THE INTRODUCTION OF A NEW MANUFACTURING FACILITY
FOR PLASTIC INJECTION MOULDING
AT
ACCO-REXEL LTD., LLANGEINOR,
SOUTH WALES.

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A thesis submitted in partial fulfilment of the
requirements of the University of Glamorgan/Prifysgol Morgannwg
for the degree of Master of Philosophy.

This research programme was carried out
in collaboration with the University of Salford, the Open University,
and Acco-Rexel Limited.

September 1993
ABSTRACT

A company faced with ever increasing competition worldwide has to continually review & improve its products, processes & systems. One such company, Acco-Rexel Ltd saw the need to re-invest in an injection moulding facility to manufacture components for its high volume stapling machine products. Injection moulding in itself is not new, but modern manufacturing methods such as Just-In-Time (small batch manufacturing) are still being developed for new & existing processes. The need to improve processes within a company forms only part of the ongoing strategies to achieve profitability & consequently, survival of the business.

This particular investment project took 2½ years to complete. The initial feasibility study included simulation of an injection moulding facility in a JIT environment. The conclusion was the investment in a 2 injection moulding machine facility with quick tool change equipment, which reduced mould-tool set-ups from typically over 60 minutes to under 30 minutes. Reducing the average leadtime for supply of plastic components from 6 weeks to 1 week gave the opportunity of lowering inventory at both manufacturing & distribution sites. The overall financial benefit was that a payback on investment was achieved in less than 2 years.

Acco-Rexel Ltd has subsequently installed an additional 2 injection moulding machines to increase its in-house capability of manufacturing plastic components.
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This thesis has been written in accordance with regulations & guidance notes laid down by The University of Glamorgan.

The Author was employed by the University of Salford as a Teaching Company Associate for the initial period of 2½ years on the introduction of an injection moulding facility at Acco-Rexel Ltd, Llangeinor, & subsequently was employed as a project engineer by Acco-Rexel Ltd.

The author is particularly interested in all aspects of manufacturing processes. This includes the relationship of people, methods, equipment, information systems & materials to products & services that satisfy the customer's needs.
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Also, a sincere thanks goes to my family, Elaine, Daniel & Lewis for their encouragement in completing this thesis, & for making do without me for many evenings in the past few years.

Finally, may I have a clear conscience regarding the completion of this thesis; for the Lord God does not look at the outward appearance of man but at the intent of a man's heart, Who will one day bring every work into judgement(HOLY BIBLE).
AUTHORS' DECLARATION.

Nearly all of chapter 2 on the background & theory of injection moulding has been researched from several sources. The author is indebted to information supplied by machinery manufacturers, material suppliers & to various published literature which has been referenced in this thesis.
DEFINITIONS

This is a list of abbreviations & nomenclature used in this thesis.

Polymers:
- ABS : Acrylonitrile butadiene styrene copolymer.
- EVA : Ethylene vinyl acetate copolymer.
- GRP : Glass reinforced plastics.
- HIPS : High impact polystyrene.
- PA : Polyamide.
- PA66 : Poly(hexamethylene adipamide).
- PBT : Poly(butylene glycol terephthalate).
- PC : Polycarbonate.
- PE : Polyethylene.
- PET : Poly(ethylene terephthalate).
- POM : Polyoxymethylene(polyacetal).
- PVC : Poly(vinyl chloride).
- PS : Polystyrene.
- SAN : Styrene acrylonitrile copolymer.

Injection moulding machine:
- A : Projected area.
- F : Clampforce.
- G : Dimensionless factor used in clampforce calculations.
- L/D : Ratio of screw length to screw diameter(page 20).
- P : Pressure at mould entry point.
- PD : Proportional derivative.
- PID : Proportional integral derivative.
- DPID : Differential PID.

Others:
- Company A : One of the injection moulding companies within the Acco-Rexel Holdings group of companies.
- Company B : As company A.
- HV/HV : High value(gross margin) products which have a high variety of components.
- JIT : Just in time.
- RE : Rexel Engineering.
1.0 INTRODUCTION

This chapter has the objective of introducing the reader to:
- The company.
- Its origin.
- The collaboration venture undertaken with various academic institutions.
- The background to the injection moulding project & how it was linked in with the product strategy to satisfy the company objectives.
1.1 The Company.

Rexel Engineering Ltd was a manufacturing company based at Llangeinor, near Bridgend, in South Wales. Since December 1992 it has become a manufacturing division of Acco-Rexel Ltd which has its headquarters in Aylesbury, Buckinghamshire. The manufacturing site at Llangeinor produces various fastening products for the office products market, such as:

- Stapling machines.
- Staples.
- Paperclips.
- Drawing pins.

This manufacturing division at Llangeinor has occupied its 11 acre site since the early 1970's and employs a workforce of over 300 employees. The company moved to this site in 1971 from London when it was owned by Ofrex Group Holdings PLC.

Products are manufactured & delivered to its distribution centre at Halesowen, Birmingham; which was previously at Aylesbury. Sales & marketing are located at Acco-Rexel Ltd headquarters, Aylesbury & are responsible for sales of all products from the manufacturing sites in the United Kingdom & Ireland.

Acco-Rexel is owned by Acco-Rexel Holdings PLC(formerly Ofrex Group Holdings), which is one of the world's largest manufacturer of office products. Acco-Rexel Holdings is owned by the American based group, Acco World Corporation which has its own parent, American Brands INC.. American Brands is renowned for products such as tobacco, alcoholic spirits, insurance and office products.

