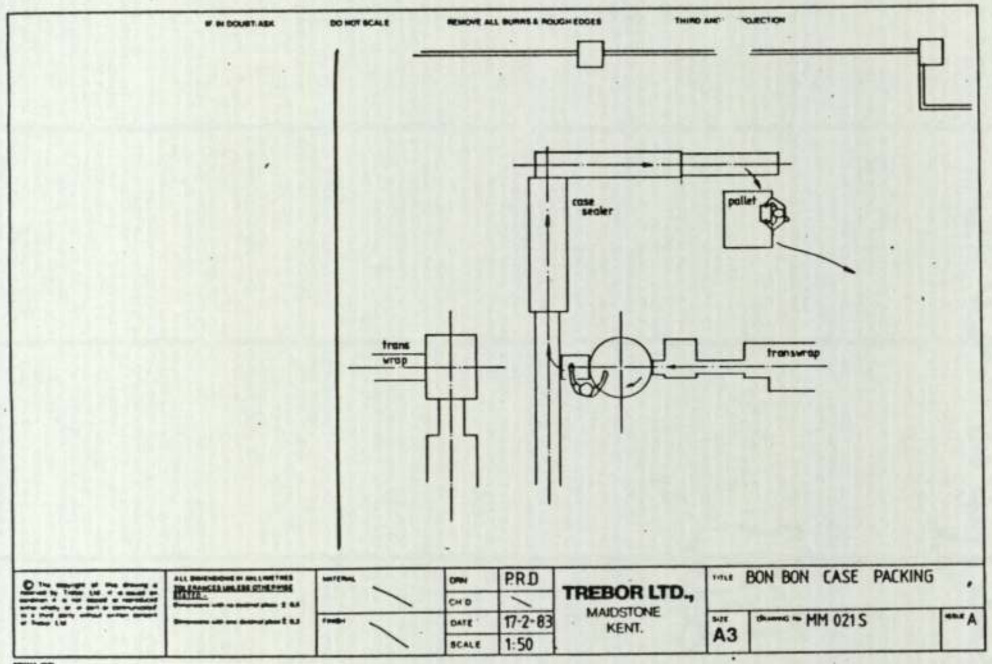
ROBOT APPLICATION DATA SHEET

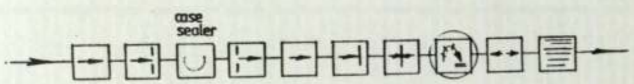
MM 020

1. Application No: 020 Date: 4.12.82 By: PRD Factory: MM
2. Application Name: BON BON BAG PACKING
3. Location: 1ST FLOOR Personnel: L. NORLEY LINE MANAGER
4. Description of Object: TRANSWRAP BAG (20 per CASE)
5. Dimensions: L 170 mm W 110 mm H 30 mm Weight: ·125 Kg
6. Description of Task: PICK UP BAG FROM CAROUSEL PLACE IN BOX (REPEAT) CLOSE BOX, PLACE ON CONVEYOR
7. Occasional Variations: BADLY SEALED BAG REJECT
8. Inspection: SEAL. REGISTRATION OF WRAP
9. Load/Unload Time: 2·5 s Positioning Accuracy: ± 10 mm
10. Operation Cycle Time: 60 s Overhead mounting possible? Y
11. How is Object Presented: RANDOMLY ON CAROUSEL
    Removed: CONVEYOR
12. Machines to be interfaced to this operation: TRANSWRAP, CASE SEALER
13. No. of Operators this Operation: 4 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	2	3	6
Noise	1	4	4
Dust, vapour		3	
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
			TOTAL: 27

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: LIMITED
17. Floor Layout Drawing No:





MM 021F

TREBOR R&D

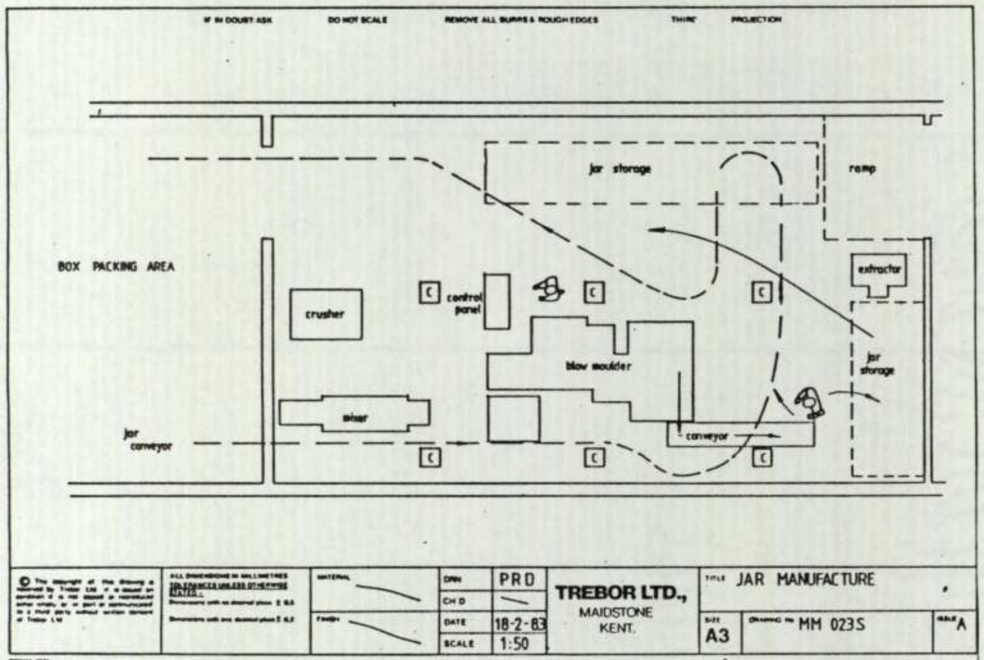
ROBOT APPLICATION DATA SHEET

MM 021

1. Application No: 021 Date: 4-12-82 By: PRD Factory: MM
2. Application Name: Bon Bon Case Palletising
3. Location: 1st Floor Personnel: L. Norley Line Manager
4. Description of Object: U300 Outer
5. Dimensions: L 317 mm W 240 mm H 105 mm Weight: 2.5Kg
6. Description of Task: Pick up box from conveyor
   Stick on label
   Stack on pallet
7. Occasional Variations: Check sealing M/C
8. Inspection: Box seal OK
9. Load/Unload Time: 2 s Positioning Accuracy: ± 5 mm
10. Operation Cycle Time: N/A s Overhead mounting possible? N
11. How is Object Presented: Roller conveyor from sealer
    Removed: Rolatruc
12. Machines to be interfaced to this operation: Socco case sealer
13. No. of Operators this Operation: 1 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	3	3	9
Noise	2	4	8
Dust, vapour		3	
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
			TOTAL: 34

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: Limited
17. Floor Layout Drawing No: —



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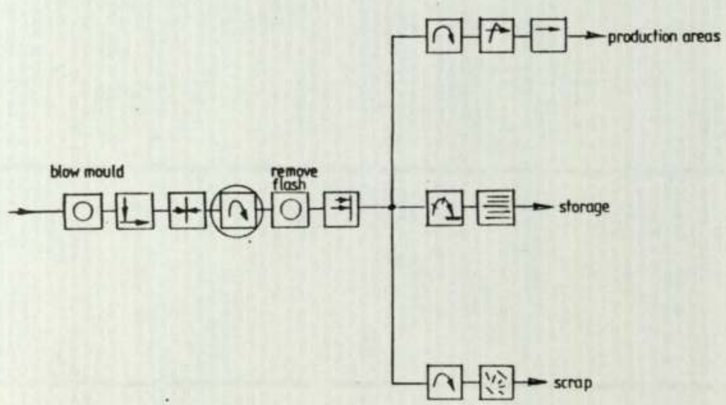


MM 023F

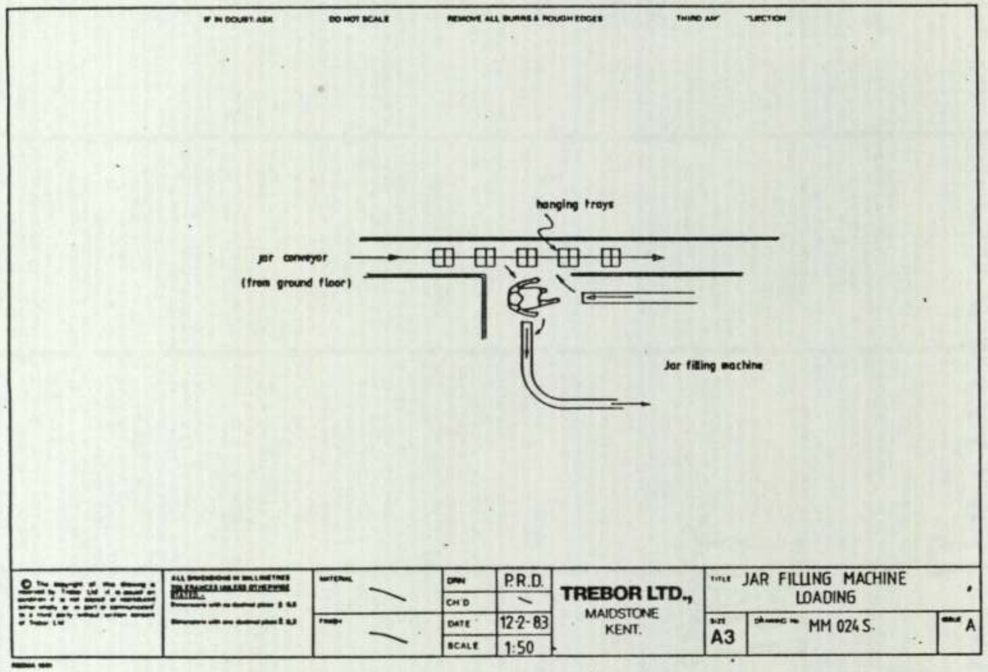
TREBOR R&D ROBOT APPLICATION DATA SHEET **MM 023**

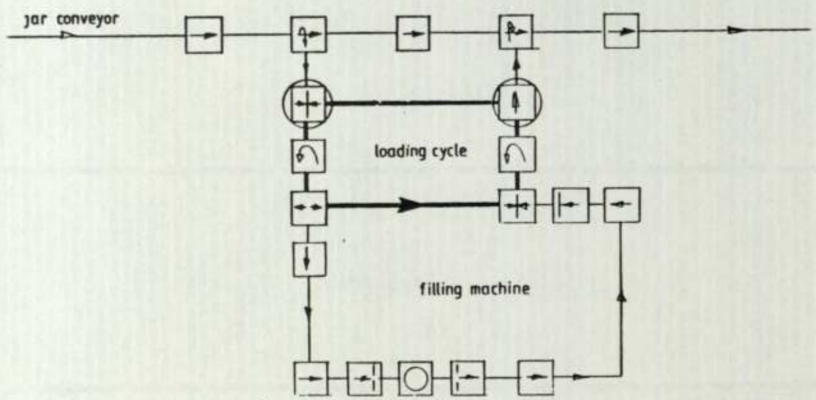
1. Application No: 023 Date: 5.1.83 By: PRD Factory: MM
2. Application Name: JAR MANUFACTURE
3. Location: GND FLOOR Personnel: —
4. Description of Object: BLOW MOULDED PLASTIC JAR
5. Dimensions: L 150 mm W 115 mm H 300 mm Weight: – Kg
6. Description of Task: PICK UP MOULDING FROM CONVEYOR
   REMOVE EXCESS MATERIAL
   PLACE ON JAR CONVEYOR OR STORAGE RACK
7. Occasional Variations: SCRAP JAR. PLACE IN SCRAP BIN
8. Inspection: GENERAL FITNESS OF MOULDING
9. Load/Unload Time: 6 s Positioning Accuracy: ± 2 mm
10. Operation Cycle Time: 6 s Overhead mounting possible? N
11. How is Object Presented: RANDOMLY ON CONVEYOR

    Removed: MOVING CONVEYOR
12. Machines to be interfaced to this operation: MOULDING M/C CONVEYOR
13. No. of Operators this Operation: 1 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	3	3	9
Noise	3	4	12
Dust, vapour	1	3	3
Temperature	2	3	6
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing	1	1	1
Oil, grease		2	
Coldroom Conds		3	
			TOTAL: 48

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: VERY LIMITED
17. Floor Layout Drawing No: IEG 036





MM 024 F

TREBOR R&D

ROBOT APPLICATION DATA SHEET

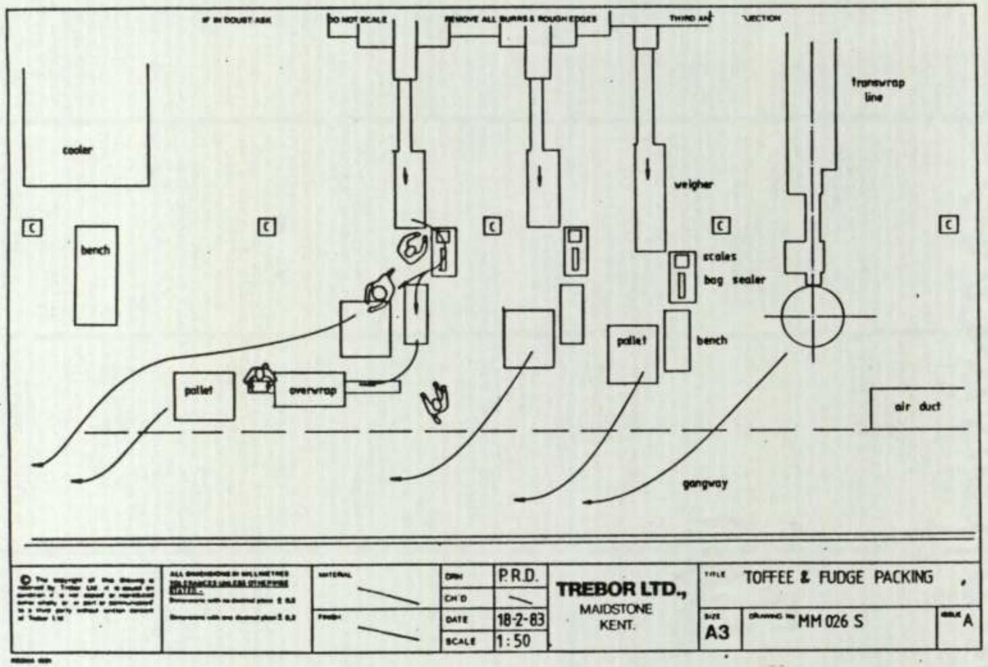
MM 024

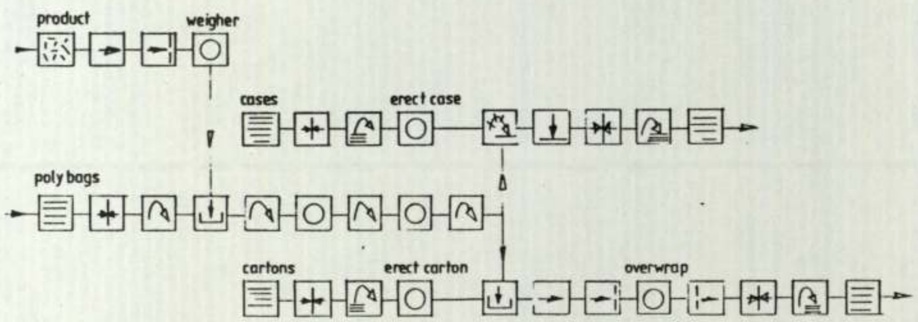
1. Application No: 024 Date: 4.12.82 By: PRD Factory: MM
2. Application Name: BON BON JAR FILLING MACHINE LOADING
3. Location: 1ST FLOOR Personnel: L. NORLEY L.M.
4. Description of Object: EMPTY & FULL PLASTIC JARS
5. Dimensions: L 150 mm W 115 mm H 300 mm Weight: 2.8Kg
6. Description of Task: GET 2 EMPTY JARS FROM MOVING JAR CONVEYOR. PLACE ON M/C CONVEYOR PICK UP 2 FULL JARS, PLACE ON MOVING JAR CONVEYOR
7. Occasional Variations: —
8. Inspection: CONDITION OF JAR
9. Load/Unload Time: 1.5s Positioning Accuracy: ± 1.5 mm
10. Operation Cycle Time: 4 s Overhead mounting possible? Y
11. How is Object Presented: ON MOVING CONVEYOR

    Removed: — " —
12. Machines to be interfaced to this operation: CONVEYOR. JAR M/C
13. No. of Operators this Operation: 1 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	2	5	10
Muscular strain	2	3	6
Noise	2	4	8
Dust, vapour	1	3	3
Temperature	1	3	3
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
		TOTAL:	42

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: OK
17. Floor Layout Drawing No: —





MM026F

TREBOR R&D

ROBOT APPLICATION DATA SHEET

MM 026

1. Application No: 026 Date: 30.12.82 By: PRD Factory: MM
2. Application Name: TOFFEE & FUDGE PACKING
3. Location: TOP FLOOR Personnel: L. MANAGERS ROY HOLMES, JOYCE BALDOCK, PETER MILLING
4. Description of Object: VARIOUS
5. Dimensions: L \ mm W \ mm H \ mm Weight: 20 Kg (MAX)
6. Description of Task: FILL POLYTHENE BAGS WITH SWEETS FROM WEIGHER. CHECK WEIGH. PACK IN OUTER OVERWRAP. STACK ON PALLET
7. Occasional Variations: ADJUST WEIGHER
8. Inspection: GENERAL CONDITION OF PACK
9. Load/Unload Time: N/A s Positioning Accuracy: ± 5 mm
10. Operation Cycle Time: N/A s Overhead mounting possible? N
11. How is Object Presented: N/A

    Removed: ROLATRUC
12. Machines to be interfaced to this operation: WEIGHER, OVERWRAP
13. No. of Operators this Operation: 10 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	3	3	9
Noise	1	4	4
Dust, vapour	_	3	_
Temperature	_	3	_
Monotony	2	4	8
Eyestrain	_	3	_
Prot. Clothing	_	1	_
Oil, grease	_	2	_
Coldroom Conds	_	3	_
			TOTAL: 26

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: V. LIMITED
17. Floor Layout Drawing No: 1ET/020

4.0 Summary

The study revealed the following points:-

- All applications were materials handling tasks.

- The majority fall into the following categories:
  Palletising
  Carton or box packing
  Machine loading/unloading

- Number of different applications; 18

- Total number of potential applications: 100+
  Split: Colchester: 20+
  Chesterfield: 40+
  Maidstone: 40+

- 4 applications are extremely unpleasant, i.e. score over 39.

TREBOR R&D ROBOT APPLICATION " DATA SHEET XXOO5A

1. Application No: OO5A Date: FEB 83 By: PRD Factory: XX
2. Application Name: JAR PACKING
3. Location: PROD^N 1 Personnel:
4. Description of Object: 2·25Kg jar
5. Dimensions: L 145 mm W 105 mm H 305 mm Weight: 2·25Kg x 6
6. Description of Task: ~~Remove~~
REMOVE EMPTY JARS FROM CASE & PLACE ON CONVEYOR (6 OFF)
PICK UP 6 JARS (FILLED) & PACK INTO CASE. INTERLEAVE CASE FLAPS
7. Occasional Variations: —
8. Inspection: JAR CAP SEAL
9. Load/Unload Time: 4 s Positioning Accuracy: ± 5 mm
10. Operation Cycle Time: 26 s Overhead mounting possible? YES
11. How is Object Presented: IN CARDBOARD CASE, UPSIDE DOWN
Removed: SLAT CONVEYOR
12. Machines to be interfaced to this operation: JAR CAPPING, FILLING PALLETISING
13. No. of Operators this Operation: 2 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk		5	
Muscular strain	2	3	6
Noise	3	4	12
Dust, vapour	1	3	3
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
		TOTAL:	33

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: GOOD — NEW APPLICATION
17. Floor Layout Drawing No: 0006/D

TREBOR R&D ROBOT APPLICATION " DATA SHEET XX0058

1. Application No: 0058 Date: FEB 84 By: [initials] Factory: XX
2. Application Name: JAR LINE AUTOMATION
3. Location: PRODN 1 Personnel:
4. Description of Object: PLASTIC JAR, JAR CAP, PACKAGING
5. Dimensions: L N/A mm W mm H mm Weight: <17 Kg
6. Description of Task: COMPLETE AUTOMATION OF JAR PACKING & PACKAGING:
DEPALLETISE, UNPACK, FILL, CAP, LABEL, PACK, CLOSE CASE, PALLETISE
7. Occasional Variations: —
8. Inspection: PACKAGING QUALITY
9. Load/Unload Time: — s Positioning Accuracy: ± 5 mm
10. Operation Cycle Time: 36 s Overhead mounting possible? Y
11. How is Object Presented: STACKED ON PALLET BOARD
Removed: —"—
12. Machines to be interfaced to this operation: COMPLETE SYSTEM
13. No. of Operators this Operation: 2-3 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	3	5	15
Muscular strain	3	3	9
Noise	3	4	12
Dust, vapour	1	3	3
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	

TOTAL: 51

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: GOOD
17. Floor Layout Drawing No: 0006/D

TREBOR R&D ROBOT APPLICATION DATA SHEET XX006

1. Application No: 006 Date: FEB '85 By: [signature] Factory: XX
2. Application Name: BIN FILLING
3. Location: PRODᴺ 1 Personnel: –
4. Description of Object: PLASTIC STORAGE BIN FOR LOOSE PRODUCT
5. Dimensions: L 600mm W 500 mm H 300 mm Weight: 20Kg
6. Description of Task: PICK UP EMPTY BIN FROM PALLET STACK, PLACE UNDER FUNNEL, WAIT UNTIL BIN IS FULL, STACK ON PALLET OF FILLED BINS
7. Occasional Variations: \
8. Inspection: LEVEL OF PRODUCT IN BIN
9. Load/Unload Time: 7 s Positioning Accuracy: ± 10 mm
10. Operation Cycle Time: 30s Overhead mounting possible? Y
11. How is Object Presented: ON PALLET STACK

    Removed: "
12. Machines to be interfaced to this operation: PRODUCT DROP FUNNEL
13. No. of Operators this Operation: 1 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	3	5	15
Muscular strain	3	3	9
Noise	1	4	4
Dust, vapour	1	3	3
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	

TOTAL: 43

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: POOR
17. Floor Layout Drawing No: 0006/D

TREBOR R&D ROBOT APPLICATION DATA SHEET MMO27

1. Application No: 027 Date: FEB '85 By: [signature] Factory: MM

2. Application Name: PACKING ASSORTMENTS

3. Location: GND FLOOR Personnel: ~

4. Description of Object: ASSORTED MOULDED SWEET PRODUCTS

5. Dimensions: L ~ 15 mm W ~ 5 mm H ~ 2 mm Weight: ~ Kg

6. Description of Task: PICK UP TRAY OF ~ 20 SWEETS, SLIDE SWEETS OFF INTO CARTON, PLACE TRAY ASIDE REPEAT 5-6 TIMES, CLOSE CARTON LID, PLACE ON CONVEYOR

7. Occasional Variations: BAD MOULDING

8. Inspection: OF EACH PRODUCT

9. Load/Unload Time: ~ 3 s Positioning Accuracy: ± 2 mm

10. Operation Cycle Time: ~ s Overhead mounting possible? Y

11. How is Object Presented: TRAYED, ON CONVEYOR

    Removed: BY CONVEYOR

12. Machines to be interfaced to this operation: PALLETISING, OVERWRAP

13. No. of Operators this Operation: 20 No. of Shifts: 2

14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk		5	
Muscular strain	3	3	9
Noise	2	4	8
Dust, vapour		3	
Temperature	1	3	3
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
		TOTAL:	32

15. Check location of columns, services, expansion joints etc. ✓

16. Space available for new equipment: V. LITTLE

17. Floor Layout Drawing No:

TREBOR R&D ROBOT APPLICATION " DATA SHEET MM028

1. Application No: 028 Date: FEB 85 By: [initials] Factory: MM
2. Application Name: PALLETISING CARTON ASSORTMENTS
3. Location: GND FLOOR Personnel:
4. Description of Object: CARTON OF MOULDED NCB SWEETS
5. Dimensions: L 200 mm W 100 mm H 80 mm Weight: <1·5 Kg
6. Description of Task: PICK UP CARTON FROM CONVEYOR, STACK ON PALLET DEPENDING UPON PRODUCT TYPE.
7. Occasional Variations: –
8. Inspection: –
9. Load/Unload Time: s Positioning Accuracy: ± 5 mm
10. Operation Cycle Time: 7.5 s Overhead mounting possible? NO
11. How is Object Presented: ON CONVEYOR

    Removed: ON PALLET BOARD
12. Machines to be interfaced to this operation: CONVEYOR
13. No. of Operators this Operation: 1 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	3	5	15
Muscular strain	3	3	9
Noise		4	
Dust, vapour		3	
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
		TOTAL:	36

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: V. LITTLE
17. Floor Layout Drawing No: —

TREBOR R&D ROBOT APPLICATION DATA SHEET MM031

1. Application No: 031 Date: FEB '85 By: [initials] Factory: MM
2. Application Name: JAR CAPPING
3. Location: 1st FLOOR Personnel:
4. Description of Object: PVC JAR & CAP
5. Dimensions: ~~L~~ ϕ90 mm ~~W mm H mm~~ Weight: – Kg
6. Description of Task: PICKUP CAP, PLACE ONTO JAR – TURN TO SEAL
7. Occasional Variations: BADLY MOULDED CAP
8. Inspection: CAP QUALITY
9. Load/Unload Time: \ s Positioning Accuracy: ± 1 mm
10. Operation Cycle Time: 3 s Overhead mounting possible? Y
11. How is Object Presented: RANDOMLY IN BOX

    Removed: ON CONVEYOR
12. Machines to be interfaced to this operation: JAR FILLING
13. No. of Operators this Operation: 1 No. of Shifts: 1/2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk		5	
Muscular strain	3	3	9
Noise	3	4	12
Dust, vapour		3	
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	

TOTAL: 33

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: POOR
17. Floor Layout Drawing No: RD 596

TREBOR R&D

ROBOT APPLICATION DATA SHEET MMO32

1. Application No: O32 Date: FEB '85 By: Paul Factory: MM
2. Application Name: MULTIPLE PALLETISING (SOFTMINTS)
3. Location: GND FLOOR Personnel:
4. Description of Object: CARTON OF 36/24 ROLLS
5. Dimensions: L 176 mm W 82 mm H 73 mm Weight: 1.3 Kg
6. Description of Task: COLLATE CARTONS, IDENTIFYING FLAVOUR, CHECK WRAP - STACK ON PALLET
7. Occasional Variations: PALLET CHANGE
8. Inspection: WRAP QUALITY
9. Load/Unload Time: 3 s Positioning Accuracy: ± 3 mm
10. Operation Cycle Time: ~15 s Overhead mounting possible? Y
11. How is Object Presented: ON CONVEYOR

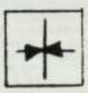
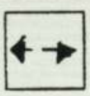
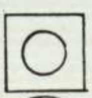
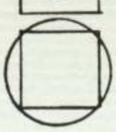
    Removed: PALLET BOARD
12. Machines to be interfaced to this operation: OVERWRAP M/C
13. No. of Operators this Operation: 1/2 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	2	3	6
Noise	2	4	8
Dust, vapour		3	
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	

TOTAL: 31

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: NOT KNOWN
17. Floor Layout Drawing No: NOT AVAILABLE

Appendix : Key to Process Flow Diagrams

Symbol	Description
	Random storage of workpieces in containers e.g. bins or cartons.
	Storage of workpieces in a definite orientation e.g. palletising.
	Flow of material.
	Branching of material flow.
	Combining of material flow.
	Positioning of workpieces in an ordered pattern e.g. on a pallet or into a carton.
	Position or orientate workpiece.
	Collate or meter material flow.
	Feed in
	Feed out.
	Grip workpiece.
	Release workpiece.
	Operation
	Inspection.

Appendix

Key to Process Flow Diagrams

FOLD OUT

APPENDIX B

Appendix B

This appendix contains three examples of the appraisal carried out on the twenty-eight potential robot applications identified by the factory surveys.

CC015	carton packing
MM023	jar manufacture
MM030	Driam pan loading

They are included as experimental evidence in support of the case-study and illustrate the problems which accompanied many of the applications studied. They are discussed further in chapters three and seven.

The first example, carton packing, is a very common application throughout the Company. These tasks are very labour intensive and have not been automated yet because either the flexibility and inspection requirements or the low volumes involved prevent it. Such applications could be automated using the Type A robot system described in chapter 7.4 which is designed to offer the flexibility to cope with rapid product changes, allowing the integration of the many low-volume lines the Company operates. The second application provides an example of the problems which arose from trying to integrate a robot system into the existing manufacturing process (see chapter 7.3).

Finally, the third application illustrates two other key difficulties experienced during the appraisal phase: lack of floorspace for the proposed system and other process development work preventing the agreement of a fixed specification.

No: CC015

PROJECT APPRAISAL

APPLICATION NAME: LOLLIPOP CARTON PACKING

	YES	NO
LIKELY FUTURE SALES SATISFACTORY?	✓	
LEVEL OF OUTPUT VOLUME GOOD?	(✓) MARGINAL	
LIFE OF PROCESS PLANT ≥ 3 YEARS?	✓	

(SCORE 0-8)

TECHNICAL SIMPLICITY	:	4
FINANCIAL BENEFIT	:	7
SOCIAL BENEFIT	:	5
		16

ANY OTHER SIGNIFICANT FACTOR:

NOT A BRANDED LINE ∴ INVESTMENT UNLIKELY
LITTLE FLOORSPACE AVAILABLE
THIS APPLICATION IS VERY COMMON THROUGHOUT THE C°

COMMENTS:

A DEDICATED M/C IS NOT SUITABLE FOR THIS OP^N DUE TO LOW OUTPUT VOLUME OF THIS LINE ON ITS OWN - SUGGESTS A FLEXIBLE SYSTEM WHICH COULD INTEGRATE >1 PRODUCT LINE WOULD BE VIABLE

MAJOR PROBLEMS ARE HIGH PACKING SPEEDS REQUIRED & GOOD FLOORSPACE UTILISATION.