This project was predominantly concerned with the supply of plastic injection moulded components to Rexel Engineering. Acco-Rexel Holdings owned several injection moulding facilities, two of which were:

- Acco Ireland, Dublin, Ireland.
Since the mid 1980's Rexel Engineering had been involved in a major capital investment programme to develop the company as a quality, low cost producer of stapling machines and staples. This was to counter the threat posed in world markets by other low cost producers particularly from the Far East.

By the end of the 1980's the investment had included:
- Automatic assembly equipment.
- Flowlines.
- Storage equipment for work in progress.
- Central computer with MPS (Master Production Scheduling) and MRPII (Manufacturing Resource Planning).
- BS5750 Quality system.
- Computer controlled power presses with a suite of progression tooling, incorporating the latest (1980's) development in pressed steel component manufacture.
- Automatic electrostatic powder paint facility.
- Automatic barrel and rack plating facilities.

The remaining part of the investment programme was to include:
- An in-house injection moulding facility.
- Computer aided design (CAD).
- New generation of stapling machines.
1.2 The collaboration venture.

In 1988 Ofrex Group Holding (now Acco-Rexel Holdings) undertook to bridge a gap to transfer technology between academic institutions and its main manufacturing companies. Those institutions included the University of Salford, the Polytechnic of Wales (now the University of Glamorgan), and the Open University. A Teaching Company (appendix A) programme was approved in 1988 and a grant was obtained from the Science and Engineering Research Council and the Department of Trade and Industry (UNIVERSITY OF SALFORD 1988). This 5 year programme would involve employing 9 graduates (known as associates). Each associate was to be employed for a period of 2 years to work on various key projects at many of the manufacturing sites within the Group.

This Teaching Company programme was co-ordinated by a senior associate at the University of Salford. Four associates out of the 9 employed were allocated to projects at Rexel Engineering. The Teaching Company programme was monitored through regular monthly and quarterly feedback meetings (ACCO-REXEL 1991d) during which supervisors monitored the progress of the project and the associate's development which included a programme of supporting studies. These supporting studies included seminars, workshops, open learning studies and visits to moulding companies such as, Flymo-Electrolux Ltd at Newton Aycliffe. The associate was required to complete a final report at the end of the Teaching Company period summarising the project achievements (ACCO-REXEL 1991c).
1.3 Project background.

The proposed injection moulding investment at Rexel Engineering was allocated to the Teaching Company programme. The Associate was employed in March 1989. The Associate had prior knowledge of design, development & manufacturing within the defence & electronic component industries, but limited experience in polymer technology. The project brief was to introduce an in-house plastic injection moulding facility in the Associate's employment period of 2 years.

Rexel Engineering's requirement for an in-house injection moulding facility came from the increasing emphasis in the use of plastics within its products, particularly injection moulded components (BARKER & CLARKE 1992). The following diagram (figure 1-1) shows the two basic types of stapling machine, metal & plastic. A metal machine consists of a metal base & metal cover & a plastic machine consists of a plastic base & plastic cover. The mechanisms for both types are manufactured from mild steel pressed blanks & subsequently plated with a nickel or a nickel & chrome finish. The use of plastics has certain advantages & disadvantages over metals (PERA 1985)(POSTANS 1978) as detailed in table 1-1.

The Associate was also part of a team responsible for the improvement in the torsional stiffness of a plastic stapling machine cover & base (appendix B)(ACCO-REXEL 1991e). This illustrates the difficulties when designing with plastics.
Figure 1-1 Types of stapling machine.

KEY

A: Standard plated anvil
B: Standard plated hinge/staple carrier mechanism
C: Plastic cover knob
D: Painted metal cover
E: Painted metal base
F: Plastic cover
G: Plastic base
### ADVANTAGES OF PLASTICS:

**PRODUCT USER:**
- Reduced noise & vibration, good absorbancy.
- Ergonomics for user are good, e.g. Ease of handling, warm to the touch, low hardness (soft feel) and low in density.

**DESIGN:**
- More complex shaped components can be produced incorporating complex radii.
- Can combine the functions of several metal components into a single component.
- Thermal properties are good.
- Special features can be incorporated e.g. moulded-in hinges.
- Manufacturing costs are reduced as there are less processes required, i.e. plating.
- Self-lubricating properties.
- Light transmission, i.e. transparent, translucent.

**MANUFACTURE:**
- Plastics can be self coloured which eliminates the need for painting or plating operations.
- Several features can be included within a plastic component, such as clips to hold other components, & the integration of several features within the one component.
- No finishing processes required, i.e. paint or plate.

**DISADVANTAGES OF PLASTICS:**

**DESIGN:**
- Cost of raw material can be two times greater than the cost of metal for low cost plastics and ten times greater for some of the engineering plastics used in some of the stapling machines.
- Strength, hardness, ductility & resistance to abrasion is lower.
- More susceptible to creep, cold flow & deformation under load & low temperature embrittlement.
- Subject to degradation by heat, light & chemicals.
- Flammable.

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Table 1-1 Advantages & disadvantages of plastics compared with metals.
Let us now consider how this need for increased emphasis upon plastic technology could be met. As part of the manufacturing strategy, Rexel Engineering had increasingly used standard components and assemblies within its stapling machines. Product variety is achieved at the last stage of manufacture before despatch. This approach is commonly known as the "Mushroom product concept" and is illustrated in figure 1-2.

This concept is based upon everything being standard throughout the majority of the leadtime (i.e. procurement and manufacturing) with variation being added at the last possible moment. The concept was presented at a conference in Birmingham in 1988 (MATHER 1988). Rexel Engineering began to implement improvements and changes in the stapling machine product which supported this concept. In 1989 the range of product had a variability & leadtime relationship as shown in figure 1-3.
Figure 1-2 Mushroom product concept (MATHER 1988).
The manufacture of metal products could be achieved within 3 weeks with the availability of stocks of steel coil. In comparison plastic machines procurement and production time was 7 weeks. This necessitated the building up of large inventory that were in most cases unique to the end product, i.e. plastic cover with moulded in customer logo.
These key components were structured within a bill of materials, summarised in figure 1-4 & were called high value/high variety components (HV/HV). High value refers more to value in gross margin of the final stapling machine product and high variety indicates the number of variations available from the component tooling. These HV/HV plastic components were the first to be considered for the in-house injection moulding facility.

Plastic components were not the only components that add variability to the final product but packaging was another. The incentive to reduce packaging variation is less than plastic components, as the value in inventory of plastic was greater than packaging and also the investment in packaging technology for in-house manufacture would be too great.

In order to begin to prioritise the high value stapling machine products a Pareto analysis (i.e 80:20 rule, i.e 80% of the worlds wealth is owned by 20% of the population) was to be completed for the stapling product range.

The separation of low and high variety components and finally the separation of packaging and metal components left the HV/HV plastic components. The number of variations of HV/HV plastic components in 1989 was 95, manufactured from 20 tools, 14 different colours and 15 customer logo's.

No mention so far has been made of materials but these HV/HV components were planned to be manufactured from a single plastic raw material in order to aid processing, acrylonitrile butadiene styrene (ABS).
Figure 1-4 Key components for improvement in leadtime.
2.0 BACKGROUND & THEORY OF INJECTION MOULDING.

The objective of this chapter is to detail the latest developments in the field of injection moulding. Injection moulding is prominent in the manufacture of plastic components in the high volume automotive industry & considerable research has been carried out over the past 50 years(EDC 1987). The best way of identifying all the past developments in injection moulding is to consider it as a "process"(Figure 2-1). A process is defined as being the transformation of a set of inputs into desired outputs(OAKLAND 1989, PAGE 9).

Figure 2-1. Key elements within a process(OAKLAND 1989).
2.1 Injection moulding equipment.

The basic elements of an injection moulding facility is the injection moulding machine. The diagram below (figure 2-2) show the various components and layout of a typical injection moulding machine.

Figure 2-2 Typical injection moulding machine design & layout (BPTA 1985) (JOHANNABER 1985).
The mould is interchangeable which allows the flexibility of manufacturing a wide range of plastic components using the same sized moulding machine. The injection unit function is to prepare the polymer to the required temperature for melting & injecting this melted polymer into the cavity under pressure to ensure complete filling of cavity. The clamping unit has the function of preventing the mould tool halves from opening during the injection process. A typical moulding cycle is shown in figure 2-3.

**Figure 2-3** Sequence of operation in an injection moulding cycle (BPTA 1985).

**KEY**

A: Close & clamp the mould.
B: Inject the molten material.
C: Hold the mould closed while components cool & screw rotates back with new charge of material for next cycle.
D: Open the mould & eject the components.
A complete breakdown of the equipment that is used in the field of injection moulding is itemised in table 2-1.

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
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<td><strong>INJECTION UNIT</strong></td>
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<td><strong>PLUNGER</strong></td>
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<td><strong>RECIPIRATING SCREW</strong></td>
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<td><strong>DRIVE MOTOR</strong></td>
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<td><strong>SERVICES</strong></td>
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<td><strong>RELIABILITY &amp; MAINTAINABILITY</strong></td>
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Table 2-1 A breakdown of the developments in injection moulding & ancillary equipment.
EQUIPMENT CONTINUED

...RAW MATERIAL HANDLING
...STORAGE
...CONVEYING
...DRYING
...BLENDING
...REGRINDING
...AUTOMATION

...MOULD TOOLS
...TYPES
...CAVITY
...COOLING
...EJECTION
...MOULD CLAMPING

...COOLING SYSTEMS

...PRODUCT HANDLING

...TOOL HANDLING

...SERVICES & LAYOUT
...TYPES
...LAYOUT

...BUILDINGS

...MAINTENANCE

Table 2-1 Continued.
Referring to table 2-1, the basic injection moulding machine types are vertical & horizontal. Vertical machines are used for insert moulding (ECKARDT 1985b, PAGE 9/3) which require special handling devices for automatic loading & unloading of inserts & components respectively. The popularity of horizontal as opposed to vertical machines (HUSKY 1980, PAGE 46) can be due to the ease of access to all areas of the equipment & the low cost of automating component removal from mould e.g by conveyor or robot).

The 5 main areas of a horizontal injection moulding machine are:
- The injection unit
- The clamping unit
- The power distribution
- The control system
- The safety equipment

2.1.1 INJECTION UNIT
There are 3 functional areas of an injection unit:
- A system to prepare & inject the melt (molten polymer).
- A method of external heating for an additional heat source during operation & start-up.
- A method of bringing melt equipment in contact with mould-tool.