DECISION:

CURRENT ROBOT TECHNOLOGY CANNOT MEET SPEC^N ALTHOUGH FINANCIAL APPRAISAL IS VERY POSITIVE ASSUMING 2 SHIFT OPERATION

IT MAY BE WORTHWHILE INVESTIGATING THE TECHNICAL FEASIBILITY OF A 'UNIVERSAL' FLEXIBLE CARTON PACKING SYSTEM

CC015

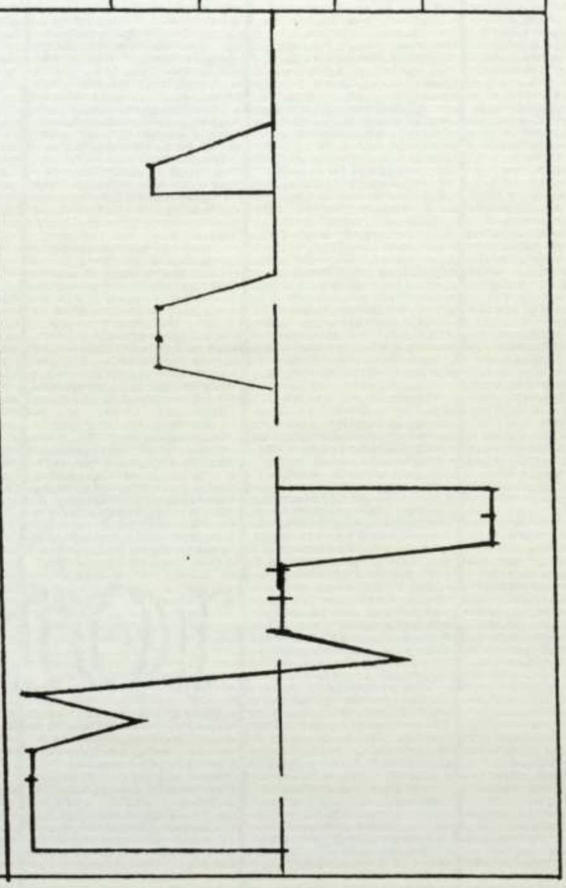
PROJECT PROFILE

FACTOR / EVALUATION	V.GOOD	GOOD	AVERAGE	POOR	V.POOR

SOCIAL
System benefits workers in terms of:
- health
- Safety
- unpleasant work
- new skills

FINANCIAL
- Low capital investment
- High net benefits
- High % rate of return
- Revenue time profile

TECHNICAL
- Probability of technical success
- Operational simplicity
- Little visual inspection required
- Proportion of process automated
- Remaining life of existing plant
- Few changes to existing process
- Floor area adequate
- Technology applicable to other areas
- Little one-off development
- Allows further use of new technology
- Improves process flexibility
- Improves process control
- Improves product quality



COMMENTS

FINANCIAL APPRAISAL

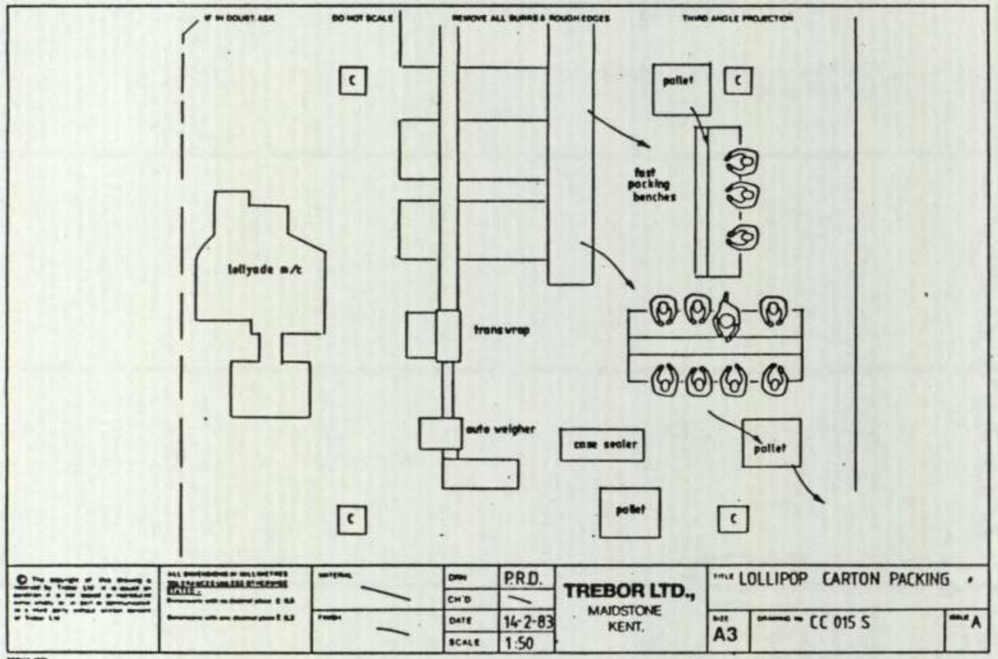
CAPITAL COST
OF SYSTEM UNKNOWN

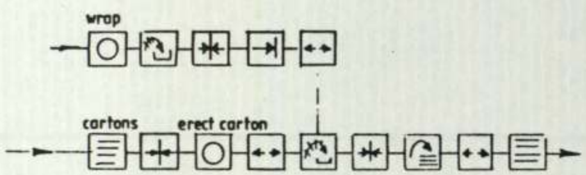
ASSUME MIN. 2YR PAYBACK REQD.

AUTOMATION OF THIS TASK
WOULD PROVIDE A
DIRECT LABOUR-COST
SAVING OF : £208K p.a. (16 opᶠ x 2 SHIFTS x £6.5Kp

INDICATES A DEVELOP-
-MENT BUDGET OF : £416K WOULD BE COST-EFFECTIVE

TARGET M/C COST OF: £26K ———— " ———— (1 opᶠ x 2 SHIFT x 2 YRS x £6





CC 015F

TREBOR R&D

ROBOT APPLICATION
DATA SHEET

CC 015

1. Application No: 015 Date: 19.1.83 By: PRD Factory: CC
2. Application Name: LOLLIPOP CARTON PACKING
3. Location: No 3 DEPT Personnel: S. ROCKE
4. Description of Object: 100 LOLLIES IN CRASHLOK CARTON C46
5. Dimensions: L 125 mm W 227 mm H 103 mm Weight: 1 Kg
6. Description of Task: PICK UP CARTON
   HAND PACK 100 LOLLIES FROM BIN
   PLACE CARTON ASIDE
7. Occasional Variations: GET CARTONS FROM STACK
8. Inspection: CONDITION OF LOLLIES
9. Load/Unload Time: — s Positioning Accuracy: ± 3 mm
10. Operation Cycle Time: 40 s Overhead mounting possible? N
11. How is Object Presented: FROM BIN
    Removed: BY HAND
12. Machines to be interfaced to this operation: —
13. No. of Operators this Operation: 16 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	:_	5	_
Muscular strain	:3	3	9
Noise	:1	4	4
Dust, vapour	:_	3	_
Temperature	:2	3	6
Monotony	:3	4	12
Eyestrain	:_	3	_
Prot. Clothing	:_	1	_
Oil, grease	:_	2	_
Coldroom Conds	:_	3	_
			TOTAL: 31

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: LIMITED
17. Floor Layout Drawing No: CCF03

No: MMO23

PROJECT APPRAISAL

APPLICATION NAME: JAR MANUFACTURE

	YES	NO
LIKELY FUTURE SALES SATISFACTORY?	✓	
LEVEL OF OUTPUT VOLUME GOOD?	✓	
LIFE OF PROCESS PLANT ≥ 3 YEARS?	✓	

TECHNICAL SIMPLICITY : 1 (SCORE 0-8)

FINANCIAL BENEFIT : 3

SOCIAL BENEFIT : 8

12

ANY OTHER SIGNIFICANT FACTORS:

THIS APPLICATION IS COMMON TO BOTH CC & MM FACTORIES

COMMENTS:

PROJECT SUFFERS FROM MAJOR TECHNICAL & OPERATIONAL DIFFICULTIES:

- BLOWMOULDER IS WORN & PRODUCES POOR QUALITY JARS ∴ REQUIRING AN UNNECESSARY INSPECTION & HAND DEFLASHING OP^{N} WHICH CANNOT EASILY BE AUTOMATED
- JAR CONVEYOR IS NOT SUITABLE FOR INTERFACING WITH AUTOMATIC EQUIPMENT
- AREA IS CRAMPED & DISORDERED
- THERE IS NO POSITIONAL CONTROL OVER ANY OF THE TASK COMPONENTS

DECISION:

NOT SUITABLE FOR AUTOMATION AS THE PERIPHERAL EQUIPMENT NEEDED ESCALATE SYSTEM COST TO AN UNACCEPTABLE LEVEL

MMO23

PROJECT PROFILE

FACTOR / EVALUATION	V.GOOD	GOOD	AVERAGE	POOR	V.POOR

SOCIAL

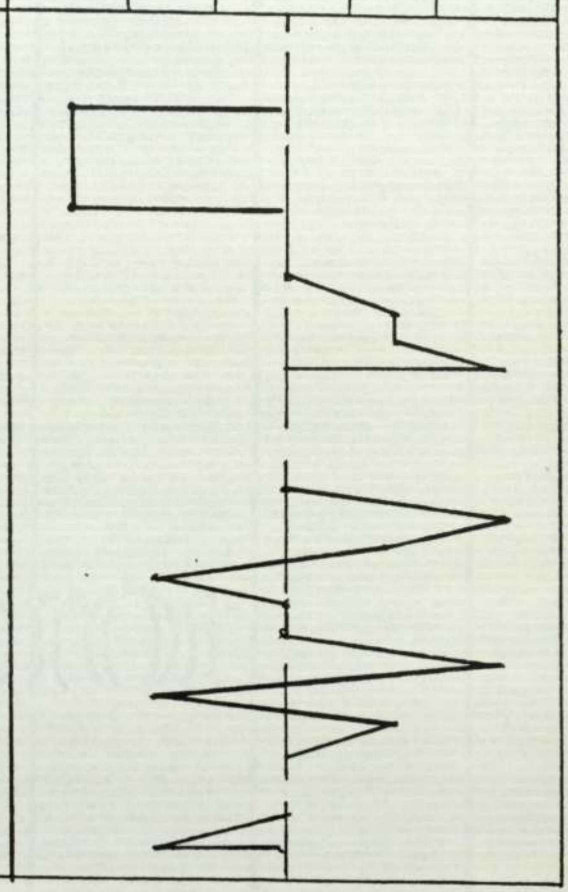
System benefits workers in terms of:
- health
- Safety
- unpleasant work
- new skills

FINANCIAL

Low capital investment
High net benefits
High % rate of return
Revenue time profile

TECHNICAL

Probability of technical success
Operational simplicity
Little visual inspection required
Proportion of process automated
Remaining life of existing plant
Few changes to existing process
Floor area adequate
Technology applicable to other areas
Little one-off development
Allows further use of new technology
Improves process flexibility
Improves process control
Improves product quality



COMMENTS

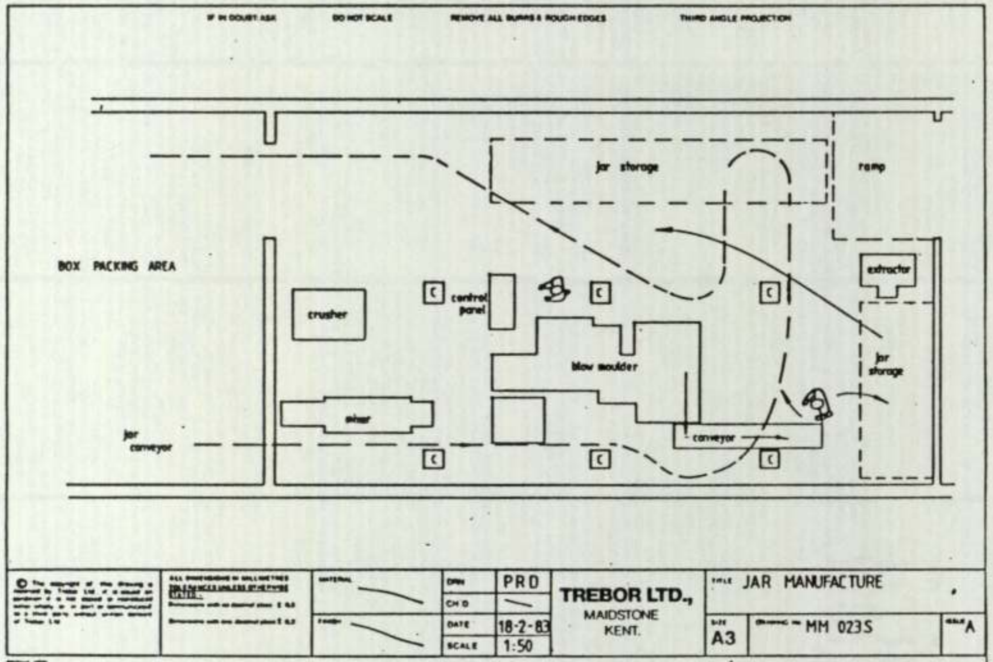
FINANCIAL APPRAISAL

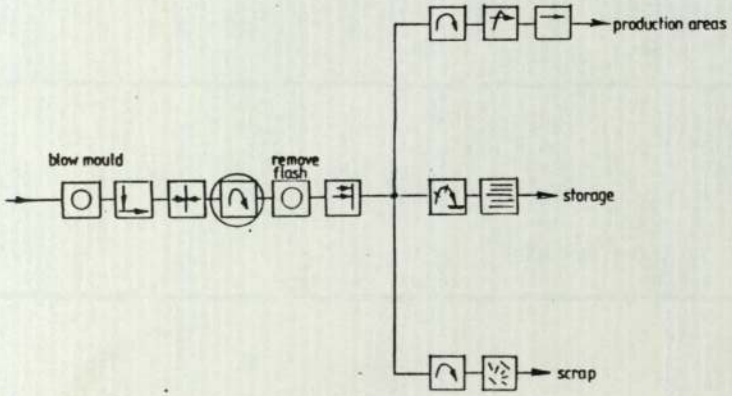
CAPITAL COSTS* £	
ROBOT	35,000
GUARDING	3,500
TOOLING	15,000
MODS TO	
– CONV^R	10,000
– MOULDER	2,500
SENSORS	1,500
	67,500

YEARLY DIRECT COST SAVINGS £p.a.	
LABOUR	£6,500
	6,500

∴ ~ 10 YEAR PAYBACK

* ESTIMATED





MM 023F

TREBOR R&D

ROBOT APPLICATION
DATA SHEET

MM 023

1. Application No: 023 Date: 5.1.83 By: PRD Factory: MM
2. Application Name: JAR MANUFACTURE
3. Location: GND FLOOR Personnel: –
4. Description of Object: BLOW MOULDED PLASTIC JAR
5. Dimensions: L 150 mm W 115 mm H 300mm Weight: – Kg
6. Description of Task: PICK UP MOULDING FROM CONVEYOR
   REMOVE EXCESS MATERIAL
   PLACE ON JAR CONVEYOR OR STORAGE RACK
7. Occasional Variations: SCRAP JAR. PLACE IN SCRAP BIN
8. Inspection: GENERAL FITNESS OF MOULDING
9. Load/Unload Time: 6 s Positioning Accuracy: ± 2 mm
10. Operation Cycle Time: 6 s Overhead mounting possible? N
11. How is Object Presented: RANDOMLY ON CONVEYOR
    Removed: MOVING CONVEYOR
12. Machines to be interfaced to this operation: MOULDING M/C CONVEYOR
13. No. of Operators this Operation: 1 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	1	5	5
Muscular strain	3	3	9
Noise	3	4	12
Dust, vapour	1	3	3
Temperature	2	3	6
Monotony	3	4	12
Eyestrain	_	3	_
Prot. Clothing	1	1	1
Oil, grease	_	2	_
Coldroom Conds	_	3	_

TOTAL: 48

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment:- VERY LIMITED
17. Floor Layout Drawing No: 1EG 036

No: MM030

PROJECT APPRAISAL

APPLICATION NAME: 'DRIAM' PAN LOADING

	YES	NO
LIKELY FUTURE SALES SATISFACTORY ?	✓	
LEVEL OF OUTPUT VOLUME GOOD ?	✓	
LIFE OF PROCESS PLANT ≥ 3 YEARS ?	✓	

ECHNICAL SIMPLICITY : 6 (SCORE 0-8)
FINANCIAL BENEFIT : 5
SOCIAL BENEFIT : 1
12

ANY OTHER SIGNIFICANT FACTOR

VERY SUCCESSFUL BRANDED PRODUCT LINE

COMMENTS

FLOORSPACE IS VERY LIMITED, ALTHOUGH LAYOUT NOT DECIDED YET.

TECHNICALLY A SIMPLE TRAY HANDLING TASK - LOW COST FIXED STOP ROBOT WOULD BE ADEQUATE.

DECISION

NO DECISION POSSIBLE DUE TO UNCERTAINTY OVER SYSTEM LAYOUT.

MM030

PROJECT PROFILE

FACTOR / EVALUATION

SOCIAL

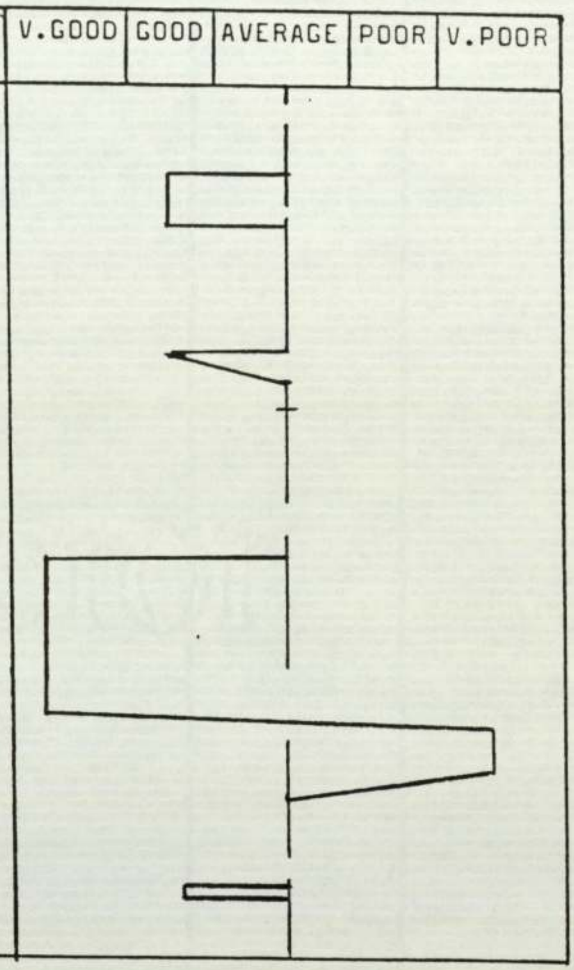
System benefits workers in terms of:
- health
- Safety
- unpleasant work
- new skills

FINANCIAL

Low capital investment
High net benefits
High % rate of return
Revenue time profile

TECHNICAL

Probability of technical success
Operational simplicity
Little visual inspection required
Proportion of process automated
Remaining life of existing plant
Few changes to existing process
Floor area adequate
Technology applicable to other areas
Little one-off development
Allows further use of new technology
Improves process flexibility
Improves process control
Improves product quality



COMMENTS

FINANCIAL APPRAISAL

CAPITAL COSTS*	£
ROBOT	18,000
TOOLING	3,000
GUARDING	3,500
CONVEYORS	3,000
CONTROLS	4,000
	31,500

DIRECT COST SAVINGS P.A.	£
LABOUR	13,000

PAYBACK : 2·4 YEARS

* ESTIMATES

TREBOR R&D ROBOT APPLICATION DATA SHEET MM030

1. Application No: 030 Date: FEB '85 By: (AW) Factory: MM
2. Application Name: 'DRIAM' PAN LOADING
3. Location: 2ND FLOOR Personnel: —
4. Description of Object: PLASTIC TRAY FOR LOOSE PRODUCT
5. Dimensions: L 600 mm W 400 mm H 81 mm Weight: 10 Kg
6. Description of Task: PICK UP TRAY FROM TOP OF STACK EMPTY CONTENTS INTO LOADING HOPPER. PLACE ONTO STACK OF EMPTIES
7. Occasional Variations: STACK HEIGHT
8. Inspection: LEVEL OF PRODUCT IN HOPPER
9. Load/Unload Time: — s Positioning Accuracy: ± 2 mm
10. Operation Cycle Time: 20 s Overhead mounting possible? Y
11. How is Object Presented: STACK ON TROLLEY
    Removed: — " —
12. Machines to be interfaced to this operation: HOPPER
13. No. of Operators this Operation: 1/2 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	2	5	10
Muscular strain	3	3	9
Noise	1	4	4
Dust, vapour		3	
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	

TOTAL: 35

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: POOR
17. Floor Layout Drawing No: NOT AVAILABLE

APPENDIX C

Appendix C

Of the twenty-eight applications originally identified, nine were studied in detail and design proposals prepared. This appendix contains condensed notes on one of these, MM029 hopper loading, as an example of this work. The notes are in four parts:

i) application data

ii) appraisal notes

iii) initial study-1983

iv) subsequent study-1985

The key points are annotated and cross-referenced to the main text.

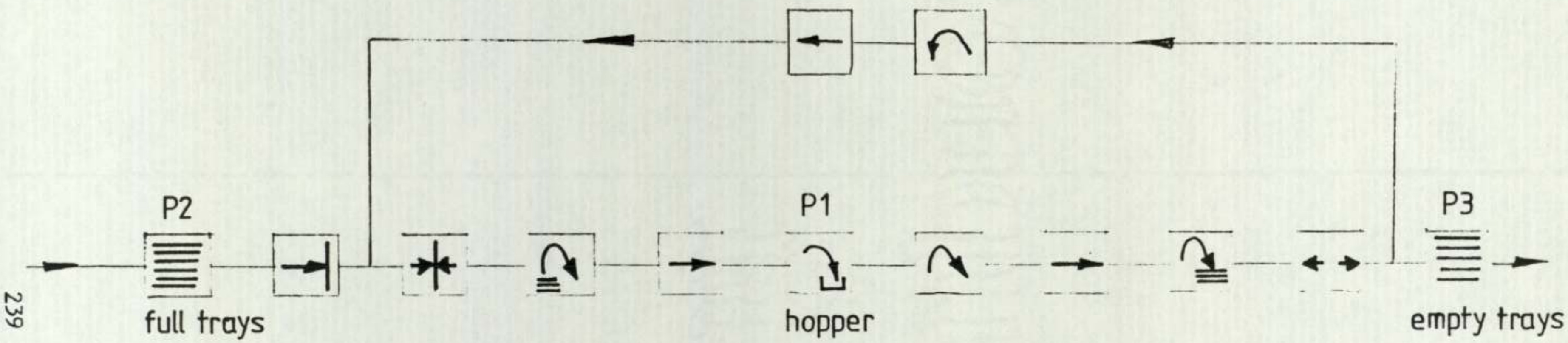
TREBOR R&D ROB(DATA **APPLICATION DATA**

1. Application No: 029 Date: 5.4.{
2. Application Name: PRODUCT LOA
3. Location: 1st FLOOR Personnel: L
4. Description of Object: PRODUCT TRAY / BIN
5. Dimensions: L 600 mm W 400 mm H 81 mm Weight: +/10 Kg
6. Description of Task: PICK UP TRAY FROM TOP OF STACK. EMPTY CONTENTS INTO HOPPER. PLACE ONTO STACK. REPEAT
7. Occasional Variations: STACK HEIGHT
. Inspection: LEVEL OF PRODUCT IN HOPPER
9. Load/Unload Time: ~30s Positioning Accuracy: ± 2 mm
10. Operation Cycle Time: 13 s Overhead mounting possible?
11. How is Object Presented: STACK ON TROLLEY

    Removed: —"—
12. Machines to be interfaced to this operation: HOPPER / WEIGHER
13. No. of Operators this Operation: 1 No. of Shifts: 1
14. Nature of the Task (score 0,1,2,3)

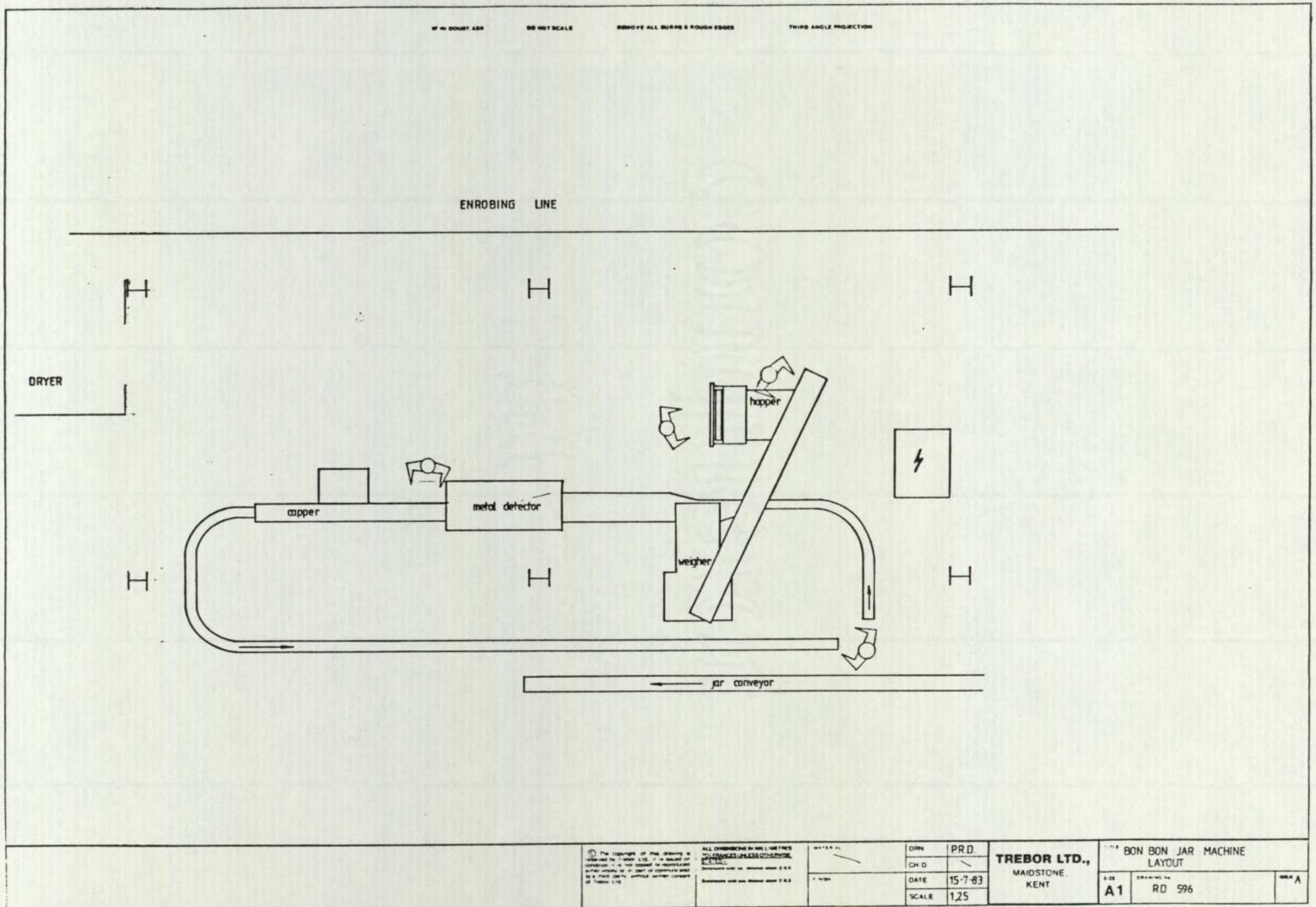
	Rating	Weight	RxW
Accident risk	2	5	10
Muscular strain	3	3	9
Noise	1	4	4
Dust, vapour	1	3	3
Temperature		3	
Monotony	3	4	12
Eyestrain		3	
Prot. Clothing		1	
Oil, grease		2	
Coldroom Conds		3	
		TOTAL:	38

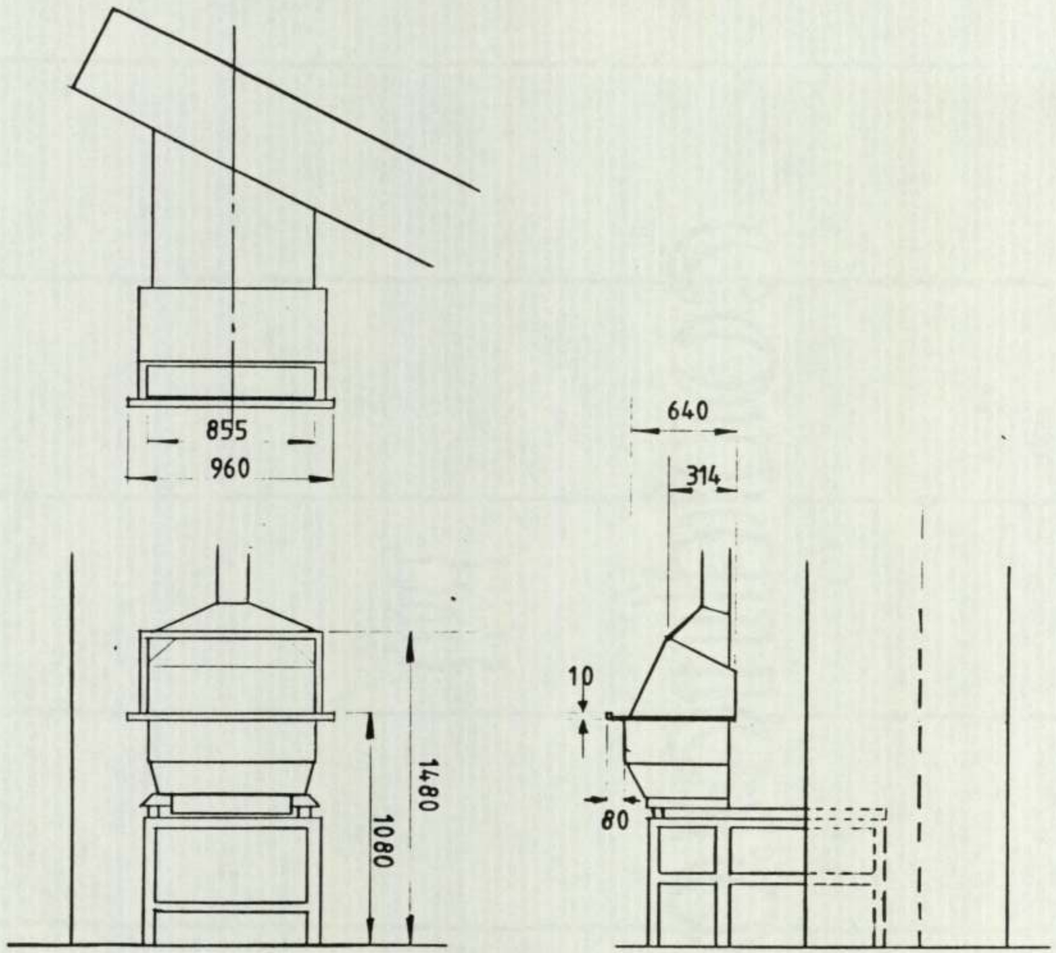
15. Check location of columns, services, expansion joints etc.
16. Space available for new equipment: VERY LIMITED
17. Floor Layout Drawing No: IEF 033 A



MM 029F

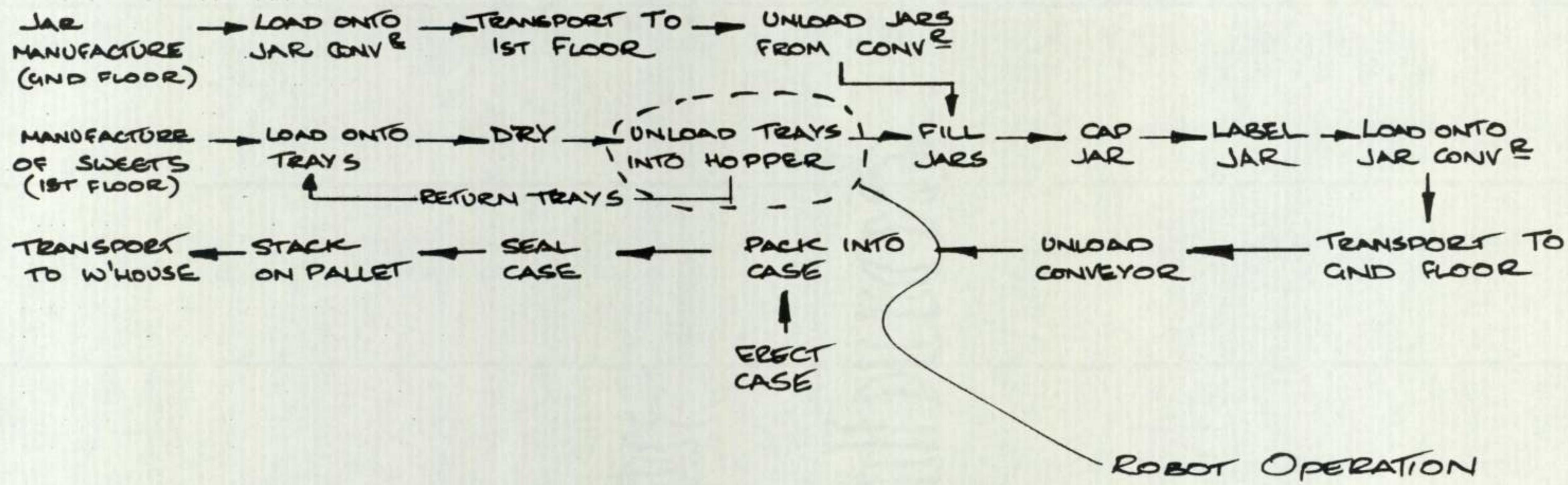
A3


IF IN DOUBT ASK
DO NOT SCALE
REMOVE ALL BURRS & ROUGH EDGES
THIRD ANGLE PROJECTION
ENROBING LINE
DRYER
hopper
capper
metal detector
weigher
jar conveyor
DRN P.R.D.
CH D
DATE 15-7-83
SCALE 1,25
TREBOR LTD.,
MAIDSTONE,
KENT
BON BON JAR MACHINE
LAYOUT
A1
RD 596
A



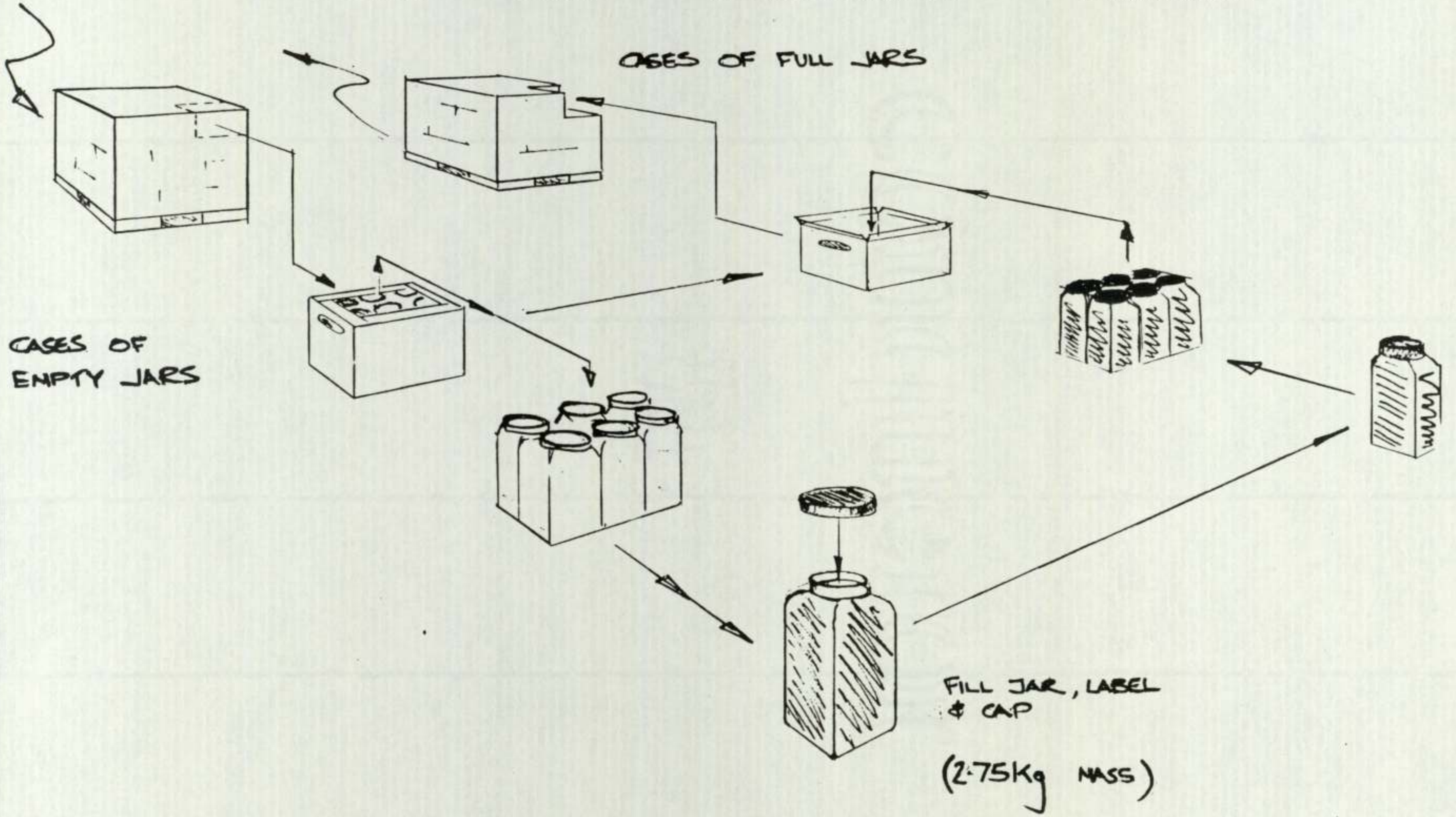
© The copyright of this drawing is reserved by Trebor Ltd. It is issued on condition it is not copied or reproduced either wholly or in part or communicated to a third party without written consent of Trebor Ltd	ALL DIMENSIONS IN MILLIMETRES TOLERANCES UNLESS OTHERWISE STATED:- Dimensions with no decimal place ± 0,5 Dimensions with one decimal place ± 0,2	MATERIAL — FINISH —	DRN PRD / CH'D — / DATE 1-6-83 / SCALE 1 : 25	**TREBOR LTD.,** MAIDSTONE KENT.	TITLE JAR FILLING MACHINE HOPPER (MM 029) / SIZE A3 / DRAWING No RD 579 / ISSUE A

REGMA 1661



Overall Bon-Bon Jars Manufacturing Process

IF IN DOUBT: ASK DO NOT SCALE REMOVE ALL BURRS & ROUGH EDGES THIRD ANGLE PROJECTION



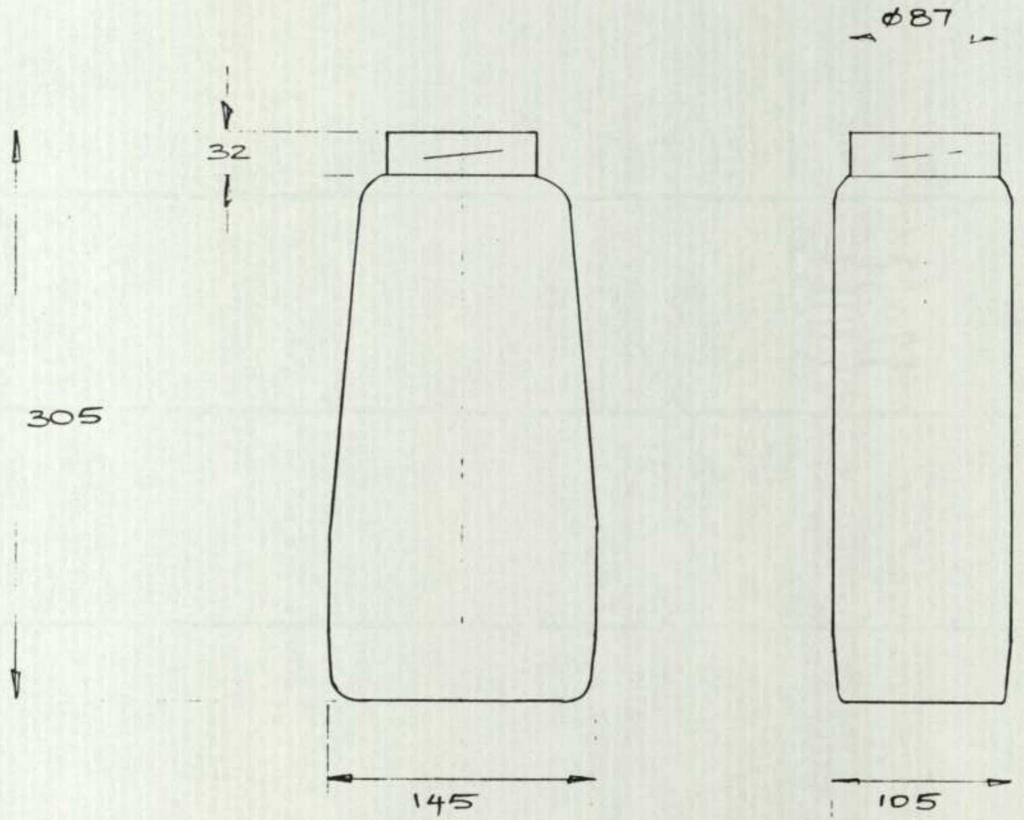
ALL DIMENSIONS IN MILLIMETRES
TOLERANCES UNLESS OTHERWISE STATED -
Dimensions with no decimal place ± 0.5
Dimensions with one decimal place ± 0.2

MATERIAL	DRN	DRD	**TREBOR LTD.,** MAIDSTONE KENT
	CH'D		
FINISH	DATE		
	SCALE		

TITLE JAR PACKING
8 JARS MIN⁻¹

SIZE A3 DRAWING No ISSUE

IF IN DOUBT: ASK   DO NOT SCALE   REMOVE ALL BURRS & ROUGH EDGES   THIRD ANGLE PROJECTION

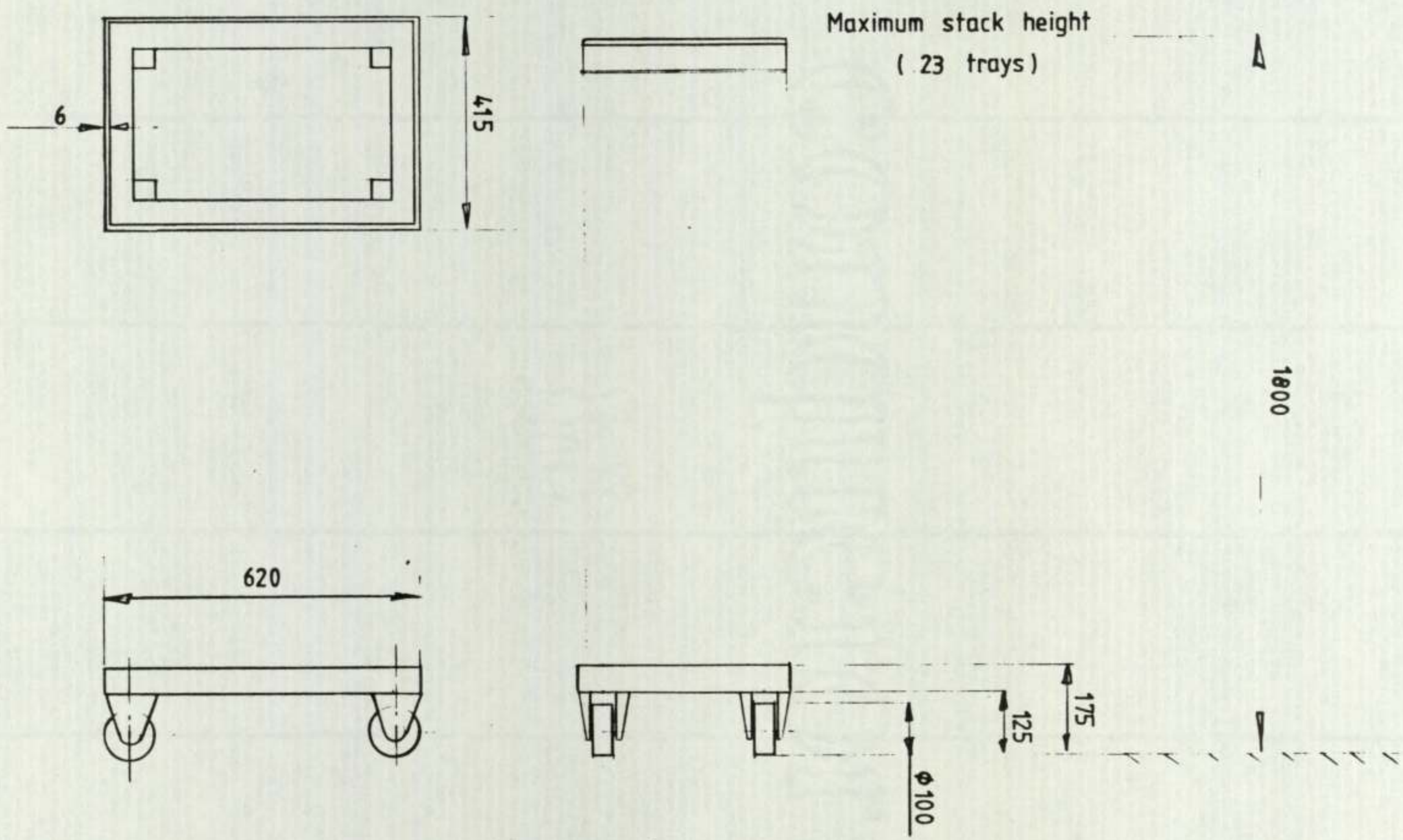


MAXIMUM WEIGHT OF FULL JAR: 3Kg

© The copyright of this drawing is reserved by Trebor Ltd it is issued on condition it is not copied or reproduced either wholly or in part or communicated to a third party without written consent of Trebor Ltd	ALL DIMENSIONS IN MILLIMETRES TOLERANCES UNLESS OTHERWISE STATED - Dimensions with no decimal place ± 0.5 Dimensions with one decimal place ± 0.2	MATERIAL — FINISH —	DRN: PAUL D; CH'D: —; DATE: 8·8·83; SCALE: —	TREBOR LTD., MAIDSTONE KENT.	TITLE: PLASTIC JAR	SIZE: A3	DRAWING No: RD 610; ISSUE:

REGMA 1661

IF IN DOUBT ASK — DO N[illegible]ALE — REMOVE ALL BURRS & ROUGH EDGES — THIRD ANGLE PROJECTION



ALL DIMENSIONS IN MILLIMETRES TOLERANCES UNLESS OTHERWISE STATED:- Dimensions with no decimal place ± 0,5 Dimensions with one decimal place ± 0,2	MATERIAL	DRN	PRD	**TREBOR LTD.,** MAIDSTONE KENT.	TITLE TROLLEY (MM 029)	
		CH'D				
	FINISH	DATE	1-6-83		SIZE A3	DRAWING No RD 580
		SCALE	1:10			ISSUE A

REGMA 1661

PROJECT APPRAISAL APPRAISAL NOTES

APPLICATION NAME: HOPPER

LIKELY FUTURE SALES SATISFACTORY ? ✓
LEVEL OF OUTPUT VOLUME GOOD ? ✓
LIFE OF PROCESS PLANT ≥ 3YEARS? ✓

TECHNICAL SIMPLICITY : 6 (SCORE 0-8)
FINANCIAL BENEFIT : 2
SOCIAL BENEFIT : 8
16

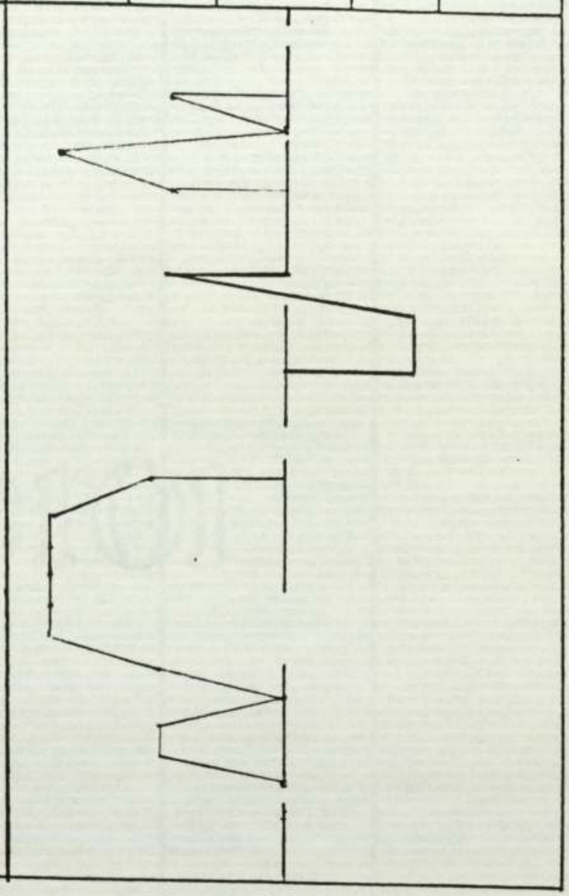
ANY OTHER SIGNIFICANT FACTOR:
COMMON APPLICATION AT CC & MM FACTORIES
SUCCESSFUL PRODUCT LINE
COMMENTS:
FLOORSPACE IS LIMITED
SIMPLE TRAY HANDLING TASK - LOW TECHNICAL RISK - GOOD FIRST APPLICATION
EXCELLENT HEALTH & SAFETY BENEFITS - OP^{R} CURRENTLY LIFTS ~20T per shift DOING THIS TASK

DECISION: SHORTLISTED APPLICATION
CARRY OUT DETAILED DESIGN STUDY

MM029

PROJECT PROFILE

FACTOR \ EVALUATION	V.GOOD	GOOD	AVERAGE	POOR	V.POOR



SOCIAL
System benefits workers in terms of:
- health
- Safety
- unpleasant work
- new skills

FINANCIAL
Low capital investment
High net benefits
High % rate of return
Revenue time profile

TECHNICAL
Probability of technical success
Operational simplicity
Little visual inspection required
Proportion of process automated
Remaining life of existing plant
Few changes to existing process
Floor area adequate
Technology applicable to other areas
Little one-off development
Allows further use of new technology
Improves process flexibility
Improves process control
Improves product quality

COMMENTS FINANCIAL APPRAISAL

ESTIMATED COSTS
£

ROBOT	50,000
TOOLING	3,000
CONVEYORS	2,000
GUARDING	3,000
CONTROLS	2,500
	£60,500

1/3RD GRANT

DIRECT COST SAVINGS

	£ p.a.
LABOUR	6,500

ROBOT CYCLE

INITIAL STUDY-1983

OP^{N}	
10	RECEIVE STACKS OF POS^{NS} A or B
20	ROBOT MOVES TO S
30	GRASPS 11th TRAY IN
40	MOVES HALF STACK TO POS^{N} C
50	RELEASES STACK
60	MOVES TO TOP OF STACK AT C
70	GRASPS TOP TRAY
80	LIFTS TRAY & MOVES TO HOPPER
90	TIPS TRAY, UNLOADING CONTENTS INTO HOPPER
100	SHAKES TRAY TO REMOVE DUST
110	MOVES TO POS^{N} D
120	RELEASES EMPTY TRAY
	REPEATS STEPS 60-120 UNTIL STACK AT C IS FINISHED
200	MOVES TO STACK POS^{N} WITH HALF STACK REMAINING
210	GRASPS BOTTOM TRAY & LIFTS
	REPEATS STEPS 40 TO 120 UNTIL STACK AT C IS FINISHED
300	MOVES TO BOTTOM OF STACK AT D
310	GRASPS BOTTOM TRAY & LIFTS FULL STACK
320	MOVES TO EMPTY STACK INPUT POS^{N} A / B.
330	PLACES STACK DOWN & RELEASES
340	MOVES TO OTHER INPUT POS^{N} A/B

TIMINGS

23 TRAYS PER STACK ~ 7.5 Kg PRODUCT @ 12 jars min^{-1}
LOADING RATE

→ 13.2 s TRAY CYCLE TIME

→ 303 s STACK CYCLE TIME (~ 5 mins)

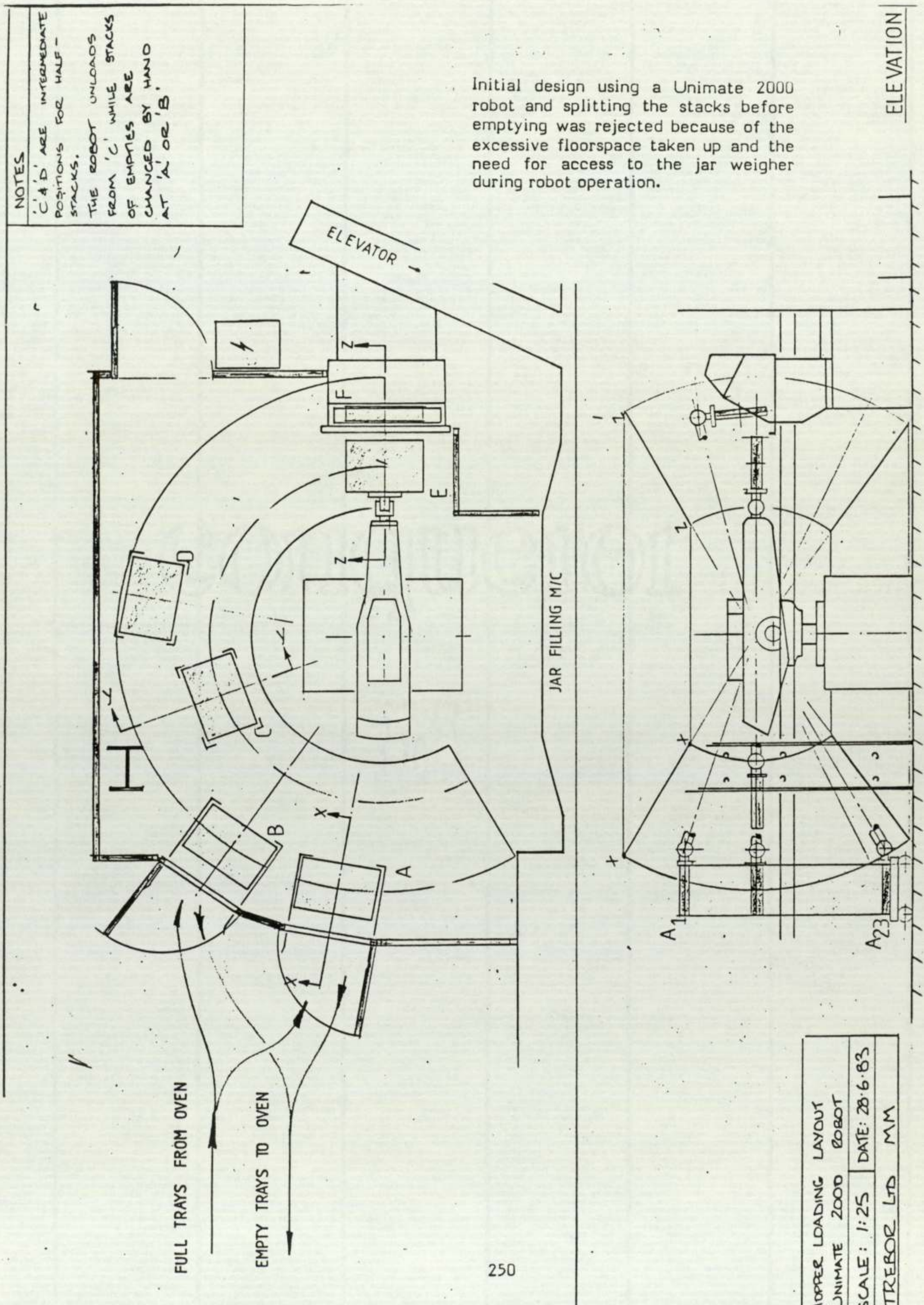
∴ 303 s OPS 10 – 340

$$303s = 1\left(OP^{N}\ 10-50\right) + 1\left(200, 210\right) + 1\left(300-340\right) + 23\left(60-120\right)$$

ESTIMATES

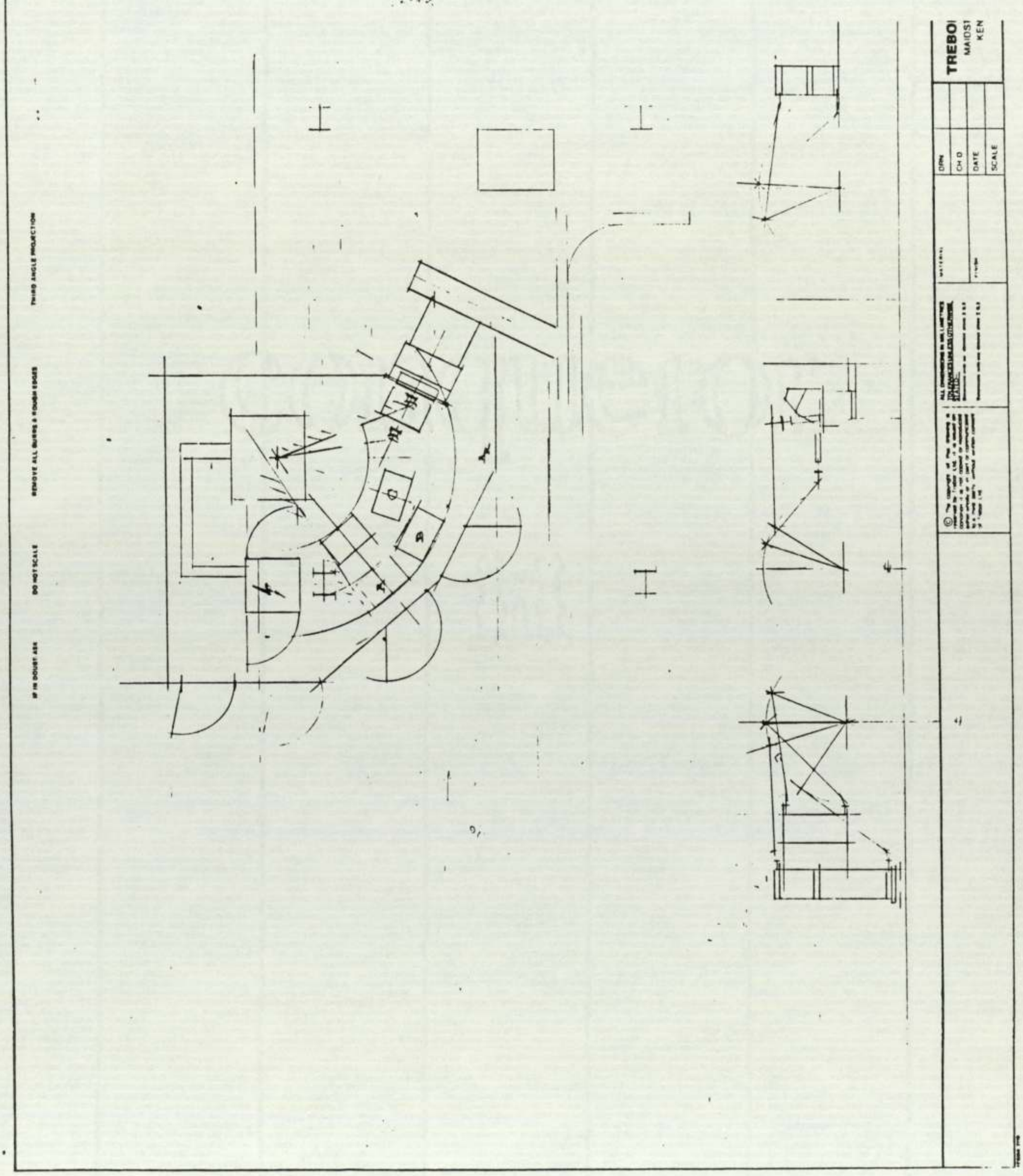
OP^N	TIME /s
60	1
70	.5
80	3
90	1
100	2
110	3
120	.5
	11 s

$23 \times (13.2 - 11)$ = REMAINING CYCLETIME AVAILABLE = ~ 50 s



Initial design using a Unimate 2000 robot and splitting the stacks before emptying was rejected because of the excessive floorspace taken up and the need for access to the jar weigher during robot operation.

A second design was prepared using a T3-746 robot to give improved space efficiency.



This proposal, based on the T3-746, was subsequently rejected when other development work on the neighbouring enrobing line and a local weakness in the factory floor were revealed.

Robot Application Proposal

PROPOSAL No: 1

PROCESS: BON-BON JAR FILLING

LOCATION: FIRST FLOOR, MAIDSTONE

DATE: 21st JULY 1983

COMPILED: P. R. DRAYSON

Trebor R&D

CONTENTS

Appendices

1.0 Application Description

This robot application proposal is concerned with the production of "Bon-Bon" sweets at Maidstone factory.

The penultimate stage of the manufacturing process is the packing of the sweets into plastic jars each containing 2.75Kg of product. The jar packing process is partially automated but the loading of product into the jar filling machine is still done by hand. This is a particularly strenuous and repetitive task requiring an operator to lift in excess of eight tonnes per shift.

It is proposed that this manual work is carried out by a robot based handling system.

1.1 Current Method of Operation

Following the panning operation the Bon-Bons are loaded into plastic trays and stacked 23 high on trolleys (see Appendix A5). The trolleys are then pushed into the drier.

After drying the trolleys are collected from the drier and lined up beside the jar filling machine ready for loading into the filling machine hopper. Hopper filling is carried out by one operator. The hopper filling cycle is summarised below:

Operation No.	Operation	Frequency	Time
1	walk to stack storage area drag one trolley of full trays to within reach of hopper	1/1	30s
2	pick up top tray from stack place at mouth of hopper	23/1	2s
3	tip product into hopper	23/1	1s
4	place emptied tray to stack of empty trays on trolley	23/1	2s
5	repeat elements 2-4 until stack is emptied or until hopper is full	23/1	115s
6	push stack of empty trays to stack storage area	1/1	30s

Stacks of empty trays are taken through the drier back

2.1 Modifications Required to Existing Process

1. Reposition hopper.
2. Maximum stacking height discipline.

2 2 Special Purpose Development Work Required

1. Interface system to hopper, shuttle mechanism and guard interlocks.
2. Tray gripping tool.
3. Trolley shuttle mechanism.

3.0 Robots Suitable for this Operation

Asea IRB-60
Cincinnati-Milacron T3-746
Unimate 2000

3.1 Robot Recommended

Cincinnati-Milacron T3-746

Reasons for recommendation;

1. This robot is suitable for the majority of future applications
2. Large vertical reach
3. Interference free 3-roll wrist enables reduction in floor space needed.
4. Electic drive machine.
5. Sophisticated control system.

to the panning room.

* Each tray contains 7.5Kg of product.

* Total weight of full tray: 9Kg.

* Maximum production rate: 33Kg/min.

* Tray loading rate: 4.54 trays/min.

* Stack unloading cycle time: 5mins.

2.0 Proposed Robot Based Method

The robotic hopper filling system consists of two main parts (see Appendix A5); the industrial robot (1) and the trolley shuttle mechanism (2).

The trolley shuttle mechanism transfers stacks of trays into and out of the unloading area. Stacks are loaded and unloaded manually outside the reach of the robot. The robot picks trays off the stack once it is positioned inside, splitting the stack in half before destacking and emptying the sweets into the hopper. Splitting the stack enables the empty trays to be stacked back onto the same trolley.

The system has the following features;

* The robot does not operate whilst the operator is changing stacks.

* Stacks of full trays may contain any number of trays on a trolley up to a maximum of 23 trays.

* If at any time during the operation of the system any of the safety interlocks are violated the robot is halted. A keyed switch is operated at the main control panel to restart the system. Only one key is kept in the production area, held by the operator responsible for the system.

* The tray gripping tool is a pneumatically actuated device which holds the tray at two points at each end. Proximity sensors in the gripper fingers ensure the tray is held before lifting.