During melt preparation the polymer is subjected to high shear rates & subsequently high strain rates when the polymer is injected through the narrow channels to the cavity, & the apparent viscosity is lowered so that the melt flows readily (OPEN UNIVERSITY 1984, UNIT 3, PAGE 34).

Various designs of injection units have been developed, earlier design were based upon the plunger principle (BOWN 1979, PAGE 23) but these suffered from inherent weaknesses such as variations in injection pressure, variation in shot weight, complex electrical switchover systems and polymer overheating in the transfer type designs. The reciprocating screw replaced the plunger injection unit in the early 1950's & plunger type machines are now manufactured for small prototype component moulding only (BOWN 1979, PAGE 29).
The reciprocating screw injection unit is usually a single unit with an hydraulic or electric drive motor as in figure 2-4. Multi-injection unit machines are manufactured for special applications & are discussed later.

Figure 2-4 Reciprocating screw injection unit (BOWN 1979).
There are two types of screw drive motors, electric & hydraulic.
Electric motors were traditionally limited (BOWN 1979, PAGE 50) but the latest drives are AC which have overcome much of the difficulties associated with previous drives (SEUTHE 1990) (table 2-2).

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<thead>
<tr>
<th>CRITERIA</th>
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<tr>
<td></td>
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<td>SMOOTH START</td>
<td>GOOD</td>
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<td>VARIABLE SPEED</td>
<td>GOOD</td>
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<td>POOR</td>
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<tr>
<td>HIGH TORQUE AT START OF INJECTION</td>
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<td>NOISE LEVEL</td>
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<td>WEIGHT</td>
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</table>

Table 2-2 Comparison of types of screw drive motors.

The barrel & screw assembly is one of the most critically manufactured components of an injection moulding machine. The screw size is normally quoted as being the ratio of length(L) & diameter(D). The length being the distance from the throat of the hopper to the end of the last flight with the screw fully forward (EUROMAP 1991, SECTION 1) (JOHANNABER 1985, PAGE 67). A general purpose barrel/screw assembly of L/D of 20 would be suitable for most polymers but there are limitations & usually a compromise is obtained to achieve equipment flexibility (BURKLE 1989). Standard screws are designed with differing geometry along the screw length consisting of a feed section followed by a compression zone in the centre & finally a metering zone near the screw tip (BRYDSON 1990, PAGE 87).
An important consideration is that when planning an operation that will involve several raw materials & when operating close to the maximum capacity of the injection unit that the machine design allows for screws with different L/D ratios to be used(HUSKY 1980, PAGE 42)

Special screw geometries can be obtained where only one type of material is to be used such as PA, PBT, PET & POM polymers. Where rigid PVC, thermosets & elastomers are required, special screw designs are required(JOHANNABER 1985, PAGE 70).

---

**Figure 2-5 Various types of design of screw(BRYDSON 1990).**

**KEY**
A: "PVC" type screw
B: "Nylon"(polyamide) type screw
C: "Polyethylene"/general purpose type screw
D: Vented barrel

---
Vented barrels (Figure 2-5) have been used in the extrusion industry since the mid 1960's. The vented barrel is based on the principle that water moisture contained within hygroscopic materials can be removed during the melt preparation and expelled to atmosphere through a vent along the barrel. The water vapour is allowed to escape through the vent as the melted polymer passes along the compression zone & over a sudden change in screw profile causing a zone of decompression (ECKARDT 1978, PAGE 5). Manufacturers have claimed that hygroscopic polymers such as ABS, PA & PC can be moulded without pre-drying when using a vented barrel (BOWN 1979 PAGE 49) thus eliminating the need for costly drying equipment. The development of dehumidifying dryers in the 1980's has meant that even greater drying efficiencies are now possible & the choice to use vented barrels is upon the preference of the moulder. There are costs associated with the more complex design of vented barrels & these have to be compared with drying systems on the basis of the required drying efficiencies & equipment costs.

Protection of the screw & barrel assembly against wear & corrosion is necessary where contact is made with materials that contain fillers (ground minerals, glass fibers) or with a corrosive environment (water, carbon dioxide, oxygen, hydrochloric acid, etc). All known thermoplastics reduce the sliding wear by the dynamic lubrication provided by a film of melted polymer (JOHANNABER 1985, PAGE 82). Unfilled & easy flowing polymers such as PS & PE can be processed with a gas-nitrided screw & barrel assembly. Where filled polymers are processed it is recommended that bi-metallic barrels & chrome-plated, ion-nitrided or fully hardened screws with armoured flights are used (JOHANNABER 1985, PAGE 83) (BOWN 1979, PAGE 46).

A key feature of maintaining the screw & barrel assembly is the frequent inspection of all wear components. To allow easy access the injection unit is usually designed to be traversed vertically or horizontally to clear the fixed platen area (BOWN 1979, PAGE 46) (HUSKY 1980, PAGE 42).

Designs of non-return valves & nozzles vary for different materials. Most materials can be processed using a standard design as shown in figure 2-6.
If a material such as PVC is processed then an open nozzle with no non-return valve is required. Where materials of low viscosity are being processed there are various shut off devices ranging from mechanical (carriage actuated) to hydraulic (cylinder actuated) nozzles (BRYDSON 1990, PAGE 81) (JOHANNABER 1985, PAGE 88) (BPTA 1989) (MINK & FISHER, FIGURE 2.4.1).