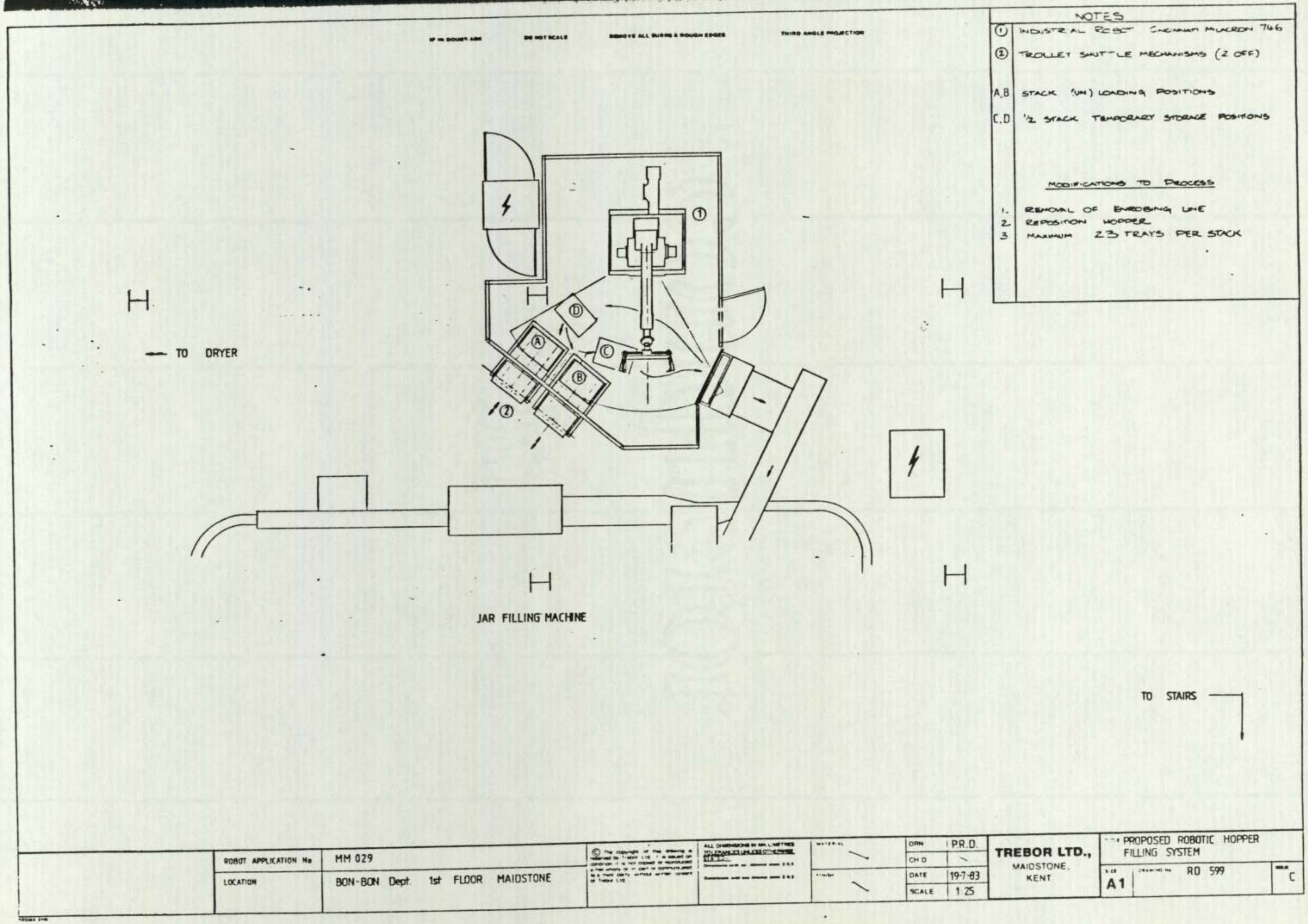
4.0 System Cost

No.	ITEM	PRICE
1	Cincinnati-Milacron T3-746 Industrial Robot complete with Version 4 computer control system, electrical power and offline program storage system.	£50,695
2	Tray gripping tool.	£ 2,635
3	Trolley shuttle mechanism.	£ 1,500E
4	Elecrical interfaces to peripheral equipment, shuttle mechanism and safety interlocks.	£ 2,500
5	Perimeter guarding, access gate and safety interlocks.	£ 2,500
	TOTAL CAPITAL COST:	£59,830

5.0 Benefits of Proposed Method

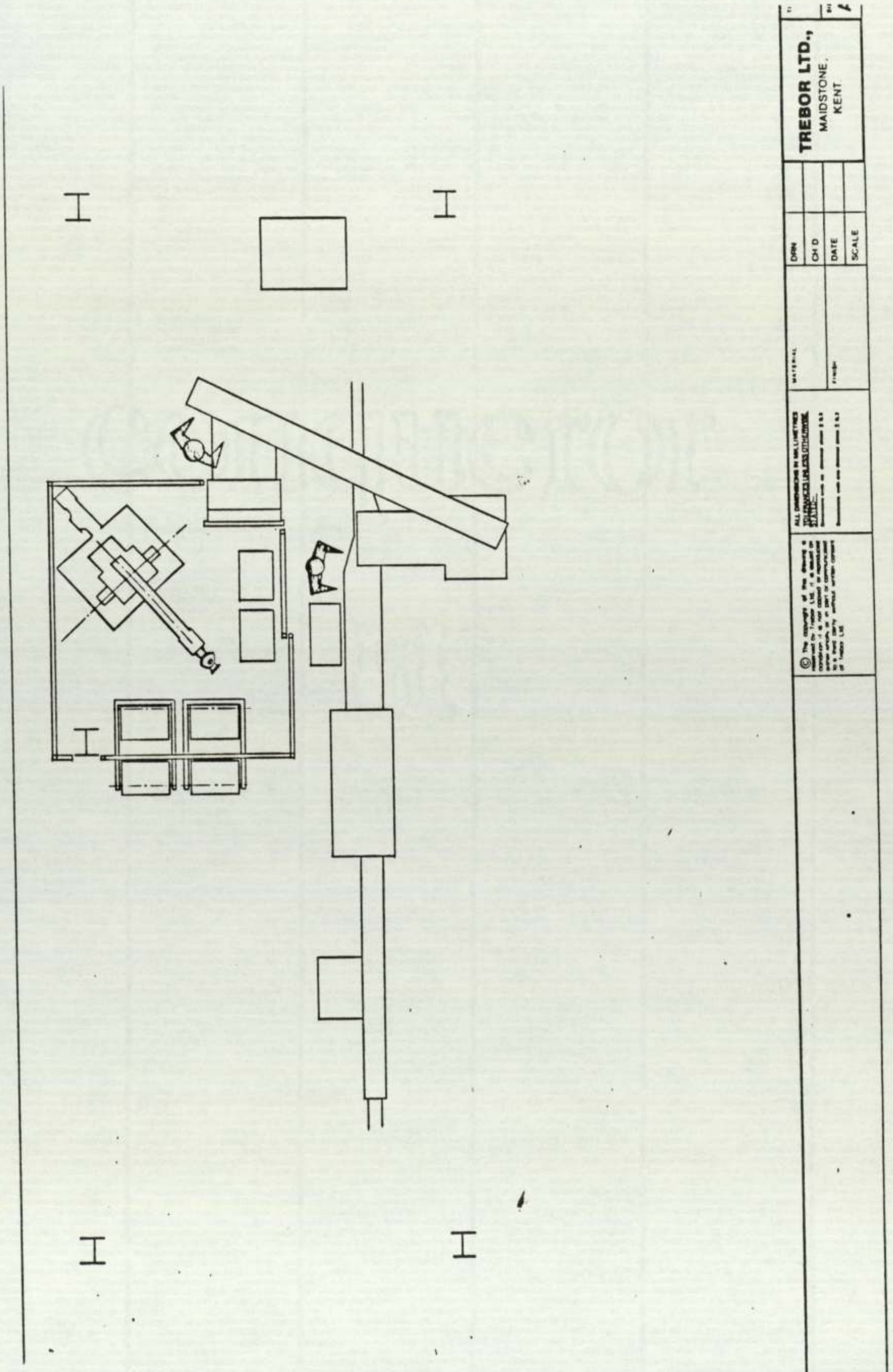
* suitable first robot application due to the low complexity of the task.

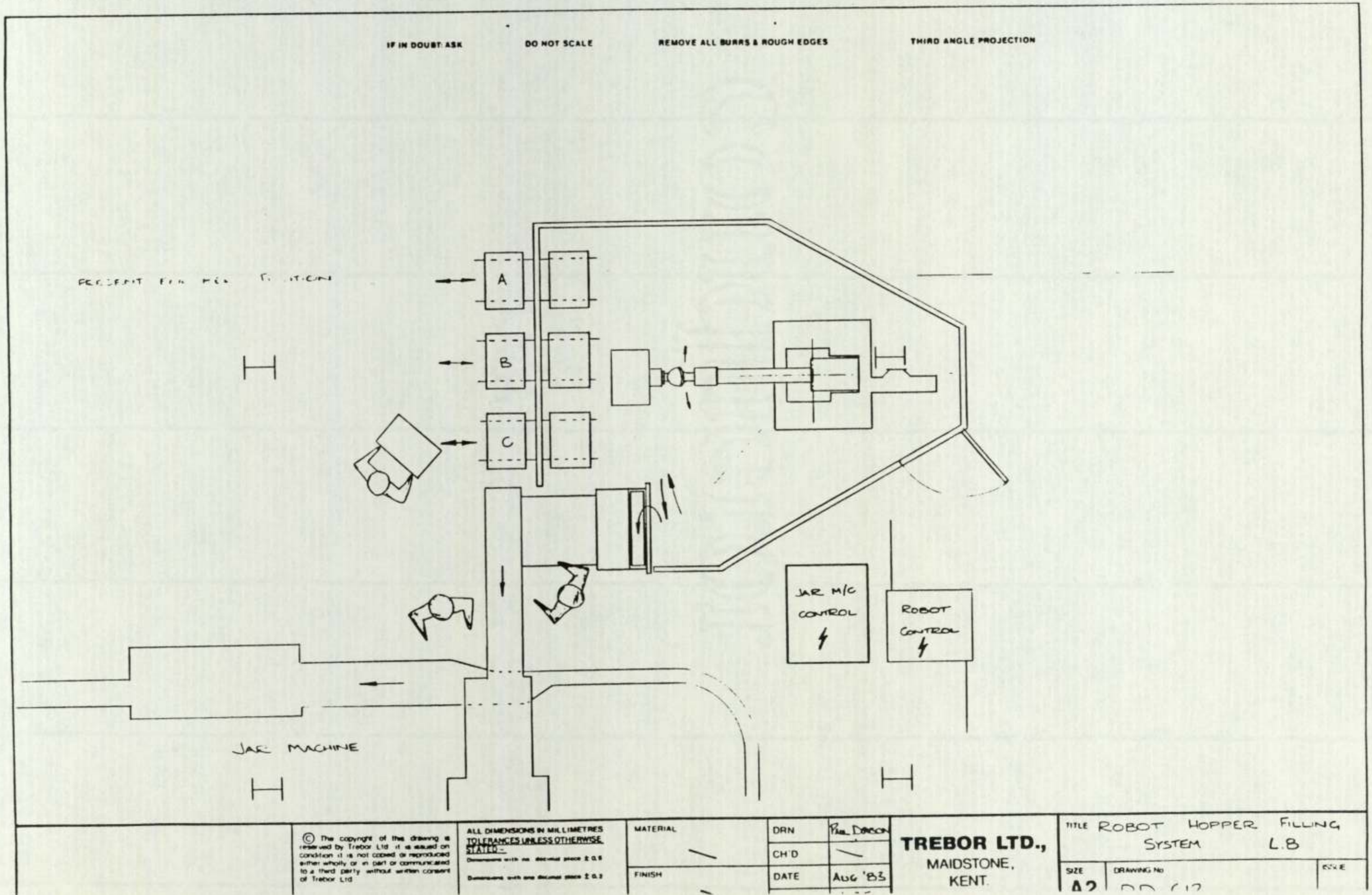
* replaces strenuous and repetitive work


NOTES
① INDUSTRIAL ROBOT
② TROLLEY SHUTTLE MECHANISMS (2 OFF)
A,B STACK (UN) LOADING POSITIONS
C,D ½ STACK TEMPORARY STORAGE POSITIONS
MODIFICATIONS TO PROCESS
1. REMOVAL OF ENROBING LINE
2. REPOSITION HOPPER
3 MAXIMUM 23 TRAYS PER STACK
TO DRYER
JAR FILLING MACHINE
TO STAIRS
ROBOT APPLICATION No MM 029
LOCATION BON-BON Dept. 1st FLOOR MAIDSTONE
DRN P.R.D.
CH D
DATE 19-7-83
SCALE 1:25
TREBOR LTD., MAIDSTONE, KENT
PROPOSED ROBOTIC HOPPER FILLING SYSTEM
A1
RD 599
C

A number of alternative designs were prepared in order to overcome these problems.

The project was abandoned in September 1983 due to uncertainty over plans for the enrobing line.




IF IN DOUBT ASK
DO NOT SCALE
REMOVE ALL BURRS & ROUGH EDGES
THIRD ANGLE PROJECTION
A
B
C
JAR M/C CONTROL
ROBOT CONTROL
JAR MACHINE
© The copyright of this drawing is reserved by Trebor Ltd. it is issued on condition it is not copied or reproduced either wholly or in part or communicated to a third party without written consent of Trebor Ltd
ALL DIMENSIONS IN MILLIMETRES
TOLERANCES UNLESS OTHERWISE STATED:-
MATERIAL
FINISH
DRN
CH'D
DATE
AUG '83
TREBOR LTD.,
MAIDSTONE,
KENT.
TITLE ROBOT HOPPER FILLING SYSTEM L.8
SIZE
A2
DRAWING No

ROBOTICS PROJECT MEETING No. 2

Held on Monday 28th January 1985

The hopper loading application was reconsidered during the factory surveys carried out in January 1985. It was subsequently decided as the most suitable application for a robot system at MM at that time. (see extract from minutes 28.1.85 below).

1. Results of further study:

PRD summarised the results of further study of the six projects previously shortlisted (Min. 3. 22.1.85).

(i) Packing of Jensen products is better suited to dedicated special purpose machinery due to the high speed requirement.

(ii) The jar capping application on Bon Bons is feasible, but should be shelved pending thorough use of the system at XX.

(iii) The loading of trayed Softmint product into the Driam pans, and combined Softmint/fruit/Spearmint carton palletising are of doubtful feasibility due to uncertainty over the form of the manufacturing process in the future.

A robot palletising cell for three products would require approximately 25 m^2 of floor space.

(iv) Palletising of Jensen products would require substantial changes to the layout and material flow in that area. Otherwise this project is technically and financially very attractive.

(v) The loading of trayed Bon Bons product into the hopper of the jar filling machine is well suited to a robotic solution.

2. Evaluation :

It was agreed that the Bon Bon hopper filling project is the best application at the present time due to the :

- moderate technical complexity
- cost saving
- elimination of unpleasant work.

The design of the system should allow for robot jar capping at a future date.

The palletising of Jensen products was agreed as an attractive project in the longer term, pending a re-appraisal of the ground floor area and successful installation of the less complicated hopper filling project.

3. PMM meeting :

It was agreed that PRD prepare a detailed proposal for the hopper filling project. This proposal to be agreed with MM team prior to submission at PMM.

PRD/
30.1.85
Distribution : MM team, PRD.

MAIDSTONE ROBOT APPLICATION

1. PROJECT OBJECTIVE :

To automate the loading of trayed Bon Bon product into the jar filling machine.

2. METHOD

Use of a gantry type 5-axis industrial robot suspended from a ceiling support beam interfaced with a stack handling mechanism and dust collection unit.

3. ROBOT TASK

i) Accept stack of full trays into robot cell.

ii) Pick up full tray from stack.

iii) Tap off excess sugar coating.

iv) Tip Bon Bons into hopper.

v) (Clean tray) - feasibility not established.

vi) Place enpty tray onto stack.

vii) Repeat 23 times for each stack.

viii) Eject stack of empty trays from robot cell.

4. REQUIREMENTS

i) Cost : £35,000 (budget price minus ⅓ grant.)

ii) Joint MM/R & D/Supplier project team.

iii) Modifications to general filling area.

iv) Development of dust collector/tray cleaning unit.

5. BENEFITS

i) Replaces a simply awful job. The operator loads approx. 20 tonnes of product per day.

ii) Direct cost saving of £7,500 p.a.

iii) Improves quality of product.

iv) Project of moderate complexity, suitable for introducing robot technology onto MM site.

P. R. Drayson 25.2.85

AUTOMATIC PRODUCT LOADING SYSTEM

SPECIFICATION

1. GENERAL REQUIREMENTS
   - 1.1 Purpose
   - 1.2 Features
2. EXTENT OF SUPPLY
3. STANDARDS
4. TECHNICAL REQUIREMENTS
   - 4.1 Performance
   - 4.2 Operating Environment
5. ACCEPTANCE TRIALS
6. MANAGEMENT
7. WARRANTY

A specification for the project was agreed, proposals tendered by two companies for turnkey systems and finance approved by the PMM.

A joint MM/R & D project team was set up to manage the project.

At the first project group meeting it emerged that there was other development work planned on the Bon-Bon production line which would lead to a 100% increase in jar filling speed.

Work was carried out in conjunction with the system suppliers to try and meet the change in specification.
It was not found possible to design a system to meet the new specification within the budget agreed and so the project was abandoned in April 1985.

1. GENERAL REQUIREMENTS

1.1 Purpose

The purpose of the proposed system is to automatically load trayed Bon Bon sweets into a jar filling machine hopper.

1.2 Features

The following features of the system are mandatory :

1.2.1 Unloading of at least three stacks at a time without operator intervention.

1.2.2 Pick up of individual trays from stack and unloading of sweet contents into existing hopper.

1.2.3 Re-stacking of empty trays onto trolley.

1.2.4 Ejection of at least three empty stacks at a time without operator intervention.

The following features are desirable but not essential and should be costed separately:

1.2.5 Removal of excess sugar dust from empty tray.

1.2.6 Collection of dust removed for reclamation.

1.2.7 System capacity of more than three stacks without operator intervention.

1.2.8 Facility to reject stack(s) from system without emptying product into hopper upon external input.

2. EXTENT OF SUPPLY

The Supplier shall :

a) Survey and review proposed application area.

b) Carry out the design and development work necessary for the requirements described.

c) Manufacture and integrate system elements necessary.

d) Conduct pre-delivery trials of the completed system at their premises.

2. cont.

e) Deliver to Maidstone site all system elements.

f) Install and commission system to specification described. Carry out acceptance trials to the satisfaction of Trebor U.K. Limited.

g) Provide training for two persons on system operation.

h) Carry out all project management involved in the above, including the submission of an outline programme with the tender and a detailed programme following receipt of order.

3. STANDARDS

The system shall satisfy the requirements of :

a) MTTA Code of Practice on the Guarding of Industrial Robots.

b) Health and Safety at Work et. Act 1974.

c) IEE Electrical Regulations.

d) Environmental protection to IP55.

In addition all surfaces to be in contact with food product to be manufactured in stainless steel. All surface finishes to be epoxy based.

4. TECHNICAL REQUIREMENTS

4.1 Performance

The line production rate is 27 kg/min. Each tray contains between 7.5 - 9 kg. This corresponds to a cycle time, at 85 % availability of 14.5 secs per tray.

4.2 Operating Environment

System to be resistant to weekly washing.

Electrical cabinets to be raised at least 50 mm above floor and to IP55 standard.

5. ACCEPTANCE TRIALS

Prior to despatch to our works, system acceptance trials to be carried out at supplier's premises to described standard of manufacture and performance specification.

6. MANAGEMENT

Mr. P. R. Drayson will be responsible for the design, contractual matters and acceptance on behalf of Trebor U.K. Limited.

The supplier will nominate a member of staff responsible for controlling all aspects of the project and liaison with Mr. Drayson.

7. WARRANTY

The proposed system to be guaranteed for a period to 12 months from delivery on both parts and labour.

APPENDIX D

Appendix D

This appendix contains condensed notes on the jar-capping system which was developed between January and September 1984. The notes are in five parts:

i) application data

ii) appraisal notes

iii) project proposal

iv) system description

v) project audit

TREBOR R&D

ROB(
" DATA

APPLICATION DATA

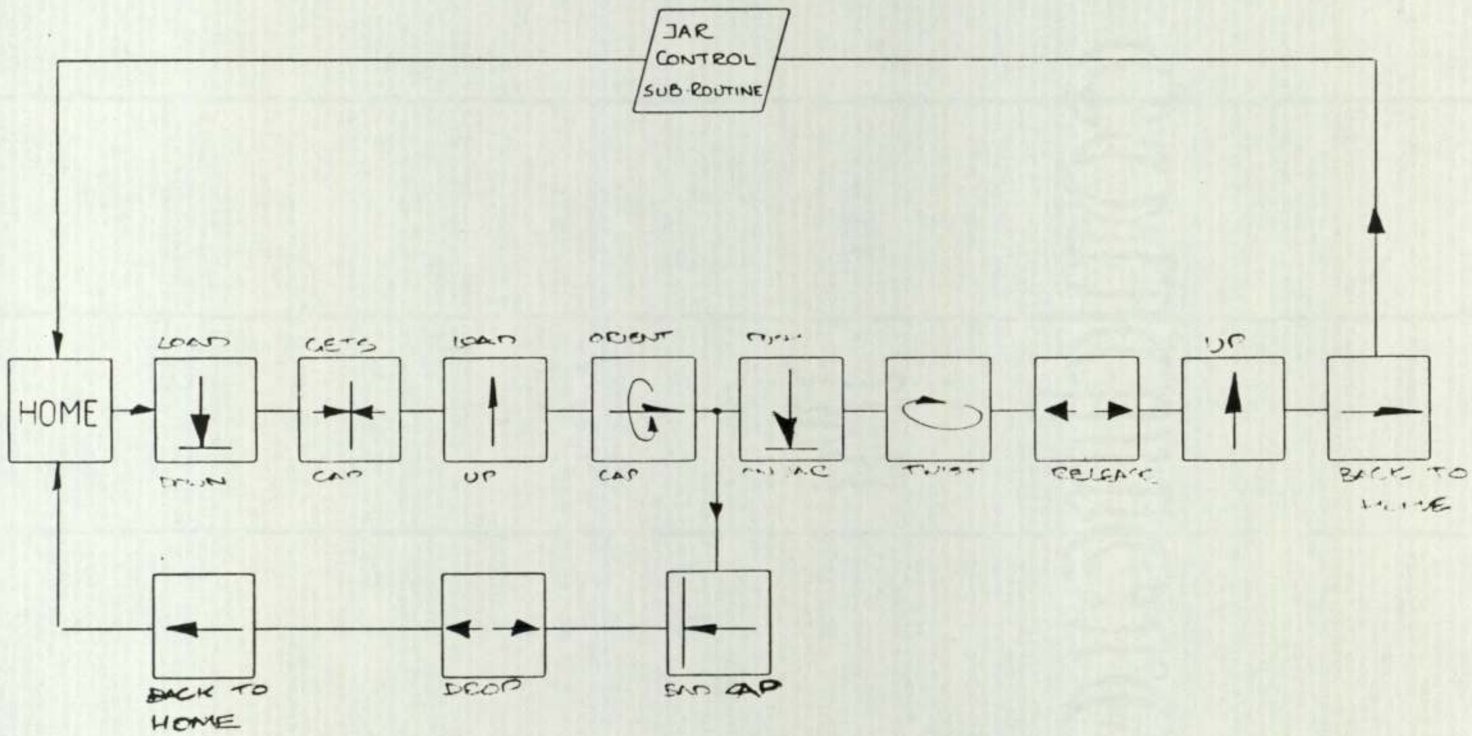
1. Application No: 007 Date: AUG'
2. Application Name: JAR CAPPING
3. Location: PROD^N 1 Personnel:
4. Description of Object: PVC JAR & CAP
5. Dimensions: L Ø90 mm W ~~ mm H ~~ mm Weight: ¼ Kg
6. Description of Task: PICK UP CAP, PLACE ONTO JAR – TURN TO SEAL.
7. Occasional Variations: BADLY MOULDED CAP
8. Inspection: CAP QUALITY
9. Load/Unload Time: – s Positioning Accuracy: ± 1 mm
10. Operation Cycle Time: 7.5 s Overhead mounting possible? Y
11. How is Object Presented: RANDOMLY IN BOX

    Removed: ON CONVEYOR
12. Machines to be interfaced to this operation: JAR FILLING
13. No. of Operators this Operation: 1 No. of Shifts: 2
14. Nature of the Task (score 0,1,2,3)

	Rating	Weight	RxW
Accident risk	:	5	
Muscular strain	: 3	3	9
Noise	: 3	4	12
Dust, vapour	:	3	
Temperature	:	3	
Monotony	: 3	4	12
Eyestrain	:	3	
Prot. Clothing	:	1	
Oil, grease	:	2	
Coldroom Conds	:	3	
		TOTAL:	33

15. Check location of columns, services, expansion joints etc. ✓
16. Space available for new equipment: GOOD
17. Floor Layout Drawing No: 0006/D

IF IN DOUBT: ASK   DO NOT SCALE   REMOVE ALL BURRS & ROUGH EDGES   THIRD ANGLE PROJECTION



© The copyright of this drawing is reserved by Trebor Ltd. it is issued on condition it is not copied or reproduced either wholly or in part or communicated to a third party without written consent of Trebor Ltd	ALL DIMENSIONS IN MILLIMETRES TOLERANCES UNLESS OTHERWISE STATED - Dimensions with no decimal place ± 0.5 Dimensions with one decimal place ± 0.2	MATERIAL —— FINISH ——	DRN: PR.D CH D: —— DATE: 13.3.84 SCALE: ——	**TREBOR LTD.,** MAIDSTONE KENT.	TITLE ROBOTIC CAPPING PROJECT ROBOT CYCLE	SIZE A3 · DRAWING No · ISSUE

PROJECT APPRAISAL

APPRAISAL NOTES

APPLICATION NAME: JAR CAP1

LIKELY FUTURE SALES SATISFACTORY ? ✓

LEVEL OF OUTPUT VOLUME GOOD ? ✓

LIFE OF PROCESS PLANT ≥ 3 YEARS? ✓

·ECHNICAL SIMPLICITY : 7 (SCORE 0-8)

FINANCIAL BENEFIT : 6

SOCIAL BENEFIT : 6

19

ANY OTHER SIGNIFICANT FACTOR

COMMON APPLICATION TO ALL THREE FACTORIES

COMMENTS

VERY SIMPLE FIRST APPLICATION - GOOD PROBABILITY OF SUCCESS

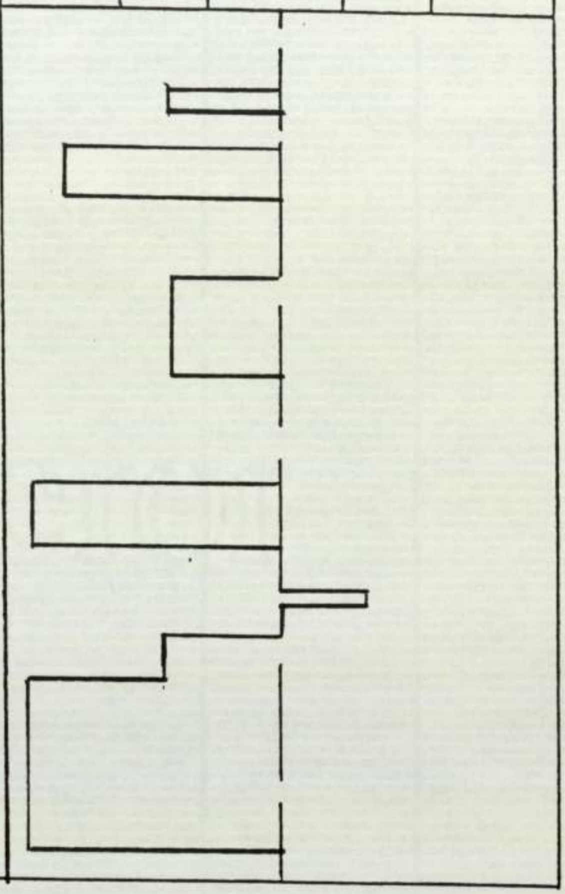
LAYOUT NOT CERTAIN UNTIL JAR PROD^{N} IS TRANSFERRED FROM MM TO XX IN SPRING '84

DECISION: CARRY OUT FEASIBILITY TRIALS AT ROBOT SUPPLIER'S WORKS.

PROJECT PROFILE

XX007

FACTOR / EVALUATION	V.GOOD	GOOD	AVERAGE	POOR	V.POOR
SOCIAL					
System benefits workers in terms of:					
health					
Safety					
unpleasant work					
new skills					
FINANCIAL					
Low capital investment					
High net benefits					
High % rate of return					
Revenue time profile					
TECHNICAL					
Probability of technical success					
Operational simplicity					
Little visual inspection required					
Proportion of process automated					
Remaining life of existing plant					
Few changes to existing process					
Floor area adequate					
Technology applicable to other areas					
Little one-off development					
Allows further use of new technology					
Improves process flexibility					
Improves process control					
Improves product quality					



COMMENTS

PROJECT PROPOSAL

Robot Application Proposal

PROPOSAL No. 4
PROCESS: E.S.M. JAR PACKING
LOCATION: PRODUCTION 1 XX
DATE: OCTOBER 1983

Trebor R&D

Application Description

Colchester is the most modern Trebor factory. Built in 1981 it utilises microprocessor controlled continuous process plant in the manufacture of three high volume lines; "Trebor Mints", "Refreshers" and "Extra Strong Mints".

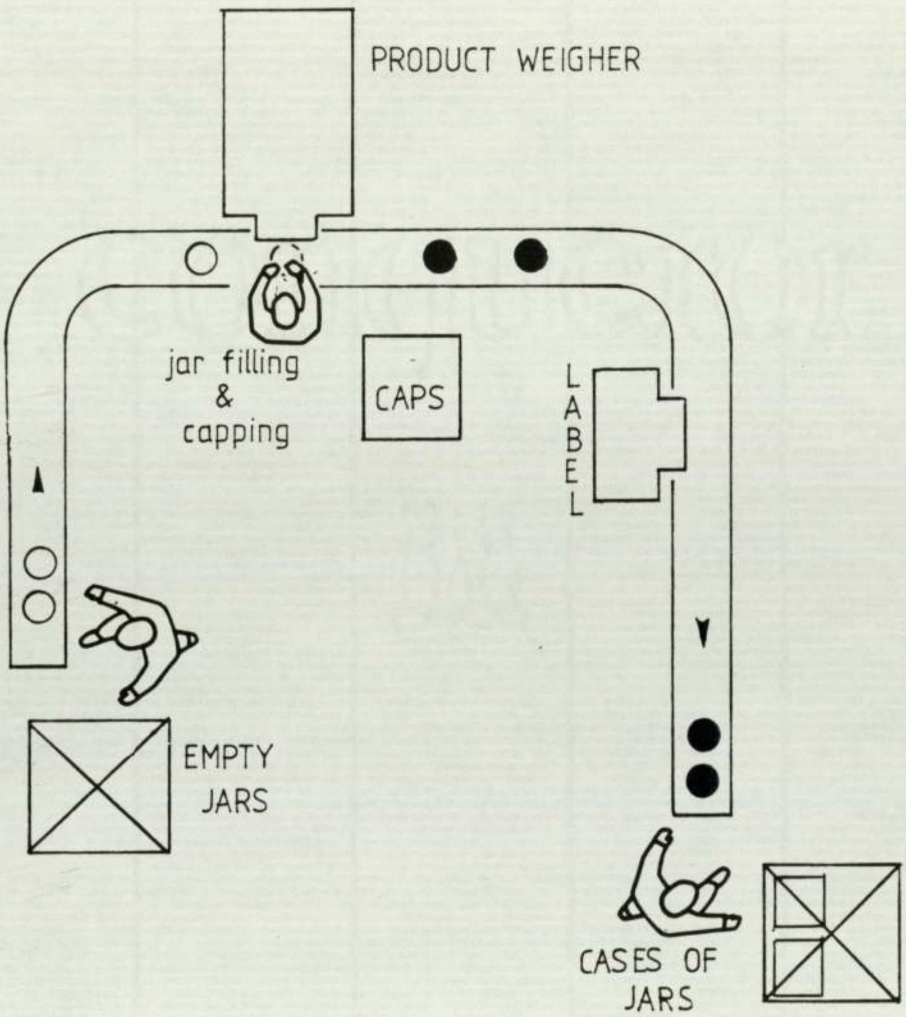
"Extra Strong Mints" (ESM) produced at Colchester are packed in one of three ways; rolls, bags and jars. Jar ESM production is a low volume line. As such, conventional packaging machinery is used which is labour intensive.

The third operation in the jar packing process is the capping of the 2.25 kg plastic jar by hand, which causes a significant quality problem. The capping operation is repetitive and tedious. As a result the operator does not produce correctly closed jars consistently which leads to product damage during distribution. Also, a cap which is not fitted correctly can be removed and replaced without breaking the seal, permitting any violation of the product to go undetected. Product violation is becoming a very serious problem for the food industry generally.

Conventional capping machines are not suitable for this process as they would require modifications to the jar and cap manufacture at prohibitive cost.

Present Method of Operation

The existing jar packing process at Colchester is shown below.



3.1 Proposed Method

To cap the jars using a DAINICHI-SYKES DAROS PT300H robot operating within a work cell. (see drawing RD 616 enclosed).

The work cell consists of:

- robot
- cap feeding unit
- cap orientation device
- jar location unit
- jar conveyor

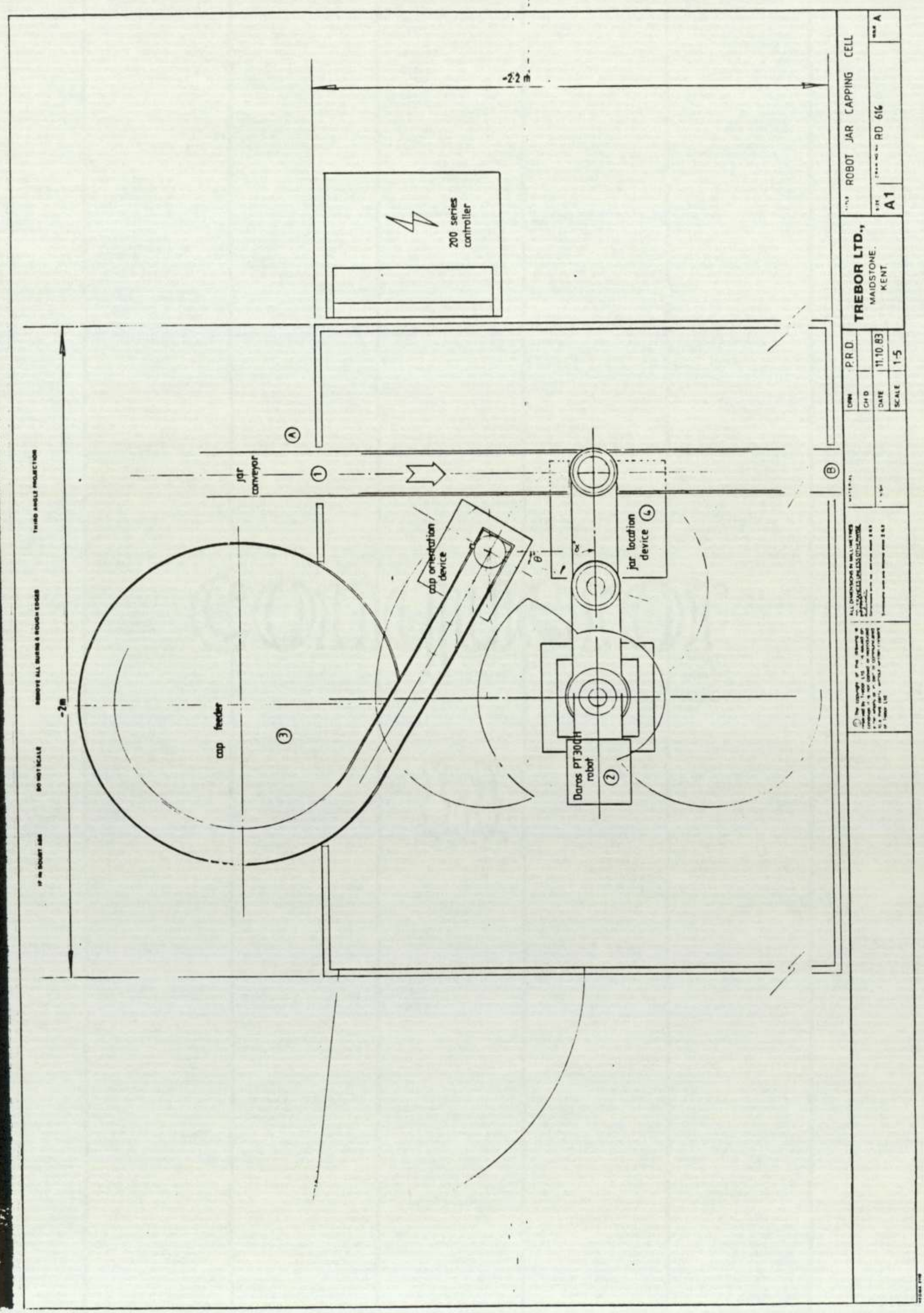
The PT300H robot was chosen for this project for the following reasons:

a) Configuration, operational capabilities and construction of the robot arm.