When specifying the size of injection unit for a specific moulding application usually the factors in table 2-3 are considered in order to achieve satisfactory mould filling & mould packing. A relationship exists between injection rate & injection pressure which means that high pressure is obtained at the expense of high injection rates. A moulding feasibility diagram can be plotted which gives the operating envelope of the moulding machine indicating whether the injection unit is capable of filling a cavity with a certain flow length & cavity thickness (OPEN UNIVERSITY 1984, UNIT 7, PAGE 26).
<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection capacity:</td>
<td>- Defined as swept or shot volume((cm^3)) or shot weight(grams of PE or PS) can be used.</td>
</tr>
<tr>
<td></td>
<td>- Minimum shot volume of tool should be 10% the maximum shot volume to reduce residence time of melt in barrel.</td>
</tr>
<tr>
<td>Screw stroke:</td>
<td>- Maximum linear movement of the screw.</td>
</tr>
<tr>
<td></td>
<td>- L:D ratio reduces as the screw moves back which eventually would reduce the effectiveness of melt preparation.</td>
</tr>
<tr>
<td>Plasticising capacity:</td>
<td>- Maximum amount of material that may be plasticised per hour.</td>
</tr>
<tr>
<td>Injection rate:</td>
<td>- This is the maximum rate at which the screw or ram can inject melt from the barrel during a single shot.</td>
</tr>
<tr>
<td>Specific injection pressure:</td>
<td>- This is the maximum pressure that may be exerted by the screw on the molten polymer during the mould packing stage of the moulding cycle.</td>
</tr>
<tr>
<td></td>
<td>- For practical design purposes (OPEN UNIVERSITY 1984, PT614, UNIT 7, PAGE 27) maximum pressure for melt delivery to the mould entry points and for mould filling should be taken at around 90MN/m^2.</td>
</tr>
</tbody>
</table>

Table 2-3 General specification for an injection unit.
Multi injection units have been fitted to moulding machines where there is a requirement for quick colour & material changeover (ECKARDT 1985b, PAGE 9/4). A typical changeover time for a single injection unit is between 5-30 minutes depending on the type of colour change i.e. black to white is more difficult than white to black. Also a change of material will require a different barrel temperatures i.e. increase of 80°C for a change from ABS to PC. In comparison a twin injection unit can minimize changeover time to a few seconds & purging the previous injection unit can be carried out while production continues. The cost of the second injection unit & associated control system can be justified on the increased utilization of the injection moulding machine.

Two(or multi) material moulding produces moulded components which may have two colours or materials in the same component. This requires two or more injection units that operate sequentially producing a moulding that has two materials in a single moulding cycle. The mould is usually mounted on a rotary table or requires a special mould tool (ECKARDT 1985b, PAGE 9/13). Examples include the manufacture of multi coloured lenses for the rear lights of a car (BPR 1991c).

Two dissimilar material moulding is possible when a material encapsulates the previous moulded material i.e a seal of TPR being encapsulated by rigid PVC (ECKARDT 1985b, PAGE 9/13).

Structural foam moulding is applicable for thicker walled parts and is produced by special purpose low pressure injection with a screw plasticising unit & a melt accumulator (ECKARDT 1985b, PAGE 9/14).

Gas assisted moulding or CINPRESS (tradename for Controlled Internal Pressure) uses a gas (usually nitrogen) which is injected into the component through the sprue which prevents sink marks in thick-walled components (ECKARDT 1985b, PAGE 9/15) (ANDERS & OTHERS 1991) (QUICK & STOUT 1991). The injection equipment includes a spider support to be located in the nozzle, a control system, pipework for gas distribution & a suitable gas storage system.
Multi-component moulding (sometimes called co-injection, 2K or sandwich moulding) produces parts which have an outer skin & a core made of different raw materials. Examples include virgin outer skin & a core of a reclaimed material, or a core of glass filler which can reduce costs & give good surface finish respectively. The moulding machine requires the connection of two injection units with a single nozzle & shut off valves for each injection unit with no special requirements for the clamping unit (ECKARDT 1985b, PAGE 9/15) (BPR 1991c) (ECKARDT 1987a). Further developments have included producing a foamed plastic core by using a blowing agent to reduce the density of the core (ECKARDT 1987b).

The shearing of the thermoplastic polymer by the action of the screw can contribute up to 60% of the required heating effect upon the material. The remaining 40% is produced by the heater bands which are clamped around the barrel. There are various types:

- Mica (3-5 watts/cm²)
- Ceramic (6-7 watts/cm²)
- Aluminium (6-7 watts/cm²)

In most cases ceramic heaterbands are fitted & mica are fitted to the nozzle where there is the possibility of damage from material leaking from around the nozzle (BPTA 1989).

Special heating methods have been developed by a Japanese manufacturer (MEIKI 1993) where 100% of the required melt is produced by the screw shearing a controlled volume of plastic granules dropped in the throat of the barrel. The barrel is kept at a constant temperature by a barrel cooling fan. The manufacturer considers that the benefits of reduced back pressure requirement & residence time of melt is an advantage over conventional heated injection units.

The control of heating is considered later under a separate heading, machine control.
2.1.2 CLAMPING UNIT

A key part of the injection moulding machine is the clamping unit & has 4 basic functions:
- Uniform distribution of clamp force.
- To hold both halves of the mould closed during injection of melt & packing stages.
- Fast opening & closing.
- Rapid adjustment for varying height tools.

There are various types of clamping units, the most common is the two fixed platen with a central moving platen. The central platen is aligned by 2 or 4 tiebars with the main weight of the platen being supported by a horizontal slide with adjustable wear plates. One manufacturer has developed a tiebar-less machine (ENGEL 1990) which overcomes the difficulties normally experienced with loading & unloading tools between tiebars.

Platen design has been standardised across manufacturers by the European Association (EUROMAP 1991) who promote standards within the plastics & rubber machinery industry. A recommendation has been published (EUROMAP 1991, SECTION 2/3) which gives all the necessary dimensions that manufacturers have to publish in their literature & recommended mounting & connection dimensions for mould tools.

When selecting a clamping unit consideration must be given to excessive platen deflection at full clamping force which if excessive can cause premature mould tool wear & reduce the quality of moulded components. Rugged extra thick platens should reduce deflection to between 0.05-0.08mm at full clamp force (HUSKY 1980, PAGE 48).

Specialised clamping units are manufactured for applications such as the packing industry where high production rates are required & one such system (HUSKY 1990) incorporates a 3 platen (1 fixed & 2 moving) configuration with two tools mounted in tandem. The central moving platen is connected to a single injection unit with a distributed feed & this configuration doubles the output of a conventional machine.
The various types of clamping systems are shown in table 2-4 & figure 2-7.

<table>
<thead>
<tr>
<th>METHOD OF CLAMPING</th>
<th>MECHANICAL</th>
<th>HYDRO/ELECTRO-MECHANICAL</th>
<th>HYDRAULIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>MECHANICAL</td>
<td>MANUAL VICE</td>
<td>TOGGLE PLUS</td>
<td>DIRECT</td>
</tr>
<tr>
<td>HYDROMECHANICAL</td>
<td>TOGGLE</td>
<td>HYDRAULIC CLAMPING</td>
<td></td>
</tr>
<tr>
<td>ELECTROMECHANICAL</td>
<td>SWINGING</td>
<td>BLOCK OR DISK</td>
<td></td>
</tr>
<tr>
<td>HYDRAULIC</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2-4 Comparison of the various clamping systems.

Figure 2-7 Various clamping methods(BRYDSON 1990)(EITB 1989).
TOGGLE PLUS HYDRAULIC CLAMPING:
Back platen
Short-stroke high-pressure ram
Floating platen
Hydraulic oil pipes
Toggle actuating cylinder
Moving platen
Fixed platen

SWINGING BLOCK (DISK):
Movement cylinder
Pressure plate
Locking cylinder
Mould height adjustment

DIRECT HYDRAULIC:
Direct locking cylinder
Moving platen
Fixed platen
Injection cylinder
Rear platen
Mould spacer
Mould halves

Figure 2-7 Continued.
Comparing the various clamping systems with regard to performance there is very little difference between the latest injection moulding machines having hydro(electro)mechanical &/or hydraulic motion & clamping. The disadvantage traditionally associated with toggle clamping was worn bearing surfaces(bushes), but this has been eliminated by pressurised lubrication systems. There is a slight advantage with toggle clamping in that the speed of opening & closing is direct & faster than any hydraulic system but this is only required where thin walled packaging components are moulded with cycle times typically less than 10 seconds. Most clamping units utilise hydraulic power but development has started with "all electric" moulding machines(CINCINNATTI 1990) which have benefitted from developments in the machine tool industry. A final comparison of the various types of clamping would include the time taken to adjust platen from minimum tool height to maximum; toggle systems usually are more difficult to adjust & require between 3-5 minutes, swing disk & direct hydraulic units between 40-50 seconds. Mould height adjustment is important when considering mould-tool change times less than 10 minutes. General specification would be as in table 2-5.

| Clampforce: | The projected area of the components and runner system within the mould tool determines the clampforce required. A simplified relationship exists for clampforce calculation(OPEN UNIVERSITY 1984, UNIT 7, PAGE 25): |
| | \[ F = PAG \] |
| where: | |
| F: Clampforce | |
| P: Pressure at the mould entry point(specific injection pressure). | |
| A: The projected area of the component & runner system. | |
| G: Dimensionless factor dependent on the geometry of the moulding (0.8-0.9 for direct gating). | |

Table 2-5 General specification of a clamping unit.
2.1.3 CONTROL SYSTEM.

Control system for injection moulding can be subdivided into 4 main areas:
- Parameters requiring control.
- Methods of control.
- Applications.
- Location.

A control system is only required where it is known that a process parameter will vary & will have an affect upon the quality of the moulded component. Table 2-6 shows a list of process parameters that have to be controlled(JOHANNABER 1985, PAGE 169).