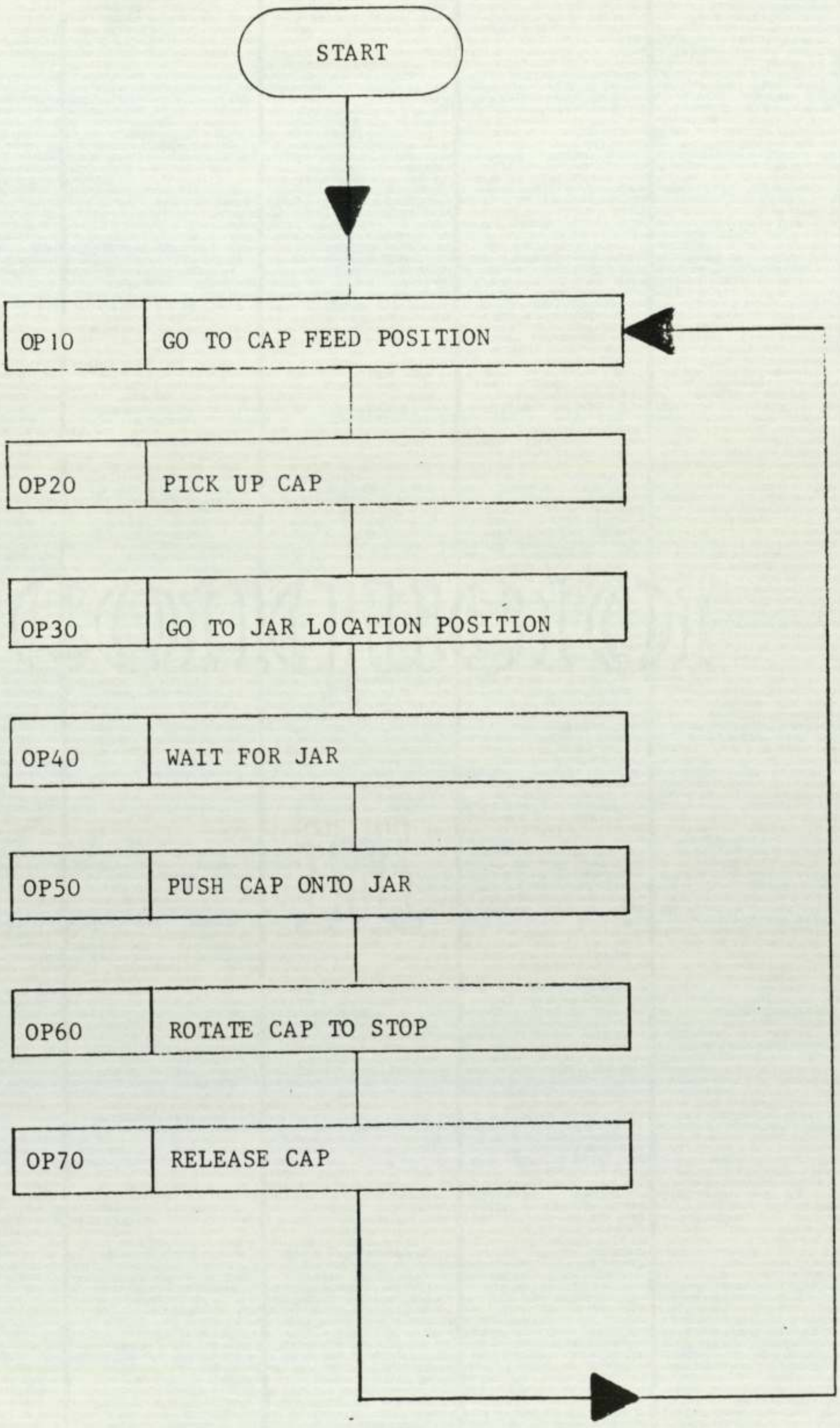
b) Expertise and resources of Dainichi Sykes.

c) Price

d) Control system


ROBOT JAR CAPPING CELL
TREBOR LTD.,
MAIDSTONE.
KENT
P.R.D.
11.10.83
1:5
A1
RD 616
200 series controller
jar conveyor
cap feeder
cap orientation device
jar location device
Daros PT 300H robot
~2·2 m
~2m

ROBOT CYCLE:


START
OP10
GO TO CAP FEED POSITION
OP20
PICK UP CAP
OP30
GO TO JAR LOCATION POSITION
OP40
WAIT FOR JAR
OP50
PUSH CAP ONTO JAR
OP60
ROTATE CAP TO STOP
OP70
RELEASE CAP

CAPITAL/PROJECT REQUISITION

PROJECT TITLE: ROBOTIC JAR CAPPING — 13.2.84

PROJECT NO: R & D 2/84 — **ACCOUNT NO:** 1476664

DESCRIPTION: AUTOMATED WORK-CELL FOR CAPPING E.S.M. JARS, COMPRISING AN INDUSTRIAL ROBOT AND ASSOCIATED TOOLING, CONVEYOR AND FEEDING DEVICES.

ANTICIPATED LIFE: 10 yrs.

ESTIMATED COST:

Outside Purchases:	£39,513	Minus Grant £29,754
Contract Labour	NONE	(Note 1 over)
TS Labour	£ 7,157	TOTAL £16,916
COST	£46,670	

JUSTIFICATION: — Anticipated savings £ p.a.

(Calculations and additional information may be shown over, or attached).

Plant additions
Reduced material
Reduced labour
Reduced fuel
Reduced maintenance
Space savings
Other overheads (specify)
Increased output

Improved customer service
Improved quality (evaluate)
Improved employee facilities
Greater safety

a) Resolves jar/cap sealing problem - improving product quality and reducing damage during distribution.
b) Eliminates manual capping task - labour saving : £9,204 and replaces unpleasant repetitive work (Note 2).
c) Demonstrates the use of a robot in production and the potential for further use of robot technology within the company.
d) Allows development of in-house experience in robot systems engineering.

TOTAL £ 9,204

Pay back equivalent to 1.8 years

Savings to be audited in 5 years.

	MFD	SJG	RWC		FWR	IRM
Initials						
Date						

Robotic Jar Capping System R & D 2/84

ESTIMATED COSTS BREAKDOWN

	£ 000.00
Outside purchases	
1. PT300H robot & controller modified to IP55 standard	22,013
2. 3m conveyor	2,500
3. Bowl feeder	2,500
4. Cap supply hopper & elevator	3,500
5. Cell safeguarding	3,000
6. Robot tooling manufacture	2,500
7. Jar locating fixtures manufacture	1,500
8. Bowl outfeed manufacture	300
9. Control system interfaces	1,000
10. Robot & feeder, plinth manufacture	700
Sub total outside purchases	39,513
Trebor Labour	
11. System design	1,000
12. Jar locating fixtures design	500
13. Bowl outfeed design	100
14. Programmes	600
15. Control system design	600
16. Robot tooling design	1,100
17. Robot & feeder, plinth design	300
18. Training XX personnel	500
19. System assembly	2,457
Sub total labour cost	7,157
TOTAL COST	46,670

PRD
20.2.84

1.DESIGN & SPECIFICATION

1.1. overall system method & layout

1.2. cap feeder

1.3. cap orientation

1.4. jar location

1.5. process modifications xx

1.6. safeguarding

1.7. end of arm tooling

DESIGN FROZEN SPECIFICATIONS AGREED

2. DEVELOPMENT

2.1. test robot

2.2. cap feeding and orientation

2.3. jar location

2.4. xx process modification

2.5. safeguarding

2.6. end of arm tooling

INDIVIDUAL UNITS OPERATIONAL

3. CONSTRUCTION & TEST

3.1. system wiring

3.2. programming

3.3. debug and test

3.4. operator/technician training

SYSTEM OPERATION AT R & D

4. INSTALLATION

4.1. prepare production area

4.2. dismantle & transport to site

4.3. construct on site

SYSTEM INSTALLED AND RUNNING AT XX

5.COMMISSIONING

5.1. Commission

SYSTEM TAKEN OVER BY PRODUCTION

6. RUN-UP

6.1. training

6.2. operation

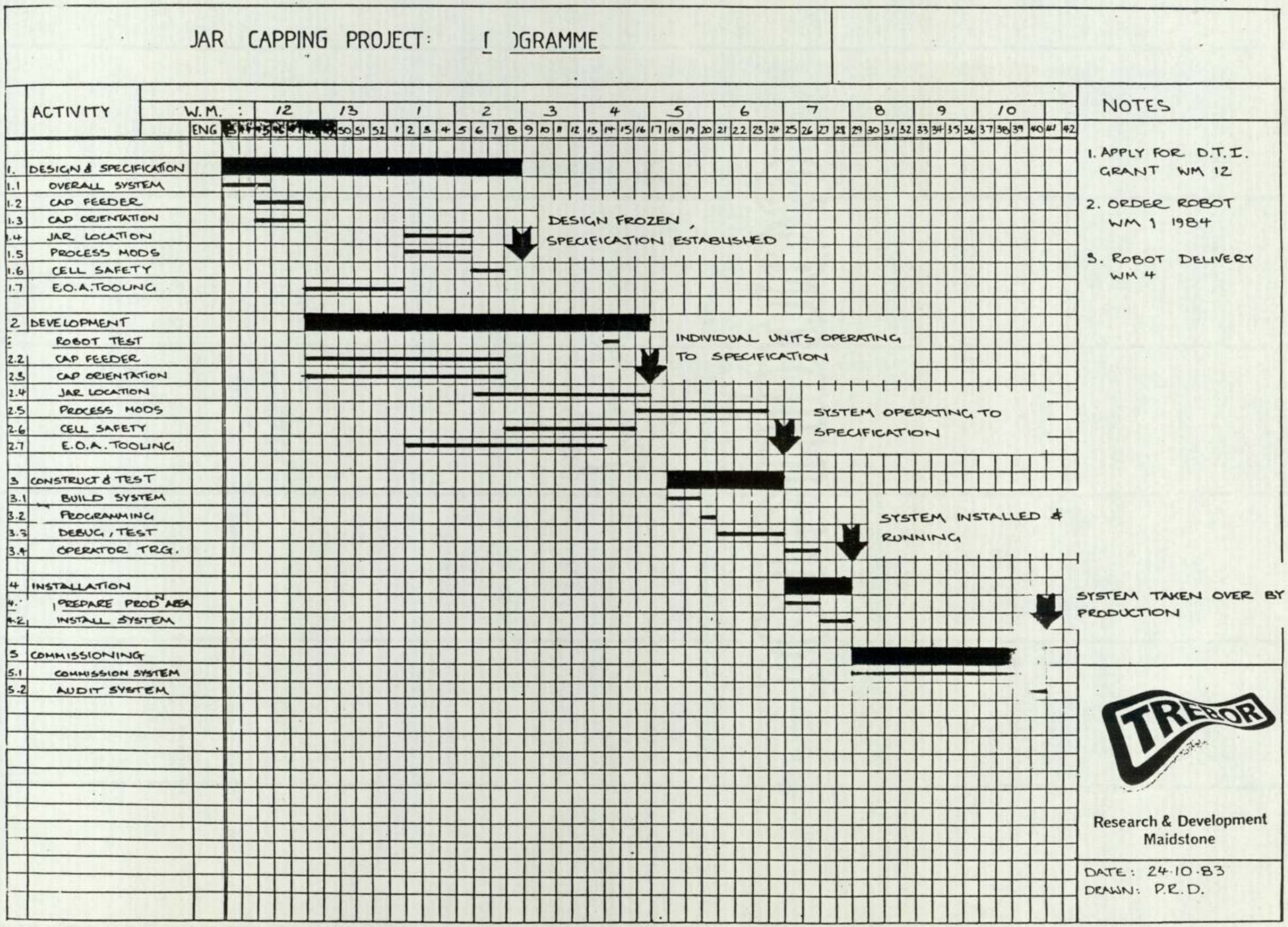
SYSTEM RUNNING TO SPECIFICATION

7. AUDIT

7.1. review project

7.2. feed back results

PROJECT COMPLETE


JAR CAPPING PROJECT: [ )GRAMME
ACTIVITY
W.M.: 12 13 1 2 3 4 5 6 7 8 9 10
ENG
NOTES
1. APPLY FOR D.T.I. GRANT WM 12
2. ORDER ROBOT WM 1 1984
3. ROBOT DELIVERY WM 4
1. DESIGN & SPECIFICATION
1.1 OVERALL SYSTEM
1.2 CAP FEEDER
1.3 CAP ORIENTATION
1.4 JAR LOCATION
1.5 PROCESS MODS
1.6 CELL SAFETY
1.7 E.O.A. TOOLING
DESIGN FROZEN, SPECIFICATION ESTABLISHED
2 DEVELOPMENT
ROBOT TEST
2.2 CAP FEEDER
2.3 CAP ORIENTATION
2.4 JAR LOCATION
2.5 PROCESS MODS
2.6 CELL SAFETY
2.7 E.O.A. TOOLING
INDIVIDUAL UNITS OPERATING TO SPECIFICATION
SYSTEM OPERATING TO SPECIFICATION
3 CONSTRUCT & TEST
3.1 BUILD SYSTEM
3.2 PROGRAMMING
3.3 DEBUG, TEST
3.4 OPERATOR TRG.
SYSTEM INSTALLED & RUNNING
4 INSTALLATION
4.1 PREPARE PRODN AREA
4.2 INSTALL SYSTEM
SYSTEM TAKEN OVER BY PRODUCTION
5 COMMISSIONING
5.1 COMMISSION SYSTEM
5.2 AUDIT SYSTEM
TREBOR
Research & Development
Maidstone
DATE: 24.10.83
DRAWN: P.R.D.

JAR CAPPING ROBOT CELL

PROJECT SPECIFICATION (THIRD DRAFT)

Ref-drawing No. RD628
-safeguarding specification
8.12.83

1. AIM OF PROJECT

To cap filled jars of ESM automatically.

2. PRINCIPLE OF OPERATION

Filled jars are transported by conveyor (1) from the weighing unit into the capping cell. An electric drive industrial robot (2) picks a cap from the feeding device (3) and fits it onto the jar held by the location unit (4). The jars pass out of the cell by conveyor to the labelling and packing area.

3. LIMITS OF PROJECT

3.1 The capping cell will be supplied as a unit to include robot, cap feeding unit, guarding, jar location unit and jar conveyors within the work cell. Limits of conveyor to be agreed.

3.2 The project includes the design, development, construction and programming of the cell, its installation and commissioning, and operator and maintenance technician training.

3.3. Following commisioning of the cell and successful completion of all trials, responsibility for the system will be taken over by XX factory. Target date for handover and commissioning period to be agreed.

3.4 All systems and procedures to be thoroughly documented.

4. DESIGN PARAMETERS

4.1 Maximum line production rate; 8 jars per minute.

4.2 Floor area, process layout and location to be agreed.

4.3 Equipment other than robot arm to be protected to IP55 standard. Robot arm specification to be agreed.

4.4. Safety system as per specification 8.12.83 ref drawing No.RD628.

4.5 Noise limit of 85 db.

4.6 Cap specification as per Johnson & Jorgensen drawing No.B18500.

4.7 Jar specification to be agreed with production division.

5. <u>CELL OPERATION-NORMAL RUNNING</u>

5.1 Jars transported up to and from cell conveyor in-line, parallel to direction of travel.

5.2 Caps loaded into bowl feeder by hand.

5.3 Jar is correctly capped when tear strip surface is fully pressed down on sealing ring and threads are engaged.

6. <u>CELL OPERATION-FAULT CONDITIONS</u>

6.1 Detection of the following fault conditions is included in the project specification:

	FAULT	ACTION
6.1.1	Power failure,electric or pneumatic	Operator signal
6.1.2.	Safety interlock tripped	System stop,operator signal
6.1.3.	Emergency stop	- " -
6.1.4.	Low on caps	Operator signal
6.1.5.	Conveyor stops	Robot waits
6.1.6.	Backlog of jars into cell from take off side	- " -
6.1.7.	Jar not in correct orientation on conveyor or over filled.	Passes through cell uncapped.

6.2 Detection of the following fault conditions is <u>NOT</u> included in the project specification:

6.2.1. Jars filled over or under weight.

6.2.2. Jars not manufactured to spcification.

6.2.3. Caps not manufactured to specification.

7. <u>MANUAL OPERATION DURING CELL SHUTDOWN</u>

Manual capping of the jars during cell failure or maintenance will be done outside the robot cell area.Provision for this to be made in ESM jar process layout.

PRD

8.12.83

c.c. AC. AG. BG. GG. JL. GR.

ROBOT JAR CAPPING CELL

SAFEGUARDING SPECIFICATION

1. The cell to be surrounded by a fixed guard barrier to a height of 2m.

2. Access to the cell to be via a gate interlocked to robot auto-cycle mode.

3. Robot working area to be marked on the floor by hatched yellow lines.

4. Warning signs on gate and guarding station "unauthorised access is not permitted".

5. Emergency stop switches provided at robot control, inside and outside of guard barrier.

6. Robot cell to be considered as a "permit to work area".

7. Guarding to be not less than 1m from any danger area.

PROCEDURES FOR ENTRY

A) General access

1. Operate power isolator.

2. Fit prsonal danger tag to power isolator and lock off.

3. Open interlocked gate. Lock open.

4. On completion, return to original condition and remove danger tag.

B). Emergency access.

1. Operate emergency stop power isolator.

2. Open interlocked gate.

C) Fault diagnosis, maintenance and programming.

1. Select reduced speed or programming mode.

2. As 1 - 4 in 'general access'.

PRD.
8.12.83

Robot Jar Capping Project

ROBOT END-OF-ARM-TOOL SPECIFICATION

1.0 General

Design should minimise size, weight, workpiece damage and cost whilst maintaining reliability and rigidity.

2.0 Task

i) grasp cap at vibratory bowl outfeed.
ii) orientate cap/jar thread.
iii) place cap onto jar, locate against sealing ring (MM jar)
iv) turn to seal.
v) release.

3.0 Design Parameters

3.1 Weight of tool less than 3Kg.

3.2 Operating times:

grasp cap less than 1s
orientate - - 3s
place/locate, seal, release } - 3s

3.3 Jar neck must be supported during capping to prevent distortion.

3.4 Tool must operate on both jar types MM & CC.

3.5 Tool mounting as per PT300H spec.

3.6 Cap outfeed from vibratory bowl: located at end of gravity feed shute, open side down.

3.7 All components to food quality standard, protected to IP55.

3.8 Robot control computer I/O allocated to EOAT, 24V rating: 3 outputs, 2 inputs.

3.9 Services available- Air supply 8 bar.
110V A.C.
24V D.C.

PRD 31.1.84

SYSTEM DESCRIPTION

These notes are taken from the robot cell maintenance manual.

A GUIDED TOUR

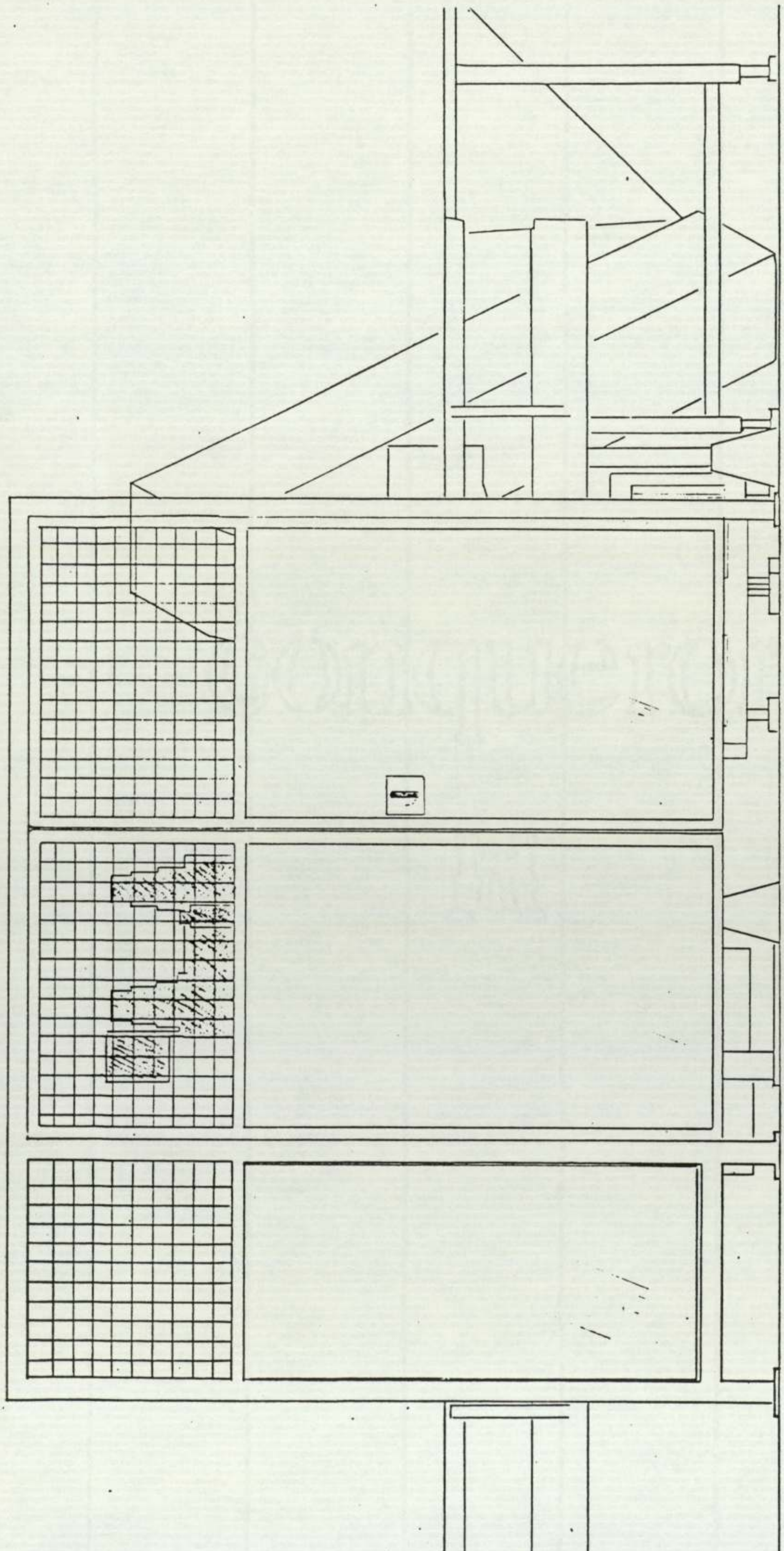
The robot cell is the second station of the ESM jar line. Jars of mints are carried by conveyor from the weigher into the robot cell.

The robot and other equipment are surrounded by safety guarding - see drawing 1.
The guarding has doors on each side for access. These are safety interlocked to the robot, causing an automatic emergency stop when opened.

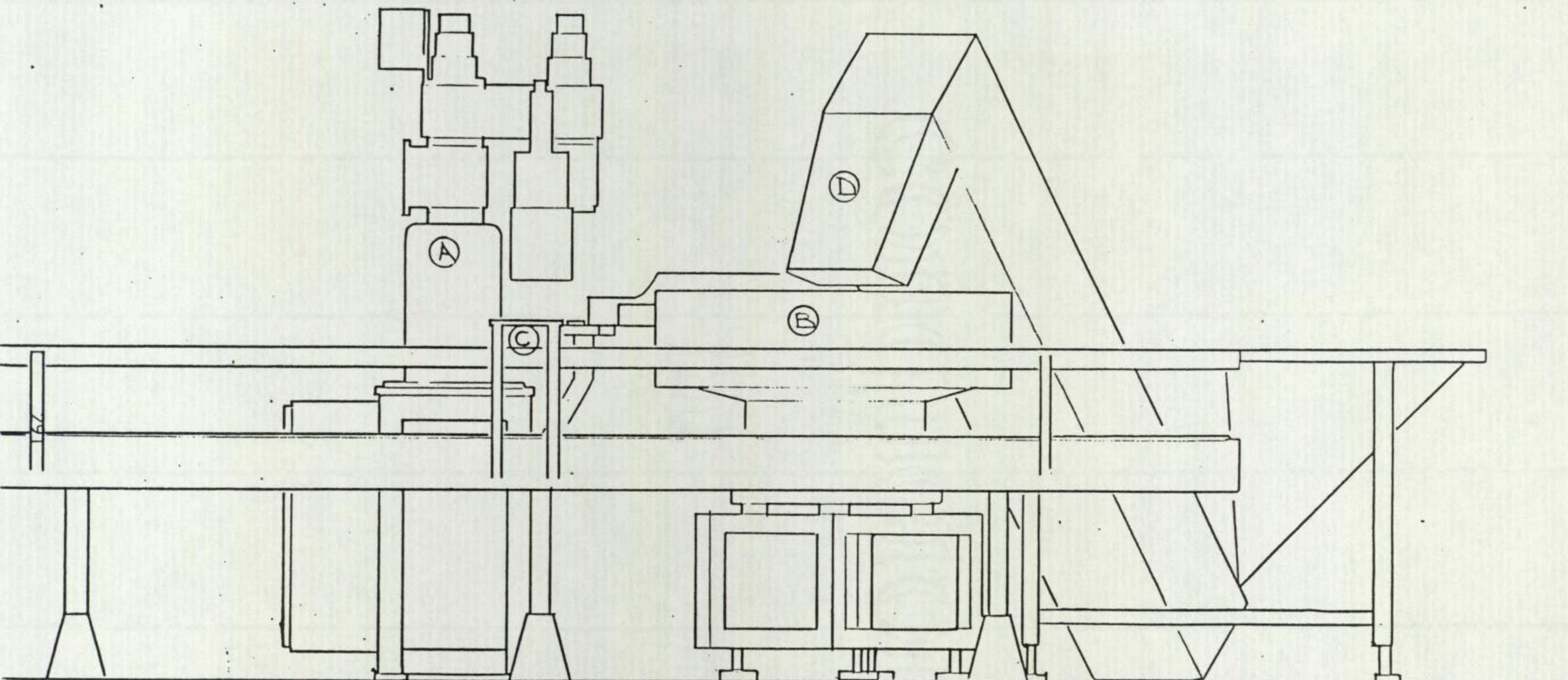
The cell is operated by means of the orange control cabinet.

When you open the cell access doors you will find (see drawing 2).

- (A) - the robot
- (B) - the vibratory bowl feeder
- (C) - the jar gates
- (D) - the cap hopper elevator



DRAWING 1



DRAWING 2

HOW THE CELL WORKS

Two or three boxes of caps are loaded into the hopper.

Caps are automatically fed to the vibratory bowl feeder which sorts them out and turns them the right way up ready for the robot.

The robot picks up one cap at a time from the bowl outfeed and turns it the right way round to align the screw threads.

When a jar is carried into the cell on the conveyor, the jar gates hold it still. Sensors beside the conveyor detect the position of the jar and signal the robot to push the cap on. After twisting the cap, the jar is let go and passes out of the cell.

The cycle then starts again.

B 2

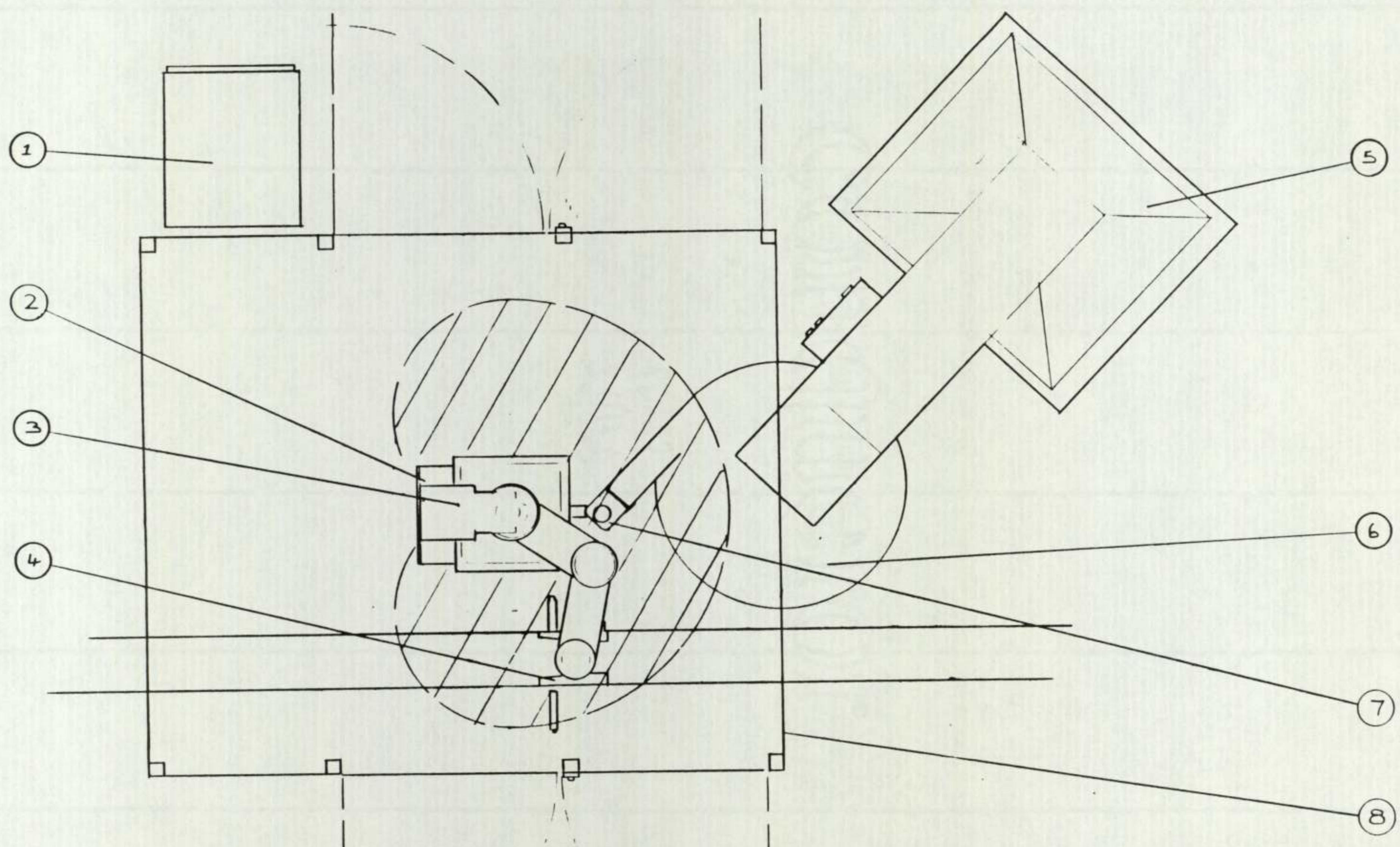
Mechanical (RD 706)

The robot cell consists of a number of principle mechanical devices controlled by the robot controller (1) via the controls interface (2).