<table>
<thead>
<tr>
<th>QUALITY FEATURE OF MOULDING</th>
<th>EFFECTIVE PARAMETER</th>
</tr>
</thead>
<tbody>
<tr>
<td>MECHANICAL PROPERTIES:</td>
<td>INJECTION SPEED</td>
</tr>
<tr>
<td></td>
<td>MELT TEMPERATURE</td>
</tr>
<tr>
<td></td>
<td>MOULD TEMPERATURE</td>
</tr>
<tr>
<td></td>
<td>CAVITY PRESSURE</td>
</tr>
<tr>
<td></td>
<td>HOLDING PRESSURE</td>
</tr>
<tr>
<td>DIMENSIONAL ACCURACY/ ABSENCE OF:</td>
<td>MELT TEMPERATURE</td>
</tr>
<tr>
<td>DISTORTION</td>
<td>MOULD TEMPERATURE</td>
</tr>
<tr>
<td></td>
<td>CAVITY PRESSURE</td>
</tr>
<tr>
<td></td>
<td>HOLDING PRESSURE</td>
</tr>
<tr>
<td>SURFACE QUALITY:</td>
<td>INJECTION SPEED</td>
</tr>
<tr>
<td></td>
<td>MELT TEMPERATURE</td>
</tr>
<tr>
<td></td>
<td>MOULD TEMPERATURE</td>
</tr>
<tr>
<td>OTHER CRITERIA:</td>
<td>PRESSURE</td>
</tr>
<tr>
<td></td>
<td>TEMPERATURE</td>
</tr>
</tbody>
</table>

Table 2-6. Moulding machine parameters that affect the required features of the moulded part.

The required features of a moulded part are almost exclusively governed by 2 process parameters, pressure & temperature; with injection speed(also pressure dependant) exercising limited influence.

There are 3 methods of controlling the parameters shown in table 2-6, manual, open loop & closed loop control(JOHANNABER 1985, PAGE 169).
Manual control systems, the operator sets the required pressure & if deviation occurs the operator will carry out adjustment, e.g. pressure & speed controls on the ejection system.

Open loop control systems, the desired output has been set & the control system will achieve this setting but will not compensate if variations occur, e.g. mould clamping unit positions.

A closed loop control compares the actual response against the set value & will compensate for changes, e.g. barrel temperature control & injection unit velocity & pressure controls.

There are 2 areas of control within injection moulding, control of temperature & controls relating to the cycle.

The control of barrel heating is critical & the control system is required to achieve the set temperature quickly with minimum overshoot & maintain this temperature until the set temperature is changed, e.g. type of material being processed is changed. The various types of control system are:

- On/off switch controls without feedback.
- 2 point controller with PD(proportional derivative)
- " " " PID(proportional integral derivative)
- " " " DPID(differential PID)

The developments in barrel heating control have come a long way from on/off switching which would cause large overshoots & undershoots of temperature. PID controllers should be standard for injection moulding machines because they provide good reproducibility of settings(JOHANNABER 1985, PAGE 174). Although a good control of barrel temperatures cannot compare with the temperature of the melt as the latter is affected by geometry, rotational speed of screw, back pressure, feed travel, enthalpy of the material, residence time. Melt temperature deviations of +/- 5-30°C are possible. Measurement of actual melt temperature have failed so far as they are expensive & inadequate(JOHANNABER 1985, PAGE 174).

Machines are manufactured predominantly either with conventional &/or microprocessor cycle control.
Earlier cycle control systems used relays but the expected lifetime is months for moulding machines that can operate millions of cycles each year (BPTA 1991, PAGE 3.2).

After relays came the development of solid-state control. This method is very expensive form of control for injection moulding machines as the physical number of electronic components required is great (BPTA 1991, PAGE 3.2). This method of control is suitable for injection moulding machines which produce components that are not affected by large variations, e.g. material (JOHANNABER 1985, PAGE 176).

A further development in control systems is the central control (remote at cabinet). The processing of the commands is performed by electronic processors which are programmable or operate from memory. Setting is done with digital switches, decade switches or switches providing digital readout. The advantage of this type of control is that monitoring of cycles is made easier & reproducibility from one batch to another can be achieved (JOHANNABER 1985, PAGE 177).

Finally integrated digital control uses binary coded components instead of analogue. Settings are done at a central point & there is no significant difference to the analogue system in efficiency (JOHANNABER 1985, PAGE 178).

In conventional logic control systems all programs sequences are hard wired. This wiring is replaced by software in a microprocessor control. The microprocessor control receives instructions that specify how the signals arriving from the operator panel are to be linked with other process parameters stored in electronic memory units (JOHANNABER 1985, PAGE 181). A typical microprocessor controlled injection moulding machine is shown in figure 2-8.
Figure 2-8 Basic elements of a microprocessor controlled injection moulding machine (JOHANNABER 1985).
The various functions of a microprocessor control can be broken down into 3 basic functions, standard, monitoring & control (Table 2-7) (JOHANNABER 1985, PAGE 185).