The principle mechanical parts are:

PT 300H robot arm (3)	- refer to section:	E
Robot gripper assembly	- - " - :	D
Jar Location fixtures(4)	- - " - :	D
Cap elevator (5)	- - " - :	D
Vibratory bowl feeder(6)	- - " - :	F
Cap location assembly(7)	- - " - :	F
Safety cell (8)	- - " - :	G

IF IN DOUBT: ASK   DO NOT SCALE   REMOVE ALL BURRS & ROUGH EDGES   THIRD ANGLE PROJECTION



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			CH'D	TITLE: ROBOT CELL LAYOUT
		FINISH	DATE: 22.1.85	SIZE: A2 DRAWING No: RD 706 ISSUE
			SCALE: 1:10	

Electrical (RD 665D)

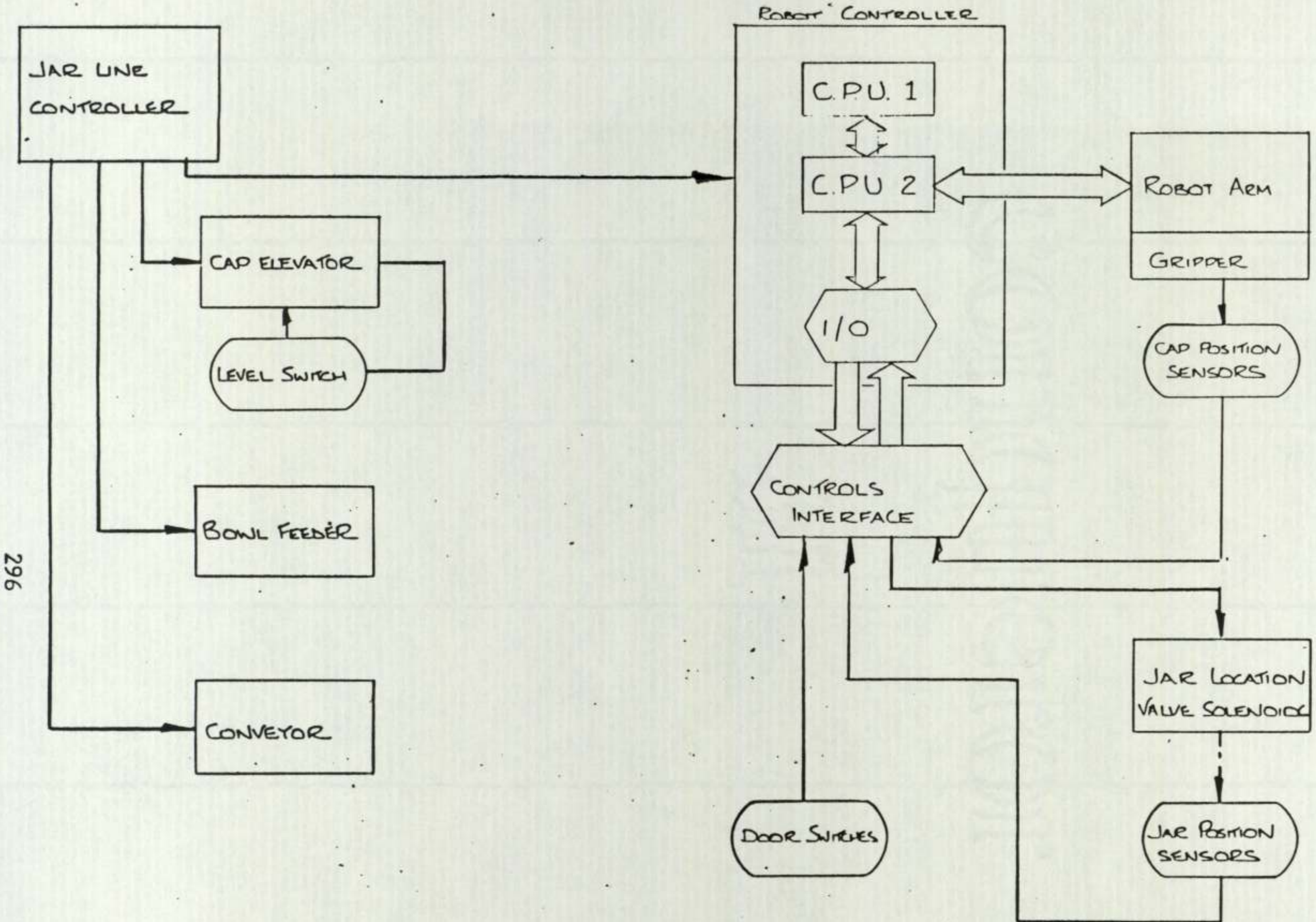
The jar capping cell is controlled by the F200D robot controller situated outside the guarded area, apart from the conveyor, cap elevator and bowl feeder which are operated by the central jar line controller.

The robot arm and gripper are controlled directly via CPU2 board to carry out the pre-recorded programme held in RAM backed up on data cassette.

The other external mechanical devices are controlled via the I/O board and the controls interface. All sensor feedback is also fed to the controller via the interface and I/O.

The principle electrical parts are:

F200D robot controller	-	refer to section:	F
Controls interface	-	- " -	: C
PT300H robot arm	-	- " -	: E
Cap sensors	-	- " -	: C
Jar location	-	- " -	: C
Safety cell	-	- " -	: C



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			CH'D	—		
		FINISH	DATE	AUG '84		SIZE A3 · DRAWING No RD 665 · ISSUE D
			SCALE	—		

REGMA 1681

PROJECT AUDIT

The project was audited in April 1985 by external accountants. For the purposes of the grant application development costs included indirect overheads not normally allocated to individual projects.

Analysis of expenditure on Stage A robotic jar capping cell during the period 13 February 1984 to 1 April 1985.

DEVELOPMENT COSTS - COLCHESTER FACTORY

Line Operators — 60 on day shift, 34 on evening shift — Labour rate (note a) £3.55 / hr.

			£
Presentations Dec '83	2 hrs	60 operators	426
Work Group Meetings	1 hr	94 opr.	333
Commissioning	8 hrs	3 opr.	85
Training	1 hr	94 opr.	333
			1177

Factory Engineers — Labour rate (note B) £16.10 / hr.

Commissioning	30 hrs	2 engrs.	966
Training	24 hrs	6 engrs.	2318
			3284

Line Manager — Labour rate (note B) £16.10 / hr.

System development	35 hrs	563

DEVELOPMENT COSTS - MAIDSTONE R & D Dept.

Development Engineers — Labour rate (note B) £16.10 / hr.

System engineering, installation and training	2207 hrs	35,532

Development Fitter — Labour rate (note c) £4.43 / hr.

System construction	807 hrs	3,575
Training course		225
		3,800

TOTAL DEVELOPMENT COSTS 44,356

	£
Daros PT300H robot	17,900
Modifications to robot	4,950
Cap feeding unit	1,670
Jar conveyor	1,590
Cell guarding	3,700
Cap supply hopper	1,700
Tooling : gripper	1,637
fixtures	1,087
cap orientation	1,737
	35,971

	£
TOTAL COST, CAPITAL AND DEVELOPMENT	80,327
Grant of ⅓rd total cost	26,775.

Notes

a) Colchester factory direct labour overhead is £3.55 per hour of which £2.79 is basic pay.

b) Development Engineers etc. are not normally costed at an hourly rate. R&D overheads over the year, allocated by number of staff gives an overhead rate of £16.10 per hour per person. This rate has been used as the basis for costing all engineering and management time involved in the project.

c) Hourly rate for the Development Fitter has been derived from basic net hourly pay plus 15% uplift for pension and insurance and £1.5 k p.a. uplift for general overheads.

Net hourly	:	£3.169 / hr
+ 15%	:	£ .475 / hr
+ £1.5 k pa	:	.78p / hr
Total		£4.43 / hr.

APPENDIX E

Appendix E

This appendix contains a diary of the robotics project which summarises the key points relevant to each stage in the implementation process.

Data from the diary is analysed in chapter four.

The method followed in the Trebor project (figure E.1) comprised fifteen main stages. Data relevant to each of these stages is summarised in abbreviated form on one page in the diary under the headings of: work carried out, milestone events, project environment and researcher's personal view. The first two headings are used to describe the more objective issues: what was done and the decisions taken. The latter two are used to report upon the less-objective influences.

The diary provided a means by which an overall view of the complete implementation process could be gained and allowed the interaction between the various parallel dimensions of the problem to be studied. This led to the identification of four sub-processes of robot adoption: engineering, technology transfer, learning and entrepreneurial processes.

Points relevant to each sub-process are highlighted in the diary by means of suffixes thus:

E - engineering process

T - technology transfer process

L - learning process

N - entrepreneurial process

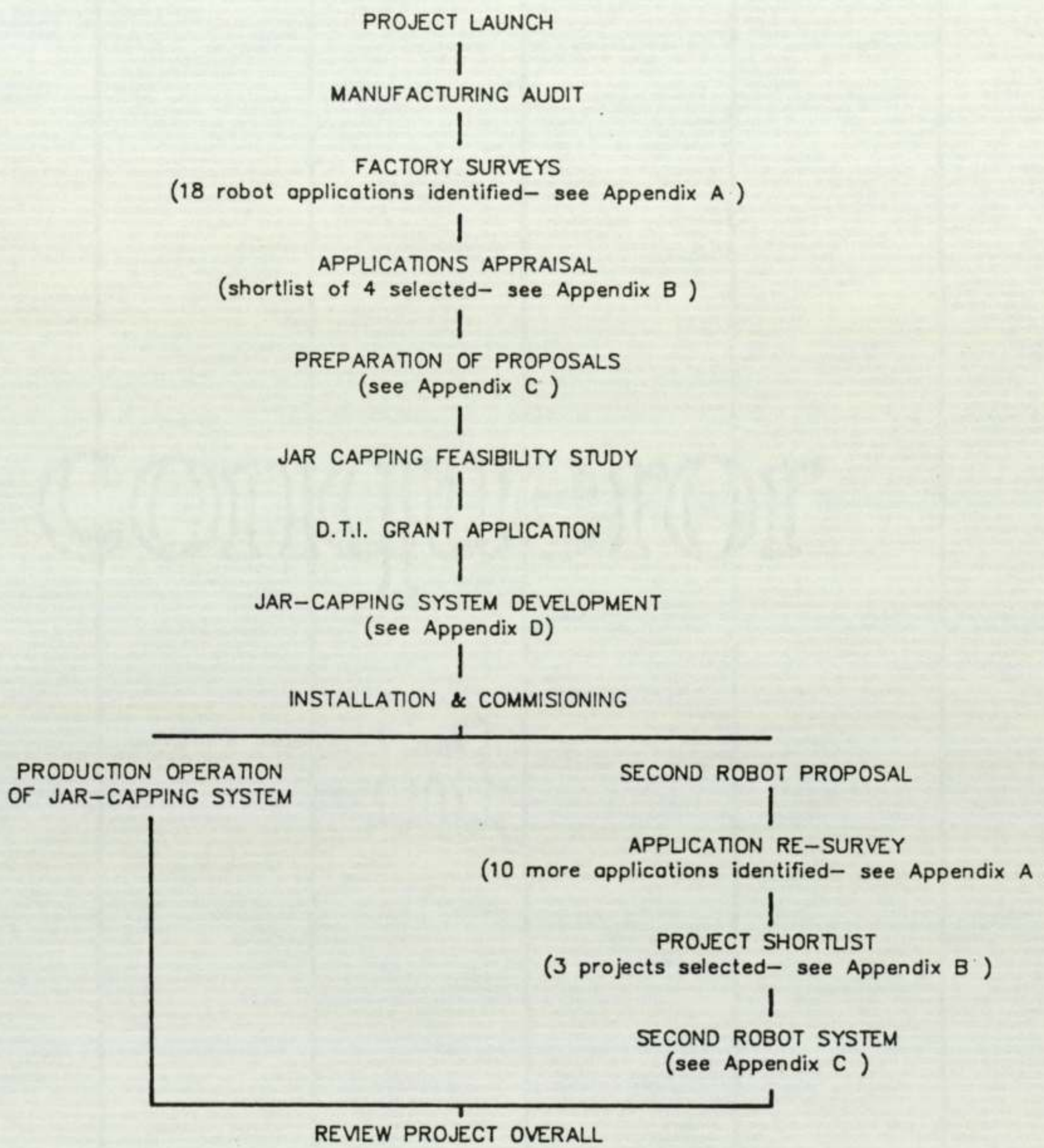

Figure E.1 The Trebor Robot Project; Outline Method

1. PROJECT LAUNCH: September 1982

Work Carried Out:

Established joint IHD - Trebor team.

Set project objectives, emphasising implementation of existing technology rather than special-purpose development[E]. Planned project in outline [E].

Milestone Events:

Development Engineer/IHD student joined Trebor[T].

Departure from Company of Technical Director[N].

Setting of project obectives.

Project Environment:

In Technical:	Reorganisation and uncertainty after loss of Technical Director - loss of confidence.
In Production:	Relief at removal of restrictions imposed by Technical Director - anti R & D back-lash. Recent introduction of microprocessor technology to process control.

Researcher's Personal View:

Concerned over loss of influence caused by departure of main project sponsor, uncertainty over work ahead.

Great interest and commitment to the project.

Aware of being a 'new-boy' and of the undercurrents between Technical and Production but could not put them into context.

2. MANUFACTURING AUDIT: October - November 1982

Work Carried Out:

Three day visit to each of the three Trebor factories to gain a familiarisation with the technologies, policies and procedures used[EL]. Contacted robot suppliers,[T] carried out desk survey of current state-of-the-art in industrial robot systems[E]. Reviewed literature on robot applications-engineering, food industry, packaging[E].

Milestone Events:

Defined the problems to be solved and previous work in the field.

Established contacts within robotics community[T].

Project Environment:

In Production: Some uneasiness over this "whizz kid poking his nose about".

Disbelief that robots were at all relevant to Trebor's problems[L].

Researcher's Personal View:

Surprised at the contrast between the new Colchester factory and the Chesterfield and Maidstone factories which had a much lower level of manufacturing technology and quite dated process plant. Aware of some hostility from Production people, feeling of isolation and the need to establish my credibility and get established. Wanted to shake loose of any close supervision and gain autonomy for running the project. The difference between Trebor and my previous company was a strong cultural shock, Trebor seemed to be more open, less urgent and less 'aggressive'. Was impressed by Trebor's philosophy that "people matter".

3. FACTORY SURVEYS: January - February 1983.

Work Carried Out:

Study of each manufacturing process to identify feasible applications for industrial robots. Establish current problem areas/needs[E].

Collection of data on potential projects[E].

Preparation of report summarising results[L].

Milestone Events:

Presentation of results at production management meeting [L] - commitment to implementation of first application. Agreed method for selecting best application.

Project Environment:

Increasing interest and commitment to the idea of using robots[L].

Emphasis on proving the technology - economics and innovation secondary. Must be totally reliable and be seen to be effective - Company had lost some confidence in its ability to innovate successfully after previous projects. Status of Technical had been reduced, no longer able to push through projects - no cohesion to follow a technical policy.

Researcher's Personal View:

Believed that progress was being made, that resistance was reducing slowly; enthusiastic at the wide potential for robots identified - getting high level backing for the project. Realised Production Director was not very committed to project. Growing understanding of Trebor culture. More comfortable with the lower level of supervision which gave increased motivation.

4. APPLICATIONS APPRAISAL: April - June 1983.

Work Carried out:

Review of appraisal techniques[E].

Meetings with each factory management team to discuss the applications identified and to agree a ranking of preferred projects[N].

Milestone Events:

Agreed shortlist of three projects to be further studied.

Project Environment:

Greater resistance to proposals at factory management meetings - doubt whether technology would work - be reliable, strong objections were raised. Questioned the need for someone to be working on robots full time.

There was little commitment to overcoming problems associated with the applications proposed.

Researcher's Personal View:

Growing awareness of the significant obstacles to projects, and the importance of non-technical issues. Project slowing down, coming up against resistance and don't clearly understand why.

5. PREPARATION OF PROPOSALS: August - September 1983

Work Carried Out:

Agreed specifications for shortlisted projects[E].

Designed solutions to the shortlist of three projects. Worked closely with robot system suppliers, particularly Asea, Dainichi, Cincinnati - who were very committed at this time[T].

Costed designs and prepared proposals[E].

Repeated redesign/re-costing after specification changes/objections[N].

Negotiation over project proposals and design changes.

Milestone Events:

None

Project Environment:

Accepted idea - but doubted effectiveness. Factory management teams not impressed by proposals, objections were raised and specifications changed which required redesigns.

Researcher's Personal View:

Felt project was slowing down, need to 'harden-up' approach; looking for ways to convince and persuade. Objections to proposals appeared to be delaying tactics; growing frustration at being given the run-around.

University team put situation into context - recharged batteries and suggested new ways to get over problems - pointed out the legitimacy of Production's point of view.

6. JAR CAPPING FEASIBILITY STUDY: September 1983

Work Carried Out:

Liaison with Dainichi-Sykes on feasibility trials [ET].

Preparation of project specification, jointly with XX* project team [N].

Demonstration of system at Dainichi.

Milestone Events:

Oct '83 high point of XX commitment, first realisation of the jar cap/neck problem.

Project Environment:

Demonstration improved XX Engineer's commitment.

Factory managers needed to know that the Production Director was in agreement and committed.

Robot company wanted contact wth higher level people or wouldn't do any more work.

Factory Development Engineering Manager very enthusiastic. Production Director just not interested.

Researcher's Personal View:

Lack of commitment to the project from top management. Strong need to get a decision on the first application as time was pressing. Seemed that little progress had been made during the Summer - "pushing water uphill".

* XX - Colchester factory
CC - Chesterfield factory
MM - Maidstone factory

7. D.T.I. GRANT APPLICATION: October - February 1983/84

Work Carried Out:

Attended seminar - emphasis on ease of obtaining government grant[T]. Outline design of system[E]. Preparation of grant application.

Negotiation with D.T.I. representative. Collaborated on undergraduate design project to design robot gripper[T].

Presentation to Production 2 workforce at Colchester[N].

Robot company helped in preparing D.T.I. application and chasing it up[T].

University gave good input to DTI application.

Milestone Events:

Decided to implement jar capping project.

Established project team - decision to do project in-house[N].

Receipt of grant offer.

Project Environment:

XX factory management committed to project, although not to it being done by Technical, preferred using an outside supplier.

Technical people not sure capping project was much of a step forward.

D.T.I. thought Trebor wasn't doing enough - "v.conservative management."

Researcher's Personal View:

Very protective of the project - very wary of other engineers getting in on the act and taking over. Felt I was selling company to the Government - persuade them to go ahead. Needed a Technical Director at this stage to provide credibility for the project both inside and outside the company, but greatly appreciated the experience that the lack of one gave me. Boosted by the decision to go ahead - very positive and enthusiastic.

8. DEVELOP JAR CAPPING SYSTEM: March - September 1984

Work Carried Out:

Investigation of problem^{E}.

Development of trial solutions^{E}.

Meetings with Colchester workgroups^{L}.

Construction of system in the lab^{E}.

Testing and pre-installation commissioning^{E}.

Milestone Events:

Dropping of automatic jar filling project from jar-line and cut back on project budget.

Project Environment:

Colchester engineers hard pressed for resource - jar line was now low priority, led to it falling behind schedule.

Increasing animosity as the project fell further behind.

Operators were highly enthusiastic.

Researcher's Personal View:

Pleased robotics project was back on track.

Believed I was losing my marginal status - too integrated within the company to be able to take overall view, and not operating at a high enough level often enough to know what's going on with respect to long term plans, concentrating too much on technical work. The commitment of the Colchester operators to the project was a great morale boost.

9. INSTALL AND COMMISSION September - October 1984

Work Carried Out:

Installed robot cell (without rest of the jar line)[E].

Commissioned system[E].

Trained operators[L].

Worked with robot suppliers on 2nd robot design[T].

Milestone Events:

Robot cell completed.

Decision to delay transfer of jar production from Maidstone.

Transfer of Development Engineer to Maidstone.

Project Environment:

Jar line now very low priority at Colchester, and so there was little commitment to robot capping as the problem had 'gone away for a while'.

Researcher's Personal View:

Frustration at the delay over the completion of the jar line. Very keen to install the jar capping robot on time to disprove the earlier doubts that were raised.

10. SECOND ROBOT PROPOSAL: November - December 1984

Work Carried Out:

Preparation of detailed proposal for robot palletising system[N].

Discussion of proposal with new Technical and Production Directors[N].

Milestone Events:

Rejection of proposal by PMM.

Project Environment:

Getting very sticky at XX - openly saying they had other priorities.

Robot company pushing automation partnership approach. First discussion in Technical - seemed a lack of commitment to 2nd robot. Colchester management team felt they were being pushed into having a second robot which caused a high level of animosity.

Researcher's Personal View:

Assumed there was no need to champion robot 2, should be a natural progression - badly misread situation. Appalled at the degree of trouble caused by a failure of communication, in contrast to very little comment over the delayed completion of jar line - disillusioned. Realised that control over the project had been lost, but thought that going to PMM again would be overdoing it. Am running out of fight - where does the drive that has been pushing me so far come from - underestimated the effort and skills needed to get commitment to robot 2.

11.APPLICATION RE-SURVEY: January - February 1985

Work Carried Out:

Resurvey of each factory for possible robot applications[E].

Discussion with factory management teams[N].

Selection of shortlist of projects[N].

Discussion with NPD team - very enthusiastic about the use of robots to provide more interesting products[LN].

Milestone Events:

The best projects identified.

Project Environment:

Colchester: no commitment to 2nd robot - no progress on jar line.

Maidstone: very committed to hopper filling project.

Chesterfield: some interest.

Technical: shocked at sudden deterioration of relationship with Colchester, started bridge-building.

Researcher's Personal View

Tired of Company politics, the emphasis on not rocking the boat rather than getting things done. Regarded resurvey as another delaying tactic. Aware of antipathy at Colchester.

12.PROJECT SHORTLIST: February - March 1985

Work Carried Out:

Liaison with robot suppliers, design of systems for shortlisted applications[TE].

Discussion with factory management teams[N].

Presentation of proposals to PMM[N].

Milestone Events:

Decision by PMM to implement hopper loading project at Maidstone.

Project environment:

Maidstone very committed to having the second robot, Chesterfield critical of the large amount of floorspace required by robot palletising system: would rather complete the new Imperials line first rather than include a robot system within the current improvements.

Robot company very disappointed that integrated palletising was dropped.

Researcher's Personal View:

Pleased that decision to do a 2nd robot had been taken.

13. PRODUCTION OPERATION OF JAR CAPPING SYSTEM: April - May 1985

Work Carried Out:

Training of operators[L].

Commissioning completed jar line[EL].

Running complete system[EL].

Training of maintenance fitters[L].

Milestone Events:

Jar line completed

Project Environment:

Operators and maintenance fitters very positive about the system, especially after they had become confident in operating it.

General improvement in atmosphere, comments that the "robot does the job alright."

Researcher's Personal View:

A little surprised at the quite positive attitude after the seven month delay in getting the system running.

14. 2ND ROBOT SYSTEM: April 1985

Work Carried Out:

Set up project team[N].

Agreed detailed specification[E].

Liaison with robot system suppliers for detailed quotations[T].

Redesign to meet specification change[E].

Milestone Events:

Change of production output specification by 100%

Decision to abandon project.

Project Environment

Very postiive commitment to the project from Maidstone team; disappointment at the need to abandon.

Robot suppliers frustrated at 6 months work put in with no result - questioned Trebor's commitment to robots.

Researcher's Personal View:

Very disappointed, but trying to understand what went wrong, why it had been so difficult over the last 8 months to progress from the first robot.

Strong commitment to looking in greater depth at the way Trebor operates, reviewing the whole project to identify the problem areas.

15. REVIEW PROJECT OVERALL: May - June 1985

Work Carried Out:

Review work to date[EN].

Investigated Trebor capital budgeting procedures.

Interviewed key people involved in project.

Presentation of conclusions at production management meeting and recommended action plan[L].

Discussion with robot suppliers[T].

Milestone Events:

None

Project Environment:

Willingness to assist in reviewing project, very open access to information and people.

Positive reaction to conclusions and commitment to act upon recommendations.

Researcher's Personal View:

Process of stepping back and reviewing very useful to gaining perspective - feeling that this should have been done earlier perhaps.

Encouraged at people's positive attitude to the review process, willing to look at the "dirty washing" as well as good points.

Feeling more of an outsider to the company again - different now in that "I can't see the wood for the trees now, but I can find my way through the forest".

APPENDIX F

Appendix F

The capital budgeting procedure used in Trebor was found to have a significant effect upon the robot project.

In order to identify the key influences, Trebor's procedures were compared with industrial norms using Pike's (199) assessment framework and the results of his study of the capital budgeting practices of UK firms.

Thus Trebor's procedure was compared with

a) firms with a capital expenditure budget of less than £5m, and

b) firms manufacturing consumer non-durable products.

The budgeting procedure is analysed in seven areas. Responses in the Trebor column are compared with the percentages for firms of similar size and industry respectively, who responded affirmatively to the question posed. For example, for section 1a - Trebor does not have a capital budget which looks beyond two years whereas 54% of firms of similar size and 82% of firms in the same industry who responded to the survey do.

The results of this analysis are summarised below and discussed in chapter 6.2.

	Trebor	size %	industry%
1. Does your firm have:			
a) a Capital budget which looks beyond 2 years?	N	54	82
b) an up-to-date capital budgeting manual or written procedures	Y	71	82
c) a formal body responsible for screening and reviewing investment proposals?	Y	77	94
d) At least one person engaged full-time in capital budgeting?	N	6	13
e) a regular review of the minimum rate of return required from projects?	N	52	50
2. Does your firm:			
a) reconsider major projects <u>after</u> approval if cost over-runs are likely?	Y	77	73
b) monitor project performance once operational	Y	79	97
c) require post-completion audits on most major projects	N	44	61
3. Does your firm require for major projects:			
a) a specific search and screening of alternatives before accepting projects?	Y		76
b) a formal financial evaluation?	Y		97
c) a formal analysis of risk?	N		30
4. What investment appraisal criteria do you use?			
a) Payback period	Y	79	76
b) Average accounting rate of return	N	45	49
c) Discounting - internal rate of return	Y	30	70
d) Discounting - net present value	N	30	42
e) Other; please specify	N		6
5. What method is used for analysing the riskiness of capital projects?			
a) shortening payback period	N	28	27
b) Raising required return or discount rate	N	22	39
c) Probability analysis	N	56	6
d) Sensitivty analysis	N	15	46
e) Measuring covariance of projects			
f) Other; please specify.			
6. Does your firm use any management science techniques in evaluating or controlling major projects?			
a) Mathematical programming	N		
b) Computer simulation			
c) Decision theory			

	Trebor	size %	industry%
d) Pert/Critical Path			
e) Other; please specify			

7. How do you incorporate inflation in project evaluations?

	Trebor	size %	industry%
a) Not at all		15	8
b) Consider at risk analysis sensitivty stage		9	23
c) Specify cash flows in constant prices and apply a real rate of return		26	44
d) Adjust for estimated changes in general inflation	Y	47	26
e) Specify different rates of inflation for all cost and revenues		17	34
f) Other; please specify			5

APPENDIX G

Appendix G

This appendix contains a summary of the financial appraisals of the nine applications studied in detail during the robot project.

Explanation of the concept of real and equivalent savings and an analysis of the results are provided in chapter 6.3.

	PROJECT/COST BENEFIT		XX007*	XX005B	XX006	CC013	CC016	MM023	MM029	MM031	MM032
	CAPITAL(STANDARD)	£	26,500	90,000	41,000	40,000	55,000	35,000	45,000	28,000	70,000
	CAPITAL (SP.PURPOSE)	£	9,471	59,000	8,000	8,000	18,000	32,500	13,000	4,000	13,000
	DEVELOPMENT	£	3,800	75,000	15,000	15,000	25,000	17,500	20,000	1,500	33,000
COSTS	TOTAL	£	39,771	224,000	64,000	63,000	98,000	85,000	78,000	33,500	113,000
	RATIO CAPITAL: DEVELOPMENT		9.5	2	3.3	3.2	2.9	3.9	2.9	21	2.5
	RATIO STANDARD: SP.PURPOSE		7	1.5	4.3	5	3.1	1.1	3.5	7	5.4
	DIRECT LABOUR	£ p.a	9,200	45,000	7,500	6,500	22,000	6,500	7,500	6,500	22,000
		RATING	7	7	8	4	8	6	6	7	8
	DIRECT MATERIALS	£ p.a			7,500						
		RATING			8						
	TOTAL 'REAL'	SAVINGS	9,200	45,000	15,000	6,500	22,000	6,500	7,500	6,500	22,000
	PAYBACK	YEARS	4.3	5.0	4.3	9.7	4.5	13.1	10.4	5.2	5.1
	SAFETY	RATING	8	4	3	2	2	8	8	8	2
		£ EQ.p.a	10,500	26,000	2,800	3,300	5,500	10,000	10,000	7,400	5,500
	QUALITY	RATING	8	7			2	5	1	8	2
		£ EQ p.a	10,500	45,000			5,500	6,200	1,000	7,400	5,500
	OUTPUT	RATING		7	3				3		4
		£ EQ p.a		45,000	2,800				3,700		11,000
	STOCK	RATING		4							
		£ EQ p.a.		26,000							
	PRODN. FLEXIBILITY	RATING	2	7	7	8	4			2	5
		£ EQ p.a	2,600	45,000	6,500	13,000	11,000			1,900	13,700
	PRODN. INF	RATING		4			2				4
		£ EQ p.a		45,000			5,500				11,000
	EXPERIENCE GAINED	RATING	9			6			6		
		£ EQ p.a.	11,820			9,700			7,500		
SAVINGS	OPERATION	RATING			5				6		
		£ EQ p.a.			4,700				7,500		
	MATERIALS HANDLING	RATING			3		2				
		£ EQ p.a.			2,800		5,00				
	TOTAL EQ. SAVINGS	£ EQ	35,420	232,000	19,600	26,000	33,000	16,200	29,700	16,700	46,700
	RATIO REAL: EQ SAVINGS		0.26	0.19	0.76	0.25	0.66	0.4	0.25	0.39	0.47
	(REAL + EQ)	PAYBACK	0.89	0.8	1.9	1.9	1.8	3.7	2.1	1.44	1.6

* AUDITED FIGURES

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BIBLIOGRAPHY

BIBLIOGRAPHY

Abair, D.W. "Modern Solutions to Old Problems - Palletising with Industrial Robots," Robots V11 Conf. Proc, Detroit, 1983

Abernathy, W.J. and Wayne, K. "Limits of the Learning Curve". Harv.Bus.Rev. Sept - Oct 1974.

Abernathy, W.J. The Productivity Dilemma, Baltimore: The John Hopkins Press, 1978.

Advisory Council for Research & Development. New Opportunities in Manufacturing. The Management of Technology: London HMSO, October 1983.

Alvey Committee A Programme for Advanced Information Technology, London: HMSO, 1984.

Ansoff, H.I.(ed) Business Strategy, Harmondsworth: Penguin Books, 1981.

Arbel, A. Shapira, R. "A 2-phase analytic approach to robotic system design". Robotics and Computer Integrated Manufacturing, Vol.1 No.2, 1984, pp 181-190.

Argote, L, Goodman, P.and Schkade, D. "The Human Side of Robotics, How Workers React to a Robot", Sloan Management Review, Spring 1983, pp.33-41

Argyle, M. The Psychology of Interpersonal Behaviour, Harmondsworth: Penguin Books Ltd., 1979

Arrow, K.J. Social Choice and Individual Values (2nd ed), John Wiley & Sons, 1963.

Asai, K. "Systems Engineering for Applying Industrial Robots to Production Systems." Robot, March 1983, pp 20-25

Avison, G "Playing to Win in the New-Tech Poker Game", The Engineer, 24th May 1984, pp. 23-24

Ayres, R.U. and Miller, S.M. Robotics Applications and Social Implications, Cambridge, Massachusetts: Ballinger Publishing Co., 1983.

Backhouse, M.E. and Hearn, N.H. Robot Gripper Design Project, Undergraduate Dissertation, The University of Aston, Department of Mechanical Engineering, 1984.

Baxter, R. "Students look at Organisational Aspects of FMS", The Production Engineer, November 1984.

Behuniak, J.A. Planning and Implementation of Robot Projects, SME Technical Paper MS80-691, 1980.

Bell, D.A. Employment in the age of drastic change: the future with robots, Abacus Press, 1984

Bell, M. The "Impact of Major New Roads on Agriculture: Legal and Administrative Aspects, PhD thesis, The University of Aston in Birmingham, 1978.

Benson, I and Lloyd, J. New Technology and Industrial Change, London: Kogan Page, 1983

Bessant, J. A Study of Inputs and their Influence on Technological Innovative Activity, Birmingham: The University of Aston in Birmingham, PhD thesis, 1978.

Bessant, J. "Non-technical factors in the introduction of micro electronics in the chemical industry," Chemistry and Industry,(4), September 1982, pp. 623-629.

Bessant, J. "Management and manufacturing innovation: the case of information technology," in Winch,G. (ed.), Information Technology in Manufacturing Processes, London: Rossendale, 1983.

Bessant, J. "Influential factors in manufacturing innovation." Research Policy" 11 (1982), pp. 117-132,

Bessant,J. and Lamming, R. "Making I.T. fit: the design of integrated manufacturing and systems", Design Studies, Vol.5, No.2, April 1984.

"BIM Report", Management Today, April 1984, P.105.

Bjørke, Ø. "Towards integrated manufacturing systems" Robotics and Computer Integrated Manufacturing, (1), (1), 1984, pp. 3-19.

Blackner, J. History of Nottingham, 1815

Blumberg, M. and Gerwin, D. "Coping with advanced manufacturing technology." EIBA Conf. INSEAD, Fontainbleau, Dec 1982.

Bowell, J.C. "How to make CAD/CAM pay", The Production Engineer, November 1984, pp.9-10.

Bowell, J.C. "CAD/CAM - Successful Implementation," Design Engineering Conference, Birmingham, September 1984.

Brady, M. and Paul, R. (eds) Robotics Research, Cambridge, Mass: MIT Press, 1984.

Brady M.,et. al. (eds) Robot Motion: Planning and Control, Cambridge, USA: MIT Press, 1982.

Braverman, H. Labour and Monopoly Capital, Monthly Review Press, 1974

Braun, E. "Constellations for Manufacturing Innovation", Omega, Vol 9 No 3, pp. 247-253, 1981.

British Robot Association Fourth Annual Conference Bedford: IFS, 1981.

British Robot Association Robot Facts, Bedford: IFS, December 1985.

Brown, J.A.C. The Social Psychology of Industry, Harmondsworth: Penguin Books Ltd., 1980

Bruce,M. "Introducing new technologies to the production process: Two Case Studies," Proc.Conf.Human-2, Bedford: IFS, 1984.

Bruce, P. "Robots: Why tomorrow has been delayed", The Financial Times 8th September 1983, p26

Bruno, C. "Labor Relations in the Age of Robotics", Datamation Vol.30 No 3 pp.179-182, March 1984.

Bublick,T. "The justification of an industrial robot", Proc. '77 Finishing conference and Exposition, 1977.

Buchanan, D. and Buddy, D. Organisations in the Computer Age, Aldershot: Gower Publishing, 1983.

Burnett, P. "Spanner in the robot's works", The Times, Sept 5th 1983, p.8.

Burnham, C.M. "Advanced Manufacturing Technology Projects - An Approach to Successful Implementation", International Machine Tool Conference, Birmingham, June 1984.

Burns, T. "Models Images and Myths", in Gruber, W. H. and Marquis, D.G. (eds), Factors in the Transfer of Technology, MIT Press, 1969.

Burns, T. and Stalker,G.M. The Management of Innovation, London: Tavistock, 1961.

Burton P.E.and Read, P. "Robot Applications in BL Cars" ISATA 81 Proceedings 10th Anniversary International Symposium on Automotive Technology and Automation, 37/1-11 Vol. 1981, Stockholm.

Cadbury, A. "Cadbury-Schweppes: More than Chocolate and Tonic", Harvard Bus. Rev., Jan-Feb, 1983, p.p. 134-144.

Carter, C.F.and Williams, B.R. Industry and Technical Progress: Factors Governing the Speed of Application of Science, London: Oxford University Press, 1957.

Cartwright,D. and Bray, D. "Undersealing on a high volume production line", Proc.Inst.Mech.Engs C295/81, 1981.

Centre for the Study of Industrial Innovation. Success and Failure in Industrial Innovation: Project SAPPHO, 1972

Chafee, E.E. "Five Models of Organisational Decision Making", National Center for Higher Education Management systems, 1983.

Chakrabarti, A.K. "Organisation Climate as a Causal Variable in Innovation", India Journal of Social Research, Vol. XlV, No.2, August 1973.

Chakrabarti, A.K. and Rubenstein, A. "Interorganisational Transfer of Technology", IEEE Trans, on Eng.Management, February 1976.

Chen, F.Y. "Gripping Mechanisms for Industrial Robots - an overview", Mechanism and Machine Theory, 17, (5), 1982, pp. 299-311.

Child, J. Organisation (2nd ed) London: Harper and Row, 1984

Churchman, W.C. The Systems Approach, New York: Delta, 1968.

Clapp, N.W. "Three Laws for Roboticists: An Approach to Overcoming Worker and Management Resistance to Industrial Robots", in Tanner, W.R., Industrial Robots, Vol.1 Ed 1979, pp 169-175

Clapp, N.W. Management Resistance to Industrial Robots, SME Technical Paper, MS80-690, 1980.

Clarke, C. and Cecil-Wright, J. "The Road to Robotics", Management Today, January 1984, pp. 68-71.

Clark, P.A. Action Research and Organisational Change, Harper and Row: London, 1972.

Cleland, D.I. and Kocasglu, D.F Engineering Management, New York: McGraw-Hill, 1981

Coates, V.T. "The Potential Impacts of Robotics", The Futurist, February 1983, pp. 28-32.

Coiffet, P. and Chirouze, M. An Introduction to Robot Technology, London: Kogan Page, 1983.

Confectionery; An Industry Sectory Overview (Fourth Edition), Keynote Publications Ltd, 1983.

Cooper, A.C and Schundel, D. "Strategic Responses to Technological Threats", Business Horizons, February 1976.

Corfield, K. "Getting the engineers we need", Proc.Inst.Mech Engrs. Vol 198B, 1984.

Cousineau, D.T. "Robots are Easy - its everything else that's hard", The Industrial Robot, March 1981, Vol.8, No.1. pp. 50-56.

Council for Science and Society — Technology and Government, London: Council for Science and Society, 1982.

Council for Science and Society — New Technology: Society, Employment and Skill, London: Council for Science and Society, 1981.

Cronshaw, A.J. — "Decoration of Chocolates Using Robot Vision", Workshop on Industrial Application of Machine Vision, New York: IEEE, 1982.

Cronshaw, A.J. — "Feasibility Study for the Application of vision to Chocolates", 1st Int. Conf. on Robot Vision and Sensory Controls, 1981, pp. 233-43.

Cusumano, M. — "Robots Step out of the factory", New Scientist, 6th January 1983.

Darnell,D. and Dale, M.W. — Total Project Management, London: British Institute of Management, (n.p.)

Davey, P. — Lecture to the SERC Robotics Course, Cranfield, December 1982.

Davey, P. — "U.K. Robotics Research Programme", The Production Engineer, June 1982.

Dempsey, P. — "How to beat obsolescence", Management Today, October 1982, pp. 54-57.

Dempsey, P.A. — "Advanced Manufacturing Technology - The Impact on Work Organisations", Eurojobs Conference, Paris, September 1984.

Denzin, N. — The Research Act in Sociology, Aldine Books, Chicago, 1970.

Delebridge, W.R. — "Simple Robots Applied to Packaging Operations", IEEE-IAS 1981 Annual Meeting, pp. 374-6, 1981.

Dept of Trade and Industry — A Programme for Advanced Information Technology, London: HMSO, 1984.

Diebold, J.T. — Automation: The Advent of the Automatic factory, Princeton, New Jersey: Van Nostrand, 1952.

Dill, D.A. and Pearson A.W. — "The Effectiveness of Project Managers: Implications of a Political Model of Influence" IEEE Transactions on Engineering Management, Vol. EM31. No.3., August 1984.

Dodd, G.G.and Rossol, L. (eds) — Computer Vision and Sensor Based Robots London: Plenum Press, 1979.

Dorf, R.C. — Industrial Robotics Handbook.

Drayson, P.R. — The Development of an Interactive Robot-Tool Positioning System, Undergraduate Dissertation, The University of Aston in Birmingham, Department of Production Technology and Production Management, 1982.

Drucker, P.F. — Innovation and Entrepreneurship, London: Heinemann, 1985.

Duffy, J. — Analysis of Mechanisms and Robot Manipulators, London: Edward Arnold, 1980

Dunn, J. — "CIM: A Key to the factory of the future," The Engineer, 10th May 1984, pp. 27-31.

Dunn, J. — "Follow the Paper Trail", The Engineer, 17th May 1984, p.40.

Dunn, M.J. — "Robot Conveyor Loading/Unloading", Proc. 10th I.S.I.R. Mar.1980, Bedford: IFS, pp. 681-686.

Edwards, M. — "Industrial Robots: a human factors perspective", Proc.Inst.Mech.Engrs., Vol. 198B, No.14, pp. 239-242.

Edwardes, M. — Back from the Brink, London: Collins. 1983.

Engelberger, J.F. — Robotics in Practice, London: Kogan Page, 1980.

Estes, V. — "Robot Justification - A lot more than dollars and cents", Proc.Conf.Robots V11, Detroit, 1983.

Estes, V.E. — "An Organised approach to implementing robots." Proc. 16th Annual Conf. Numerical Control Society, Los Angeles, March 1979, pp. 287-326.

Ettlie, J.E. — "A note on the relationship between managerial change values, innovative intentions and innovative technology outcomes in food sector firms", R & D Management, (13)4, 1983.

Ettlie, J. — "Technology Transfer - From Innovators to Users", Industrial Engineering, Vol.5, No.6, 1973.

Eustace, P. — "Towards 2001" The Engineer, 23 Feb 1984, pp. 20-21.

Fairey Automation Ltd. — Product Literature 1982.

Farman, P. — Robotics bibliography 1970-1981, Bedford: IFS, 1981.

Faro, A. and Messina, G. — "Robot network analysis", Computers in Industry 4, (3) Oct. 83, pp. 293-298.

Farrands, C. — "The robotics challenge to European Industry." European Trends, (4) 1983, pp.19-31.

Fisher R, and Ury W. — Getting to Yes, London: Hutchinson & Co, 1983.

Fischer, W.A. et.al. — "Conference Report: The Role of the Product Champion", R & D Management, Vol.15, No.1, 1985, p.71.

Fleck, J. "The Adoption of Robots in Industry", Physics in Technology, Vol.15, 1984, pp. 4-11.

Fleck, J. "The Effective Utilisation of Robots: The Management of Expertise and Knowhow", Proc. 2nd Conf on Automated Manufacturing, Bedford: IFS, 1983.

Fleck,J. "Introduction of the Industrial Robot in Britain", Robotica (1984) Vol.2, pp. 169-175.

Fleck, J. "Robotics in Manufacturing Organisations", in Winch, G. (ed) Information Technology in Manufacturing Processes, London: Rossendale, 1983. December, 1982.

Fleck, J. "Labour-management relations and the introduction of industrial robots in the car industry", Proc. Conf. Robots in the Automotive Industry, April 1982.

Fleck, J. Final Report on the Diffusion of Robots in British Manufacturing Industry: Grant No. GR/A/8605, TPU, The University of Aston in Birmingham, June 1982.

Foster, K. Industrial Decline The University of Aston in Birmingham, Department of Mechanical Engineering, October 1983, (unpublished).

Foulkes, F.K. and Hirsch,J.L. "People Make Robots Work". Harvard Business Review, January - February 1984, pp.94-102.

Foreman,T. "Revenue blind by Science?", Accountancy,February 1984, p. 54

Franklin,D. "DCF: Useful, But Not Always the Right Tool", Accountancy, February 1984, pp. 100-102.

Freeman, C. The Economics of Industrial Innovation, Harmondsworth: Penguin, 1974.

Friedrichs, G. "Sociale und Wirtschaftliche Aspekte bei Verwendung von Industrie-Robotern", 3rd I.S.I.R., Zurich, 1973.

Froehlich,L. "Robots to the rescue", Datamation, Vol.27, 1981, pp.140-161.

Gebhardt, A. and Hatzold,O. "Numerically Controlled Machine Tools" in Nasbeth, L. and Ray, G.F. (Eds), op.cit.

Gestenfeld,A. and Berger,P. A Model for Economic and Social Evaluation of Industrial Robots
12th I.S.I.R. Bedford: IFS, 1982

Gerstenfeld, A. Berger, P. A Systems Approach to Industrial Robots. Boston University Working Paper, October 1982.

Gerwin, D. "Control and Evaluation in the Innovation Process: The Case of Flexible Manufacturing Systems." IEEE Trans. on Engineering Management, Vol. EM-28, No.3. August 1981, pp. 62-70.

Gill, C. "The Future", in Marsh, P. (consultant), Robots, London: Salamander, 1985.

Glaser, B.
Strauss, A. The Discovery of Grounded Theory, London: Weidenfeld and Nicholson, 1968.

Glautier, M.W.E. and Underdown, B. Accounting Theory and Practice, London: Pitman, 1982

Gold, B. "Potential Limitations of Robotics: Guides to Managerial Evaluations", European Journal of Operations Research, September 1983, pp 13-17.

Gold, B. "Robotics, Programmable Automation and Improving Competitiveness", Exploratory Workshop on the Social Impacts of Robotics, Washington D.C.: congress of the United States, OTA 1 February 1982, pp. 90-117.

Goldhar, J.D and Jelinek, M "Plan for Economics of Scope" Harvard Business Review, Nov-Dec 1983.

Grab, E. "Robot palletising Centre", Proc. Conf. 13th ISIR, Stockholm, Bedford: IFS, 1984, pp.287-296.

Grant, M.W "Practical Aspects of Factory Automation" Proc.Conf.Factories in 2001. AD, January 1984.

Green, K. and Morphet, C. Research and Technology as Economic Activities, SISCON: Butterworths, 1977

Greenhalgh, K. "Organisational Problems of High Technology", Proc. Conf. Factories in 2001 AD, January 1984.

Gregory, A. Internal report on microprocessor applications at Forest Gate factory, Trebor Limited, 1980.

Gregory, G. "The factory of Japan's future" Management Today. April 1984, pp. 66-71.

Hamidi-Noori, A. and Templar, A. "Factors Affecting the Introduction of Industrial Robots", Int.Jnl.Operations of Prod.Mgt., Vol,3. No.2, 1983, p.55.

Handy, C.B. Understanding Organisations (2nd edition), Harmondsworth: Penguin, 1982.

Hanify, D.W. "Application of economic risk analysis to industrial robots", Proc.3rd I.S.I.R, Zurich, 1973.

Harris, S. "The Management of Innovation", Management Today, April 1984, pp. 105-106.

Hartley, J. Robots at Work Bedford: IFS (Publications) Ltd U.K., 1983.

Hasegawa, Y. "New developments in the field of industrial robots," Int.Jnl.Prod.Research, Vol.17, 1979, pp. 160-172.

Hasegawa, Y. Analysis of Complicated Operations for Robotisation, SME Technical Paper No. MS79-287, 1979.

Hasegawa, Y. Workstudy for Robot Operation System Design Proc.8th I.S.I.R, 1978.

Hastings, W.F. "Economics of Automation", Proc. Conf.Factories in 2001 AD, Jan. 1984.

Haupt, B.J. "The Systems Approach to Automation in the Modern Plant", Proc. Autofact 4 Conf., SME/RI, 1982, Section 5.1-5.11.

Hayes, R.H. and Wheelwright, S.C "Link manufacturing process and product life cycles", Harv.Bus.Rev. (1) 1979, pp 133-149.

Heginbotham, W.B. "Present Trends etc., in the Use of Industrial Robots", Proc.Inst. of Mech.Engineers., 1981.

Heginbotham, W.B. "The basic economics of industrial mechanisation and automation", Int. Jnl. Prod.Res., 1973, Vol.11. No.2, pp.147-154.

Heginbotham, W.B. "Can Robots Beat Inflation"., SME Technical Paper MS77-756 1977.

Heginbotham, W.B "Factors Affecting the Successful Application of IR Technology", The Industrial Robot, September 1973.

Herzberg, F. Work and the Nature of Man, World Publishing Co. 1966.

Hill, T.J "Manufacturing implications of determining corporate policy", Int. Jnl. Prodn.Management, 1, (1), pp. 3-11, 1980.

Hinson, R. "Study analyses utilising robots in palletising" Industrial Engineering, 16 (2) February 1984.

Hofstede, G. Cultural consequences: International Differences in Work-Related Values Sage, Beverley Hills. 1980.

Holland, D. "Adopt automation - but with some consideration" The Production Engineer, May 1984, pp. 40-42.

Holland, D.A. "Some experiences on the road to automated flexibility", Proc. Conf.Economic, Social, Financial and Technical Effects of Automation, Inaugural of the Dainichi-Sykes Integrated chair in Advanced Maufacturing Technology, Salford, 27-28th November 1984.

Holmes, G. "R & D Disclosure Standard: A Touch of the Schizoids?", Accountancy, February 1984, pp. 55-57.

Holz, B.F. "New Approach to economic evaluation of FMS", The Production Engineer, Nov. 1984, pp. 22-27.

Homan S and Dowis, J. "Introduction of Robot Technology at Dec. Pheonix". 1st Annual Pheonix Conf. on Computers and Communications 1982, pp. 27-31.

Howard, J.M. "Focus on the Human Factors in Applying Robotic Systems", Robotics Today, December 1982.

Howard, K and Sharp, J.A. The Management of a Student Research Project, Aldershot, Hants: Gower Publishing Co, 1983.

Husband, T.M. "The Impact of New Technology on Production", Omega, Vol.15, No.3, 1984.

Ioannou, A. and Rathmill, K. "Data Base Provides Tool for Robot Selection", Industrial Robot, September 1982.

Ingersoll Engineers Industrial Robots Report, Volume 1 & 2, NEL, 1980.

Institution of Production Engineers Innovation in Manufacture, London: I.Prod.E, 1982.

International Conference on Assembly Automation (2nd 1981 Brighton), IFS Conferences Ltd, 1981.

International Symposium on Industrial Robots (2nd 1972: IIT Research Institute), Chicago, 1972.

International Symposium on Industrial Robots (5th: 1975: III Research Institute), Soc. of Manufacturing Engineers, Michigan, 1975.

International Symposium on Industrial Robots (7th 1977: Tokyo), Japan Industrial Robot Assoc., 1977.

International Symposium on Industrial Robots, (8th: 1978: Stuttgart), IFS Ltd, 1978.

International Symposium on Industrial Robots, (9th 1979: Washington DC), SME, Michigan, 1979.

International Symposium on Industrial Robots, (10th 1980. Milan), IFS Ltd, 1980.

International Symposium on Industrial Robots (11th: 1981: Tokyo), Japan Industrial Robot Association, 1981.

Jolly, B.S. "New Technology demands a new breed of engineer-manager", Electrical Review, July 25th, 1980. pp. 27-28.

Jones, B. Skills, Tacit Knowledge and the Automation of Metalworking Production., The University of Aston Management Centre, Nov. 1983.

Jones, F. "The Word-Processor - a case study in introducing a micro-electronic system". The Managerial Implications of Micro-electronics in Twiss, B.C.(ed), London: Macmillan, 1981.

Kahn, H. The Coming Boom - Economic, Political and Social, London: Hutchinson & Co, 1983.

Kanter, R.M. The Change Masters, London: Unwin, 1983.

Kay, J. "Robot Palletiser - Factors Affecting Accuracy of Bag Placing" 4th British Robot Assoc. Annual Conference, 1981, pp.143-5.

Kay, N.M. The Innovating Firm: A behavioural theory of Corporate R & D. London: Macmillan, 1979

Kellock, B. "Why automation fails to cut manning levels" Works Management, July/Aug 1984, pp. 37-41.

Kepner, C.H. and Tregoe, B.B. The New Rational Manager, London: John Martin Publishing Ltd, London: 1981.

Klein,L. "The production engineer's role in industrial relations", The Production Engineer, December 1978, pp. 27-29.

Kidder, T. The Soul of a New Machine, Harmondsworth: Penguin Books Ltd, 1983.

King, W.J "The Unwritten Laws of Engineering", Mechanical Engineering May, June, July 1944.

Kjellberg,T. "A Method to Analyse Handling Problems in Robotic Applications", 2nd Conference on Industrial Robot Technology, Birmingham, 1974

Kirkman, J Good Style in Scientific and Engineering Writing, Pitman, 1980.

Knott, K and. Getto R.D. "Model for evaluating alternative robot systems under uncertainty", Int.J.Prod.Res, 1982, Vol. 20, No.2. pp.155-165.

Kondoleon,A.S "Cycle Time Analysis of Robot Assembly Systems". Int.Symp. on Ind.Robots 9th Washington D.C Mar 1979, pp, 575-587

Kondratiev, M.D The Major Economic Cycles Vorposy Conjunctkury Vol.1 1925

Kraft, P. Programmers and Managers Berlin: Springer-Verlag, 1978.

Lane,D. and Acland,J. Industrial robotics - a bibliography, Institution of Electrical Engineers, London, 1981.

Langrish,J. "Studies of Innovation: A Fresh Look", Innovation Studies in the UK Conf. 30th May - 1st June, 1979.

Lawrence,P. Managers and Management in West Germany, Croom Helm, 1980.

Lawrence, P. German Engineers: Anatomy of a Profession, Oxford Univ.Press, 1981.

Lawrence, P.R. and Lorsch,J.W. "Differentiation and Integration in Complex Organisations" Administrative Science Quarterly, Vol 12 No.7, June 1967.

Lawrence P.R and Lorsch J.W Developing Organisations: Diagnosis and Action, Reading, Mass: Addison-Wesley, 1969.

Lee, V. "Robotics: an all embracing science", Packaging Today, pp. 59-64, April 1985.

Lechtman, H., and Nof,S.Y. "Performance Time Models for Robot Point Operations" Int. Jnl of Production Research, October, 1983.

Lenk, J.D. Handbook of Controls and Instrumentation, Englewood Cliffs, USA, : Prentice Hall, 1980.

Lewis,A. Nagpal, B.K.and Watts, P.L. "Robotics: Market growth, application trends and investment analysis" Proc.Inst.Mech Engineers Vol.199 No B1, pp 35-39.

Lewis,A., Nagpal B.K. and Watts, P.L. "Investment Analysis for Robotic applications", Proc.Conf. 13th Industrial I.S.I.R.,Chicago, 1983.

Liff, H.J. et.al. "A technology assessment of robots", Proc. 7th ISIR, 1977.

Lorsch, J.W. "Organisation Design: A Situational Perspective", Organisational Dynamics, Autumn 1977.

Lowe, J.C. Implementation of Computer and Microprocessor Control Systems, PhD Thesis, The University of Aston in Birmingham; September 1982.

Luh, J.Y.S. "Conventional Controller Design for Industrial Robots - A Tutorial" IEEE Transactions: Systems Man Cybernetics, May/June 1983.

Lumby, S, Investment Appraisal and Related Decisions, Wokingham: Van Nostrand Reinhold (UK) Co.Ltd., 1983.

Lundstrom,G. Industrial Robots - Gripper Review, Bedford: IFS, 1977.

Lupton, T. "The Practical Analysis of Change in Organisations" Inst of Management Studies, Vol. 12, 1965.

Lupton, T. The management of change to advanced manufacturing systems, The Royal Society, London, October 1984.

Macdonald,R.M "Drawing up the purchasing specification", Proc Inst.Mech.Engrs, Vol 199, No. B1, pp. 41-45.

Machine Tool Trades Association Safeguarding Industrial Robots: Part 1, London: MTTA, 1982.

Macri,G.C. "Who Really Resists the Advancement of Robots?", SME Technical Paper MS82-191, 1982.

Maidique,M.A "Entrepreneurs, champions and technological innovation," Sloan Management Review, Vol.12 No.2, pp 59-76,Winter 1980.

Makarov,I.M., Anikeev P.P. and Nazaretov, V.M. "Modular design of robot based industrial technology", Proc. 5th Int.Conf on Programming Research, North Holland Publishing Co., 1983, pp. 609-618.

Mansfield, E. et. al. — The Production and Application of New Industrial Technology, New York: Norton & Co, 1977.

Marsh,P. (consultant) — Robots, London: Salamander Books Ltd, 1985.

Marsh, P. — The Robot Age, London: Sphere Books, 1982.

Marsh, P. — "Sweet dreams about robots in factories", New Scientist, 27th March 1980, p.992.

Marshall, A. — "Is the robot working?, Works and Plant Maintenance, January 1983.

McGregor,D. — The Human Side of Enterprise, New York: McGraw-Hill, 1960.

McIlvaine - Parsons,H. and Kearsley,G.P. — "Human Factors Engineering in Robotics", 13th ISIR and Robots 7 Vol.1, Amsterdam: North Holland Publishing, 1983.

McManus, J.J. — "FMS Needs Management Commitment", The Production Engineer, November 1984, p.18.

Mellon,E. — "Automation in the Pharmaceutical Industry-the Filling and Packing of Tablets", Chem Eng (GB), No. 380, May 1982, pp. 178-81.

Metzer,H., Warnecke, H.J. and Zippe, H. — Neue Formen der Arbeitsstrucktturierung im Produktionsbereich", Z ind Fertig (65) pp. 665-670,1975.

Meyer, R.J — "A Cookbook Approach to Robotics and Automation Justification", SME Technical Paper MS82 - 192, 1982.

Miller, R.K. — "The Bottom Line, - Justifying a Robot Installation", Robotics World, April 1983.

Mills, J.B — "A Phased Approach to Alternative Loom Technology; A Case Study", Proc. Human-1 Conf., Bedford: IFS, 1983.

Moeller,K.H. — "Automatic Handling of Materials with Industrial Robots", IND-ANZ (Germany), vol.99, No 89, pp. 1755-8, Nov. 1977.

Moore, W.L. and Tushman, M. — "Managing Innovation over the Product Life Cycle", Readings in the Management of Innovation, Boston: Pitman, 1982.

Morgan,C. — "Robots - Tool or Labour", Industrial Robot, December 1977.

Morgan,C. — Robots: Planning and Implementation, IFS, 1984.

Morton, J.A. — Organising for Innovation, New York: Mc Gow-Hill, 1971.

Mumford,E. and Pettigrew,A. — Implementing Strategic Decisions, Longmans: London, 1975.

Nabseth,L. and
Ray, G.F. The Diffusion of New Industrial Processes, Cambridge: Cambridge University Press, 1974, p.7.

Nakai,H. "Actual siutation of Robot in the Packaging Operation in Japan", Packaging Japan, July 1984, Vol.5 No.22, pp. 34-38.

Naruki, K. "How to Promote automation in Japanese Industries", Proc. 2nd Int. Conf. on Assembly automation, May 1821, Bedford: IFS, 1981.

National Economic Development
Office Innovation in the U.K., National Economic Development Council, 1983.

Newman, D.J.and
Harden, M.J. "Comprehensive Calculation of Life Cycle Costs for Robotic Systems", RI/SME Conf. Detriot June 4-7, vI, pp 2-83 (14).

Noble, D. "Social Choice in Machine Design. The Case of Automatically Controlled Machine Tools", in Zimbalist, A (ed), Case Studies on the Labour process, 1979, pp 18-50.

Nof, S.Y Decision Aids for Applying Industrial Robot Operations, Proceedings of the AIIE Conference, 1982.

Nof, S.Y.
and Lechtman,H. "Robot Time and Motion System Provides Means of Evaluating Alternate Robot Work Methods", Industrial Engineering April 1982, pp. 38-48.

Office of Technology
Assessment Exploratory Workshop on the Social Impacts of Robotics, US Govt. Printing Office, Washington DC, 1981.

Ohmae, K. The Mind of the Strategist, Harmondsworth: Penguin Books Ltd, 1983.

Oliver, M. "The Management and Training Implications of Innovation and Change due to Advanced Manufacturing Technologies", Proc. 1st Int. Conf. Human Factors in Manufacturing, Bedford: IFS, 1983.

Ottinger,L.V. "Evaluating Potential Robot Applícations in a Systems Context", Industrial Engineering, January 1982, pp. 80-87.

Ottinger,L.V. "Engineering Robots Systems for Existing facilities", Industrial Engineering February 1982.

Owen, A.E. "Economic Criterion for Robot Justification". The Industrial Robot, September 1980, pp. 176.

Parnaby, J. "Designing the total system", The Production Engineer, November 1984, pp.53-54.

Pascale, R.T. "Zen and the art of management", Harvard Business Review March - April 1984, pp. 153-162.

Paul, R.P. Robot Manipulators Boston Mas: MIT, 1981.

Paul, R.P, and Nof, S.Y. — "Work Methods Measurement A Comparison between Robot and Human Task Performance", Int. J. Prod. Res, V.17 May - June 1979, pp. 277-303.

Pavitt, K. (ed.) — Technological Innovation and British Economic Performance, London: Macmillan, 1980.

Pearce, D.W. — Cost - Benefit Analysis, London: Macmillan, 1983.

Pinchot (III), G. — Intrapreneuring, London: Harper and Row, 1985.

Pike, R.H. — Capital Budgeting in the 1980's, London: Inst. Cost and Management Accountants, 1982.

Porter, G. — "Popular and Unpopular Science", The Smallpiece Lecture, The Royal Society, 12th September 1985, Leamington Spa: The Smallpiece Trust, 1985.

Porter, M.E. — Competitive Strategy, New York: Macmillan, 1980.

Preece, D.A. — "The management of the adoption and introduction of new Technology." in Bullinger H.J (ed) Human Factors in Manufacturing 2nd International Conference, June 1985 Stuttgart, Bedford: IFS, 1985.

Primrose, P.L. Leonard, R. — "Use of a conceptual model to evaluate financially flexible and manufacturing system projects", Proc. Inst. Mech.Engrs., Vol. 199, No. B1, pp. 15-21.

Primrose, P.L. and Leonard, R. — "Evaluating the "intangible" benefits of flexible manufacturing systems by use of discounted cash flow algorithms within a comprehensive computer program", Proc. Inst. Mech. Engrs., Vol. 199 No. B1, pp. 23-28

Primrose, P.L. Bailey, F.A. and Leonard, R. — "The Practical Application of Discounted Cash Flow to Plant Purchase using an Integrated Suite of Computer Programs", Accounting and Business Research, Winter 1984, pp. 27-31.

Pugh, D.S. and Hickson, D.J. — The Aston Programme, Organisational Structure in its Context, Farnborough: Saxon, 1976.

Quinlan, J. — "Packaging with Robots", Materials Handling Eng. (USA), vol. 36, No.11, pp. 74-5, Oct. 1981.

Radnor, M. et al. — "Implementation in OR and R & D", Operations Research, Vol.18, No.6, 1976.

Rapaport, R.N. — "Three dilemmas in action research", Social Science Research Council Conf, York: England, 1970.

R.I.B.A. — Plan of work for Design Team Operation, London: RIBA Publications, 1983.

Robson,I. "Managing the Introduction of Robots for Factory Efficiency", Robots and Flexible Automation Conference, Birmingham, September 1984.

Roddy, D. Introduction of Microelectronics, Pergamon, 1978.

Rogers, E.M., and Shoemaker, F.F. Communication of Innovations (2nd ed), New York: The Free Press, 1971.

Rooks, B. "Are new rules needed in the battle to justify Advanced Manufacturing Technology" The Industrial Robot, Vol.11 No.4. December 1984,p. 207.

Roper,C. "Self help kits for successful systems", CADCAM International, Feb 1985, pp. 26-28.

Rosato, P.J. "Robotic Implementation - Do it Right," Proc. 13th International Symposium on Industrial Robots and Robots 7 Chicago: Robotics International/SME, April 1983.

Rose, J. "Robots, present and future" Rev. Inf and Autom. (Spain) Vol. 12, No.42, pp. 49-59, 1979.

Rosenberg, N. Perspectives on Technology, CUP, 1976.

Rosenbrock H.H. "Engineers and the Work that People Do", IEEE Control Systems Magazine, Vol. No. 3 September 1981.

Rosenbrock, H.H. "Robots and People", Measurement and Control (15),March 1982, pp. 105-112.

Rossenbrock,H.H. "Designing automated systems - need skill be lost?", Science and Public Policy, December 1983.

Rossol, L. "Technological Barrier in Robotics A Perspective from Industry," in Brady, M. and Paul, R. (eds) Robotics Research, Cambridge, Mass: MIT Press, 1984.

Rothwell, R. "The Characteristics of Successful Innovators and Technically Progressive firms (with some comments on innovation research)". R & D Management, Vol 7, No.3, 1977.

Russell, G.A. and Zambuto, A. "Identifying Feedback Mechanisms in a Dynamical Model of the Manufacturing Process". Manufacturing Systems, Vol. 13, No.2. pp. 101-104.

Sawyer, J.H.F. Group Technology, University of Aston, Dept. of Production Technology and Production Management, 1982.

Schmidt-Streier, U. and Weiss, K. "Planning for the Introduction of Industrial Robots and Peripheral Equipment for Manipulation of Work pieces", Tech. Rundsch (Switzerland), Vol.70, No.44, 1978.

Schon, D.A. "Champions for Radical New Inventions", in Hainer et. al. (eds), Uncertainty in Research, Management and New Product Development, Reinhold, 1967.

Schwartz,H. and Davis, S.M. "Matching Corporate Culture and Business Strategy", Organisational Dynamics, Summer 1981, pp. 30-48.

Schwind, G. Robots: A flexible solution for tough unitizing jobs, Material Handling Engineering, September 1983, pp. 36-40.

Scott, P.B. The Robotics Revolution, Oxford: Basil Blackwell, 1984.

Seed, A.H. "Cost Accounting in the Age of Robotics", Management Accounting, Vol. 66, No. 4, October 1984, pp. 39-43

Seering, W.P. "Robotics and Manufacturing - a Perspective", in Brady M, and Paul, R (eds.) Robotics Research, Cambridge, Mass:, MIT Press, 1984, pp.973-982.

Senker, P. "Some Problems in Justifying CAD/CAM," Proc. 2nd European Conf. on Automated Manufacturing,Birmingham, May 1983, pp. 59-66.

Simons, G.L. Robots in Industry, Manchester: NCC Publications, 1980.

Skinner, W. Manufacturing in the Corporate Strategy, New York: John Wiley & Sons, 1977.

Skinner, W. "Manufacturing the missing link in corporate strategy", Harv, Bus,Rev., 42 pp. 136-145, 1969.

Slack, N. "Flexibility as a manufacturing objective", Production Operations and Management Workshop, London Business School, January 1983.

Sladek, J. Roderick, London: Granada Publishing Ltd, 1980.

Small, B.W. "Paying for the Technology - making the intangibles, tangible", Proc. 2nd European Conf. Automated Manufacturing, Birmingham, May 1983, pp 183-189.

Smith, D. "New Scope for Automation", Food Manufacture, pp. 35-39, November 1983.

Smiles, S. Men of Invention and Industry, 1884.

"Steady growth for robots in 1984", The Industrial Robot, Vol.12. No.1, March 1985, pp.30-34.

Social Science Research Council SSRC Newsletter, No.39, April 1979.

Stauffer, R.N. "Developing the Robot Workplace" Robotics Today, 4 (6), December 1982, pp. 29-30.

Steel, L. "Managers' misconceptions about technology", Harvard Business Review, Nov - Dec 1983.

Steiner, G.A. Strategic Planning, New York: Free Press, 1979.

Sternberg,D. How to Complete and Survive a Doctoral Dissertation, New York: St Martins Press: 1981.

Sullivan, M.J. "The Right Jobs for Robots", Manufacturing Engineering, November. 1982, p.51.

Sullivan, W.G. and Lieu, M.C. "Economic analysis of a proposed industrial robot", Industrial Engineering, 16,(10) Oct 1984, pp. 118-119.

Susnjara, K. "Does your plant need robots?", Robotics World, January 1983, pp. 26-31.

Sutcliffe, I. "Robot applications in the food Industry" Food, February 1983, pp. 17-21.

Swords-Isherwood, N.and Senker,P.(eds.) Microelectronics and the Engineering Industry The Need for Skills, London: Francis Pinter, 1980.

Tanner, W.R. A Users Guide to Robot Applications, SME Technical Paper MS 76-601, Michigan: SME, 1976.

Tanner, W.R. Industrial Robots - Vol 1 Fundamentals, Detroit: SME, 1979.

Tanner, W.R. "Selling The Robot - Justification for Robot Installations" SME Technical Paper MS 78 - 702, 1978.

Taylor, F.W. Scientific Management, Harper 1911,1947.

Teale, D. "Considerations for Implementing Robots", Procs. 4th BRA Conf., Bedford: IFS, 1981.

Thomis,M.T. The Luddites: Machine-Breaking in Regency England, Hampden, CT: Archon Books, 1970.

Thompson,E.P. The Making of the English Working Class, New York: Pantheon Books, 1963.

Thompson, H.B. "Improving U.S. Industry's Competitive Position: Strategy for Success", Proc.Autofact 4 Conf. SME/RI, 1982.

Thompson,J.D. Organisations in Action, New York: Mc Graw-Hill, 1967.

Thouless R.H. Straight & Crooked Thinking, Pan Books, 1974.

Tichy, N.M. Managing Strategic Change, New York: John Wiley, 1983.

Touche Ross & Co Manual of Financial Reporting and Accounting, Butterworths, 1982.

TURU. The Introduction of Robots: An Issue for Negotiation, Trade Union Research Unit, Ruskin College, Oxford, July 1981.

Twiss, B. Lecture on the Management of Innovation at the Department of Interdisciplinary Higher Degrees, the University of Aston in Birmingham, 7th April, 1983.

Twiss,B. Managing Technological Innovation, London: Longman, 1974.

Twiss, B.C.(ed.) The Managerial Implications of Microelectronics, London: Mcmillan, 1981.

Utterback, J. "Innovation in Industry and the Diffusion of Technology", Science, (183), February 1974 pp. 620-628.

Van Blois,J.P. "Robotic Justification Considerations", SME Tech Paper, M882-193, 1982.

Van Blois, J.P. "Strategic Robot Justification, a Fresh Approach", Rob Today, Vol.5, 2nd April 1983, pp.44-48.

Vogel,P. and Bullinger, H.J. "Application of principles of work structuring for the planning of robot system". Proc. IFAC Workshop Nov 1983, Pergamon Press, Oxford, 1983, pp.121-125.

Vonnegut, K. Player Piano, London: Granada Publishing. 1983.

Voss, C.A. "Production/Operations Management - A Key Discipline and Area for Research", Omega, Vol.12, No.3, 1984, pp. 309-319.

Vukobratovic,M. and Potkonjak,V. Dynamics of Manipulation Robots, Berlin: Springer-Verlag, 1982.

Vuzelov, V. "A Modular Approach to flexible Automation", Proceedings of the 2nd International Conference on FMS, Bedford: IFS, 1983.

Warr,P.B. Psychology at Work, Penguin Books, 1981.

Ward,D. "Robotics Growth in UK Hindered by Wrong Attitude to Investment", The Engineer, 13th November 1980, p.31.

Warnecke, H.J. and Ahrens, V. "Loading and unloading of pallets using sensor assisted robots" Proc. 4th IFAC/IFIP Symposium 26-28 Oct '82 Pergamon Press, Oxford UK, 1984, pp. 63-70.

Warnecke, H.J. and Schraft. R.D. "Planning the Introduction of I.R and Peripheral Equipment for Materials Handling with the Aid of Computers", 8th ISIR, Stuttgart 1978.

Warnecke,H.J. and Schraft,R.D. Industrial Robots: Applications Experience, Bedford: IFS, 1982.

Wearne, S.H. Short bibliography of books and papers on project management University of Bradford, January 1984.

Weinstein, C. "Robots in Industry - Too few or Too many?" Electronics and Power, May 1978.

West, D. "How to Identify Profitable Applications for Robots." Getting Robots and Automation Systems to Work, Seminar Inst.Mech - Engineers, November 1982.

Wheelwright,S.C. "Reflecting corporate strategy in manufacturing decisions" Bus. Horizons, 21(1), pp. 57-66, 1978.

Wheelwright, S.C. and
Hayes, R.H. "Competing through manufacturing", Harvard Business Review, Jan - Feb 1985, pp. 99 - 109.

Wilcock,D. "Just what is AMT and how can it be implemented?", The Production Engineer, June 1984, pp.10-11.

Wilkinson,A. "Technology - an increasingly dominant factor in corporate strategy" R & D Management (13) 4 1983, pp.245-259.

Wilkinson, B. "Managing with New Technology, Management Today October 1982.

Wilkinson, B. The Shopfloor Politics of New Technology, London: Heinemann, 1983.

Wobbe,W. "Social and Organisational Aspects of the Introduction of Robots into Industrial Production", S.O.F.I., 1979.

Young, J.N. The Year in Perspective - UK Food and Drinks Market 1984, Leatherhead: Food RA, 1985.

Zermeno-Gonzalez, R.
The Development and Diffusion of Industrial Robots, PhD,(Vols. I & II), The University of Aston in Birmingham, 1980.

Zermeno,R., Moseley,
R, and Braun, E. "The Robots are coming - slowly" in Forester, T (ed) The Microprocessor Revolution, Oxford: Basil Blackwell, 1979.

NOTES

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CHAPTER ONE

1. A robot is a reprogrammable multi-function manipulator designed to move materials, parts, tools, etc., through variable programmed motions for the performance of a variety of tasks; it is a series of active servo-drives joined by solid but elastic links.

2. Burnett P., "Spanner in the robot's works", The Times, September 5th 1983, p.8.

3, Avison,G., "Playing to Win in the New-Tech Poker Game", The Engineer, May 24th 1984, pp.23-24.

4. "Steady growth for robots in 1984", The Industrial Robot, vol. 12, No.1, March 1985, pp.30-34.

5. Bessant,J., "Influential factors in manufacturing innovation", Research Policy 11 (1982), pp.117-132.

6. Ayres, R.U. and Miller, S.M., Robotics Applications and Social Implications, Cambridge Mass: Ballinger Pub.Co., 1983.

7. Ibid., p.98.

8. Fleck,J., "The Adoption of Robots in Industry", Phys. Technol., Vol.15, 1984, p.4.

9. Fleck,J., "Robotics in Manufacturing Organisations", Make-IT 1982 Seminar, p.4.

10. Skinner, W., Manufacturing in the Corporate Strategy, New York: John Wiley & Sons, 1977.

11. Husband T.M., "The Impact of New Technology on Production", Omega, Vol.15. No.3m 1984.

12. Advisory Council for Applied Research and Development, New Opportunities in Manufacturing. The Management of Technology, London: HMSO, October 1983, p.30.

13. Advanced Manufacturing Technology (AMT) is a general term to cover the application of various techniques such as computer aided design, flexible manufacturing systems and robotics. ACARD defines AMT as: any new technique which, when adopted, is likely to require a change not only in manufacturing practice, but also in management systems and the manufacturer's approach to the design and production engineering of the product (ref. ACARD, op.cit., p.7).

14. Voss, C.A., "Production/operations Management - a key discipline and area for research" Omega (12), No.3. 1984, pp.309-319.

15. Young, J.N., The Year in Perspective - UK Food and Drinks Market 1984, Leatherhead: Food RA, 1985, p.3.

16. British Robot Association, Robot Facts, Bedford: IFS, 1985.

17. Pugh, D.S. and Hickson, D.J., The Aston Programme, Organisational Structure in its Context, Farnborough: Saxon, 1976.

18. Through a previous IHD project: Corcoran M.P., Engineering Improvements in the Quality Production of Boiled Sweets, PhD thesis, The University of Aston in Birmingham, 1982.

19. Carter, C.F. and Williams, B.R., Industry and Technical Progress: Factors Governing the Speed of Application of Science, London Oxford University Press, 1957.

20. Nabseth,L. and Ray, G.F., The Diffusion of New Industrial Processes, Cambridge: Cambridge University Press, 1974.

21. Chakrabarti, A.K. and Rubenstein, A., "Interorganisational Transfer of Technology", IEEE Transactions on Engineering Management, February 1976.

22. Rogers, E.M. and Shoemaker, F.F., Communication of Innovations, (2nd edition), New York: The Free Press, 1971.

23. Science Policy Research Unit, Project SAPPHO, 1973.

24. Bessant, J., 1982, op.cit., (Note 5), p.119.

25. Zermeno-Gonzalez, R., The Development and Diffusion of Industrial Robots Vols. i & ii, PhD thesis, The University of Aston in Birmingham, 1980.

26. Zermeno, R., Moseley, R. and Braun, E., "The robots are coming - slowly" in Forester, T. (ed.), The Microprocessor Revolution, Oxford: Basil Blackwell, 1979.

27. Fleck, J., Final Report on The Diffusion of Robots in British Manufacturing Industry: Grant No. GR/A/86053, TPU, The University of Aston in Birmingham, June 1982.

28. Fleck, 1982, loc.cit., (Note 9).

29. Davey, P., Lecture to the SERC Robotics Course, Cranfield, December 1982.

30. Bessant, J. and Lamming, R., "Making IT fit: the design of integrated manufacturing systems", Design Studies, Vol.15, No.2, April 1984, p.109.

31. Social Science Research Council, SSRC Newsletter, No.39, April 1979, p.12.

32. Rothwell, R., "The Characteristics of Successful Innovators and Technically Progressive firms, R & D Management Vol.7 No.3, 1977.

33. Utterback, J., "Innovation in Industry and the Diffusion of Technology", Science Vol. 183, February 1974, pp.658-62.

34. Bessant, J., loc.cit.

35. Lowe, J.C., Implementation of Computer and Microprocessor Control Systems, PhD thesis, The University of Aston in Birmingham, September 1982, p.136.

36. Bessant, J., loc.cit.

37. Bell, M., The Impact of Major New Roads on Agriculture: Legal and Administrative Aspects, PhD thesis, The University of Aston in Birmingham, 1978, p.104.

38. Clark, P.A., Action Research and Organisational Change, Harper and Row: London, 1972, p.23.

39. Ibid., p.24.

CHAPTER TWO

40. Fleck,J., 1982, op. cit., (Note 27).

41. McManus, J.J. "FMS Needs Management Commitment," The Production Engineer, November 1984, p.18.

42. ACARD, op.cit., (Note 12), p.8.

43. National Economic Development Office, Innovation in the UK, NEDC, 1983.

44. SPRU, op.cit., (Note 23).

45. Bessant, J., 1982, op.cit., (Note 5).

46. Twiss, B., Managing Technological Innovation, London: Longman, 1974, p.3.

47. "BIM Report", Management Today, April 1984, p.105.

48. Bessant, J., 1982, op. cit., (Note 5), p.126.

49. Ettlie, K., "Technology Transfer - from Innovators to Users", Industrial Engineering, Vol.5. No.6., 1973.

50. Chakrabarti, A.A. and Rubenstein, A., 1976, op.cit., (Note 21).

51. Radnor M. et al, "Implementation in OR and R & D", Operations Research, Vol.18 No.6., 1976.

52. Braun,E., "Constellations for Manufacturing Innovation", Omega Vol.9 No.3., 1981 pp. 247-253.

53. Bessant, J., 1982, op.cit., (Note 5), p.117.

54. Twiss, B., Lecture on the Management of Innovation at The University of Aston in Birmingham, IHD Total Technology Scheme, April 7th, 1983.

55. Fleck,J., "The Effective Utilisation of Robots: The Management of Expertise and Knowhow", Proc.2nd Conf. Automated Manufacturing, Bedford: IFS, 1983.

56. Bessant, J., "Management and manufacturing innovation: the case of information technology", in: Winch G. (ed.), Information Technology in Manufacturing Processes, Rossendale: London, 1983, p.18.

57. Ibid, p.25.

58. Ibid, p.26.

59. Ibid, p.18.

60. Mills, J.B., "A Phased Approach to Alternative Loom Technology: A Case Study", Proc. Human - 1 Conf., Bedford: IFS, 1983.

61. Greenhalgh, K., "Organisational Problems of High Technology", Proc.Conf.Factories in 2001AD, January 1984.

62. Ibid., p.2.

63. Ibid., p.3.

64. Fleck, J., 1983, op.cit., (Note 55), p.64.

65. Ibid., p.67.

66. Utterback, J., op.cit., (Note 33), p.662.

67. The word 'organisational' is used in the sense of the structure, management and operation of the activities of the company and the people who work within it.

68. Carter and Williams, 1957, op.cit., (Note 19).

69. Burns, T. and Stalker, G.M., The Management of Innovation, London: Tavistock, 1961.

70. Kanter, R.M., The Change Masters, London: Unwin, 1983, p.27.

71. Burns, T. and Stalker,G.M., op.cit., p.33.

72. Ibid, p.34.

73. McGregor, D., The Human Side of Enterprise, New York: McGraw-Hill, 1960.

74. Handy, C.B., Understanding Organisations (2nd edition), Harmondsworth: Penguin, 1982, p.29.

75. Tichy, N.M., Managing Strategic Change, New York: John Wiley, 1983, p.45.

76. Ibid, p.47.

77. Gill,C., "The Future", in Marsh, P. (consultant), Robots, London: Salamander, 1985, p.154.

78. Gill, C., loc.cit.

79. Gill, C., loc.cit.

80. Smiles, S., Men of Invention and Industry, 1884.

81. Schon, D.A., "Champions for Radical New Inventions", Harvard Business Review, March-April 1963 p.8.

82. Maidique, M.A., "Entrepreneurs, champions and technological innovation", Sloan Management Review, Vol.12. No.2., Winter 1980.

83. Schon, D.A., loc.cit., (Note 81),

84. SPRU, 1973, op.cit., (Note 23),

85. Ohmae, K., The Mind of the Strategist, Harmondsworth: Penguin, 1983.

86. Twiss, 1983, op. cit., (Note 54).

87. Edwardes, M., Back from the Brink, London: Collins, 1983, p.258.

88. Twiss, B., op.cit., (Note 46), p.15.

89. Schon, D.A., loc.cit., (Note 81).

90. Kanter, R.M., op. cit., (Note 70), p.157.

91. Fischer, W.A. et. al., "Conference Report: The Role of the Product Champion", R & D Management, Vol.15 No.1, 1985, P.71.

92. Avison, P., loc.cit., (Note 3).

93. Rogers, E.M. and Shoemaker, F.F., 1971, op.cit., (Note 22).

94. Bessant, J., A Study of Inputs and their Influence on Technological Innovative Activity, Birmingham: The University of Aston in Birmingham, PhD thesis, 1978, p.38.

95. Nabseth, L. and Ray, G.F., 1974, op.cit., (Note 20).

96. Bessant, J., 1978, op.cit., p.61.

97. Tanner, W.R., A Users Guide to Robot Applications, SME Technical Paper MS76-601, Michigan: SME, 1976.

98. Liff, H.J. et.al., "A technology assessment of robots", Proc. 7th ISIR., 1977, p.650.

99. Haupt, B.J., "The Systems Approach to Automation in the Modern Plant", Proc.Autofact. 4 Conf, SME/R1, 1982, Section 5.1 - 5.11.

100. Estes, V.E., "An organised approach to implementing robots", Proc.16th Annual Conf. Numerical Control Society, Los Angeles, March 1979, pp.287-326.

101. Macri, G.C., "Who Really Resists the Advancement of Robots?", SME Technical Paper MS82-191, Michigan: SME, 1982.

102. Warnecke, H.J., and Schraft, R.D., Industrial Robots: Applications Experience, Bedford: IFS, 1982.

103. Teale, D., Considerations for Implementing Robots, Proc. 4th B.R.A. Conf., 1981, p.172.

104. Dorf, R.C., Industrial Robotics Handbook, Reston, 1983, p.81.

105. Grab, E., "Robot palletising centre (RPC), Proc. Conf. 14th I.S.I.R., Bedford: IFS, 1984, pp.287-296.

106. Warnecke, H.J., and Schraft R.D., op.cit., (Note 102), p.172.

107. Nof, S.Y. and Lechtman, H., "Robot Time and Motion System Provides Means of Evaluating Alternate Robot Work Methods", Industrial Engineering, April 1982, pp.38-48.

108. Nof, S.Y., Knight, J.L. and Salvendy, G., "Effective Utilisation of Industrial Robots - A Job and Skills Analysis Approach", AIIE Trans., Vol.12, 1980, p.216.

109. Wobbe, W., "Social and Organisational Aspects of the Introduction of Robots into Industrial Production", SOFI, 1979.

110. Rosenbrock, H.H., "Designing automated systems - need skill be lost?", Science and Public Policy, December, 1983, p.275.

111. Parnaby, J., "Designing the total system", The Production Engineer, November 1984, pp. 53-54.

112. Bjørke, Ø., "Towards integrated manufacturing systems", Robotics and Computer Integrated Manufacturing, Vol.1 No.1, 1984, pp.3-19.

113. Vuzelov, V., "A Modular Approach to Flexible Automation", Proc. 2nd. Int.Conf. Flexible Manufacturing Systems, Bedford: IFS, 1983.

114. Smith, D., "New Scope for Automation", Food Manufacture, November 1983, pp.35-39.

115. Lee, V., "Robotics: an all embracing science", Packaging Today, April 1985, pp. 59-64.

116. Sutcliffe, I., "Robot Applications in the Food Industry", Food, February 1983, pp.17-21.

117. Grab, E., op.cit., (Note 105), p.294.

118. Sutcliffe, I., op.cit., p.17.

119. Smith, D., op.cit., p.35.

120. Lee, V., op.cit., p.59.

121. Nakai, H., "Actual Situation of Robot in Packaging Operation in Japan", Packaging Japan, Vol.15 No.22, July 1984, pp.34-38.

122. Ibid, p.38.

123. Hasegawa, Y., "New developments in the field of industrial robots, Int.Jnl. Production Res., Vol.17, 1979, pp.160-172.

124. Froehlich, L., "Robots to the rescue", Datamation, Vol.27, 1981, pp.140-161.

125. Bublick, T., "The justification of an industrial robot", Proc. '77 Finishing Conference and Exposition. 1977.

126. Lewis, A., Nagpal B.K., and Watts, P.L., "Investment Analysis for Robotic Applications", 13th I.S.I.R., Chicago 1983.

127. Hastings, W.F., "Economics of automation", Proc.Conf.Factories in 2001AD, January 1984.

128. Goldhar, J.D. and Jelinek, M., "Plan for Economies of Scope", Harvard Business Review. Nov-Dec 1983.

129. Owen, A.E., "Economic Criterion for Robot Justification", The Industrial Robot, Vol.6., September 1980, p.176.

130. Small, B.W., "Paying for the Technology-making the intangibles tangible", Proc. 2nd. Conf. Automated Manufacturing, Birmingham, May 1983, Bedford: IFS, 1983, pp.183.189.

131. Senker, P., "Some Problems in Justifying CAD/CAM", Proc. 2nd Conf. on Automated Manufacturing, Birmingham, May 1983, pp. 59-66.

132. Hanify, D.W., "Application of economic risk analysis to industrial robots", 3rd I.S.I.R., Zurich, 1973.

133. Gold, B., "Potential Limitations of Robotics: Guides to Managerial Evaluations", European Journal of Operations Research, September 1983, pp.13-17.

134. Knott,K. and Getto, R.D., "Model for evaluating alternative robot systems under uncertainty", Int.Jnl. Production Research, Vol.20 No.2 1982, pp.155-165.

135. Gerwin, D., "Control and Evaluation in the Innovation Process: The Case of Flexible Manufacturing Systems", IEEE Trans. on Engineering Management, Vol. EM-28, No.3, August 1982, pp.62-70.

136. Heginbotham, W.B., "The basic economies of industrial mechanisation and automation", Int.Jnl. Production Research, Vol.11. No.2, 1973, pp.147-154.

137. Primrose, P.L. and Leonard, R., "Evaluating the 'intangible' benefits of flexible manufacturing systems", Proc. Instn. Mechanical Engineers, Vol.199, No.B1, 1985, pp.23-28.

138. The 'payback' of an investment is the time period required to recover in cash the amount outlaid in cash on the project.

139. Glautier, M.W.A. and Underdown, B., Accounting Theory and Practice, London: Pitman, 1982.

140 Lumby, S., Investment Appraisal and Related Decisions, Wokingham: Van Nostrand Reinhold, 1983.

141. Primrose, P.L. and Leonard, R., op.cit., (Note 137), p.23.

142. Discounted cash flow (DCF) is a method of investment appraisal which discounts all cash flows associated with the investment to their equivalent value at the present time.

143. Internal rate of return (IRR) is that rate at which the present values of the cash inflows is the same as the present value of the cash outflows; i.e. the net present value is zero.

144. Indirect costs are all production costs not related specifically to a cost unit.

145. Porter, G., "Popular and Unpopular Science", The Smallpiece Lecture, The Royal Society, 12th September 1985, Leamington Spa: The Smallpiece Trust, 1985.

146. Primrose, P.L. and Leonard R., loc.cit., (Note 137).

147. Gold, B., "Robotics, Programmable Automation and Improving Competitiveness", Exploratory Workshop on the Social Impacts of Robotics, Washington D.C.: Congress of the United States, O.T.A., February 1982, pp.90-117.

148. Gold, B., 1983, op.cit., (Note 133), p.14.

149. Gold, B., 1982, op.cit., (Note 147), p.98.

150. Gold, B., 1982, loc.cit.

151. Rooks, B. (ed.) The Industrial Robot, Vol.11 No.4, December 1984, p.207.

152. Hastings, W.F., op.cit., (Note 127).

153. Nabseth, L. and Ray, G.F., op.cit., (Note 95), p.302.

154. Hastings, W.F., op.cit., (Note 127), p.3.

155. Gerwin, D., op.cit., (Note 135), p.69.

156. Holland, D.A., "Some experiences on the road to automated flexibility", Proc. Conf. Economic, Social, Financial and Technical Effects of Automation, Inaugural of the Dainichi-Sykes Robotics Integrated Chair in Advanced Manufacturing Technology, Salford, 27-28th November 1984.

157. Ibid., p.5.

CHAPTER THREE

158. Gregory, A., Internal report on microprocessor applications at Forest Gate factory, Trebor Limited, 1980.

159. Marsh, P., "Sweet dreams about robots in factories. "New Scientist, March 27th 1980, p.992.

160. Bessant, J., 1978, op.cit., (Note 94), p.61.

161. Ottinger, L.V., "Evaluating potential robot applications in a systems context", Industrial Engineering, January 1982, pp.80-87.

162. See for example Warnecke and Schraft, 1982, op.cit. (Note 102).

163. Twiss, B., 1974, op.cit., (Note 46).

164. Teale, D., 1981, op.cit., (Note 103), p.171.

165. Kanter, R.M., op.cit., (Note 70), p.160.

166. The production management meeting (PMM) is a monthly meeting between the production director and general works managers.

167. Macri,G., "Analysis of First UTD Installation Failures", in Tanner, W.R. (ed.), Industrial Robots Vol.1 Fundamentals, SME, 1979, p.56.

168. Behuniak J.A., Planning and implementation of robot projects, SME Tech. Paper MS80-691, 1980.

169. Cousineau, D.T., "Robots are Easy-its everything else that's hard", The Industrial Robot, Vol.8, No.1, March 1981, pp.50-56. see also Warnecke and Schraft, (Note 102), Ottinger, (Note 161), and Estes, (Note 100).

170. Twiss, B., 1976, op.cit., (Note 163).

171. The reach envelope is the volume that the end of the robot arm can reach in 3-dimensional space.

172. Tool centre point (TCP) is a given point (either programmable or fixed) about which the robot's end-of-arm tooling is centred for the purposes of programming.

173. All industrial robots consist of a series of flexible joints - either rotary or translational which are also known as axes. Six axes are required to reach all points within the reach envelope without redundancy. 2-axis robots are mostly used for pick and place or assembly applications.

174. Grant application document February 1984.

175. Parallel processing is a facility offered by robot computer control systems which employ a multi-processor architecture. This allows the robot to do more than one thing at once, for example moving whilst monitoring a counter.

176. IP55 is a standard for the environmental protection of machinery against water and dust ingress.

177. Macri, G., 1982, op.cit., (Note 167).

178. The project group is an extension of the workgroup concept applied by Trebor and other companies such as Volvo and Electrolux. The principle of the project group is that a team is formed from the people directly concerned with the problem or who have relevant special skills, led by one person who reports to management. All members of the group are regarded as being equal and jointly responsible for the success of the project.

179. See Fleck, 1982, op.cit., (Note 27) and Wilson.

CHAPTER FOUR

180. Fischer, W.A., et. al., op.cit., (Note 91), p.72.

181. Fleck, J., 1983, op.cit., (Note 55), p.68.

182. The Institution of Production Engineers, Innovation in Manufacture, London: I.Prod.E., 1982.

183. Burns, T., "Models, Images and Myths", in Gruber, W.H. and Marquis D.G., (eds.), Factors in the Transfer of Technology, M.I.T. Press, 1969.

184. See for example the sales literature of General Electric's robot division.

185. See Michael Edwardes' account of his period at BL cars for example, op.cit., (Note 87).

186. Maidique, M.A., "Entrepreneurs, champions and technological innovation", Sloan Management Review. Vol.12 No.2, Winter 1980, p.66.

187. Mumford, E and Pettigrew A., Implementing Strategic Decisions, London: Longman, 1973.

188. Maidique, M.A., loc.cit., (Note 186).

189. Pinchot (III) G., Intrapreneuring, London: Harper and Row, 1985.

CHAPTER FIVE

190. Child, J., Organisation (2nd edition), London: Harper and Row, 1984, p.283.

191. Greenhalgh, op.cit., 1984 (Note 61).

192. Fleck, op.cit., 1983 (Note 55), p.67.

193. See for example Behuniak, op.cit., (Note 168).

194. Rothwell, 1977, op. cit., (Note 32).

195. Child, J., op.cit., (Note 190). p.118.

196. Lawrence, P.R. and Lorsch, J.W., Developing Organisations: Diagnosis and Action, Reading Massachusetts: Addison - Wesley, 1969, p.25.

197. Cadbury, A., "Cadbury-Schweppes: More than Chocolate and Tonic", Harvard Business Review, Jan-Feb 1983, pp.134-144.

198. Lorsch, J.W., "Organisation Design: A Situational Perspective", Organisational Dynamics, Autumn 1977. p.486.

CHAPTER SIX

199. Pike, R.H., Capital Budgeting in the 1980's, London: Inst., Cost and Management Accountants, 1982.

200. Gold, B., 1982, op.cit., (Note 147).

201. Seed, A.H., "Cost Accounting in the Age of Robotics", Management Accounting Vol.66 No.4, October, 1984, pp.39-43.

202. Van Blois, J.P., "Strategic Robot Justification, a Fresh Approach", Robotics Today, Vol.5, April 2nd 1983, pp 45-48.

203. Primrose, P.L. and Leonard, R., 1985, op.cit., (Note 137).

204. Seed, A.H., op.cit., (Note (201), p.39.

205. Fixed costs are those that accrue in relation to the passage of time and which, within definable limits, tend to be unaffected by fluctuations in the volume of output.

206. Variable costs are those that tend to vary in direct proportion to changes in the volume of output of the cost centre to which they relate.

207. See for example Tanner, 1976, op.cit., (Note 97); Warnecke and Schraft, 1982, op,cit., (Note 102).

208. Gold, 1983, op.cit., (Note 133).

209. Clarke, C. and Cecil-Wright, J., "The Road to Robotics", Management Today, January 1984, pp.68-71.

210. Thompson, H.B., "Improving U.S. Industry's Competitive Position: Strategy for Success", Proc. Autofact 4 Conf., SME/RI, 1982, p.5.

211. Primrose, P.L. and Leonard, R., op.cit., (Note 137), p.24.

212 Holland, D.A., op.cit., (Note 156), para.4.3

213. Van Blois, J.P., op.cit., (Note 202), p.45.

214. Ward, D., "Robotics Growth in UK Hindered by Wrong Attitude to Investment", The Engineer, November 13th 1980, p.31.

CHAPTER SEVEN

215. Engleberger, J.F., Robotics in Practice, London: Kogan Page, 1980.

216. The overwrapping machines used in all three factories were both dated and inefficient. They could not be relied upon to produce a consistently good wrap and so all cartons were visually inspected for wrap quality. They also required continual adjustment by operators and clearance of repeated jamming of cartons within the machine. This problem could be tolerated because an operator had to be near the machine to palletise the wrapped cartons.

217. Ward, D., loc.cit., (Note 213).

218. Seering, W.P., "Robotics and Manufacturing - a Perspective", in Brady, M. and Paul, R. (eds.), Robotics Research, Cambridge, Mass: MIT Press, 1984, p.974.

219. Fleck, J., 1982, op.cit., (Note 27).

220. Naruki, K., "How to Promote Automation in Japanese Industries", Proc.2nd Int.Conf.Assembly Automation, 18th-21st May 1981, Bedford: IFS, 1981.

221. Vuzelov, 1983, op.cit., (Note 113).

222. Bjørke, 1984, op.cit., (Note 112).

223. Group technology is a form of production-system layout whereby the equipment necessary to produce a family of similar products are grouped together in cells: the aim being to reduce stock and handling costs.

224. Vuzelov, 1983, op.cit., (Note 113).

CHAPTER EIGHT

225. Fleck, J., 1982, op.cit., (Note 27).

226. Haimidi-Noori, A. and Templer, A., "Factors Affecting the Introduction of Industrial Robots", Int Jnl Operations of Prod. Mgt., Vol.3 No.2, 1983, p.55.

227. Bessant, J., 1982, op.cit., (Note 5).

228. Zermeno-Gonzalez, 1980 op.cit., (Note 25), p.207.

229. Rogers and Shoemaker, 1971, op.cit., (Note 22).

230. Kanter, R.M., 1983, op.,cit., (Note 70).

231. Warnecke and Schraft, 1982, op.cit., (Note 102).

232. Parnaby, J., 1984, op.cit., (Note 111).

233. Vuzelov,V., 1983, op.cit., (Note 113).