<table>
<thead>
<tr>
<th>BASIC FUNCTIONS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>STANDARD:</td>
<td>OPERATION CONTROL</td>
</tr>
<tr>
<td></td>
<td>TIMER FUNCTIONS</td>
</tr>
<tr>
<td></td>
<td>DISPLACEMENT ACTUATOR FUNCTIONS</td>
</tr>
<tr>
<td></td>
<td>ALPHANUMERIC DATA DISPLAY</td>
</tr>
<tr>
<td></td>
<td>LIMIT-VALUE MONITORING</td>
</tr>
<tr>
<td></td>
<td>MALFUNCTION INDICATION</td>
</tr>
<tr>
<td>MONITORING:</td>
<td>SELF-DIAGNOSIS OF MALFUNCTIONS</td>
</tr>
<tr>
<td></td>
<td>CRT (CATHODE RAY TUBE) DISPLAY</td>
</tr>
<tr>
<td></td>
<td>CONTROL SETUP PROCEDURE</td>
</tr>
<tr>
<td></td>
<td>CALCULATION OF OPERATING DATA</td>
</tr>
<tr>
<td></td>
<td>ACCEPTANCE OF DATA FROM OPERATING CARRIER</td>
</tr>
<tr>
<td></td>
<td>CONNECTION TO A CENTRAL MONITORING SYSTEM VIA INTERFACE</td>
</tr>
<tr>
<td></td>
<td>CORRECTION VIA A CENTRAL MONITORING SYSTEM</td>
</tr>
<tr>
<td>CONTROL:</td>
<td>ALL TEMPERATURE CONTROL (MOULD, BARREL &amp; HYDRAULIC SYSTEM)</td>
</tr>
<tr>
<td></td>
<td>PROCESS CONTROL (SPEED &amp; HOLDING PRESSURE)</td>
</tr>
</tbody>
</table>

Table 2-7 Basic functions of a microprocessor control system.

The control cabinet location is usually centralised & can be remote or an integral part of the machine. The latest microprocessor controlled machines allow the operator to move the controls (VDU & keyboard) to position around the clamping unit or injection unit in order to improve visibility.

Electro-hydraulic systems are mainly used within injection moulding machines, but growing interest is being expressed in an "all electric" moulding machine (CINCINNATTI 1990).

A comparison of both "hydraulic" & "electric" powered moulding machines is shown in table 2-8.

Hydraulic machines are fitted with electrically powered hydraulic pumps. There are variations in designs of the hydraulic power systems where two pumps can be used with the combination of an accumulator in order to reduce the power consumption (SEUTHE 1990).
<table>
<thead>
<tr>
<th>MACHINE TYPE</th>
<th>ELECTRIC CAPACITY (INSTALLED) KW</th>
<th>POWER CONSUMPTION (AVERAGE) KW</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL ELECTRIC</td>
<td>15</td>
<td>3.5</td>
</tr>
<tr>
<td>HYDRAULIC</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>HYDRAULIC + ACCUMULATOR</td>
<td>11 (24% less)</td>
<td></td>
</tr>
<tr>
<td>HYDRAULIC + ACCUM. + ELECTRIC MOTOR</td>
<td>10 (32% less)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2-8 Comparison of 2 types of power systems for injection moulding machines, 150 tonnes clampforce (CINCINNATTI 1990) (SEUTHE 1990).

Electric machines in comparison have a lower power consumption even though the installed capacity is identical. All electric machines require 7 motors to achieve all the required movements. The overall benefit of electric machines is the overall power consumption is considerably less than an equivalent hydraulic machine. Electric machines have additional benefits e.g. reduced noise levels. Power efficiencies of electric machines is typically 90–95% compared to hydraulic machines at 30–50% (CINCINNATTI 1990).

One final note on hydraulic powered machines is that the condition of the hydraulic oil governs the machine operation & it is recommended that an automatic oil filtration system is fitted to reduce contamination by particles & moisture (KIRKHAM 1991).

Safety is covered under the section "methods" later in the chapter but the safety of injection moulding machines is primarily the responsibility of the manufacturer. The manufacturer has to design equipment which would not present a safety hazard to its users under the current legislation, Health & Safety at Work Act 1974 (BRYDSON 1990, PAGE 201). A British standard has been published which adopts an European standard (EN201) which recommends safety requirements for the design & construction of injection moulding machines (BS6679 1985). Aspects such as recommended noise levels should be agreed by customer & manufacturer as there are differences in legislation in each countries.
This does not relate to the services in the general facility but to the services that are installed on the injection moulding machine to supply power to ancillary equipment such as robotics & material handling systems. Services that can be fitted by the manufacturer (HUSKY 1980, PAGE 54) can include:

- Electrical power outlets, single & three phase.
- Compressed air.
- Electrical & communication supplies for information technology systems.
- Cooled water for cooling hopper throat, hydraulic system & for mould temperature controllers.

Reliability & maintainability are key elements if the required lifetime of the moulding machine is to be achieved. The reliability of injection moulding machines is difficult to predict unless the manufacturer has a proven record of the lifetimes of past equipment installations. Most moulding machines are required to operate with the minimal of attention & for long periods between maintenance schedules. The use of modern microprocessor control increases the expected lifetime & typically very little failure is expected for a period spanning 10 years as most moulding machines are depreciated over a period of 7 years. Abuse & a lack of periodic servicing will reduce significantly the lifespan of the moulding machine.

Maintainability refers more to the methods of regular servicing & the ease of servicing. A requirement placed on companies when they adopt a recognised quality system (BS5750 1987) is that regular calibration of the equipment is required & any deviations to be remedied quickly. Manufacturers usually offer (at increased cost) this calibration service as part of the regular maintenance service contract.
2.1.4 RAW MATERIAL HANDLING

The days of lifting & pouring granular raw plastic material in a hopper & drying with no more than a simple hand dryer are quickly disappearing. Instead automatic centralised drying, blending, recycling, & conveying of raw materials directly to the hopper throat is becoming the norm. Why the need for improved raw materials handling? Benefits include (LITHERLAND 1990):

- Increased drying efficiencies.
- Labour savings.
- Space savings.
- Reduced contamination.
- Aesthetics, better housekeeping.
- Better inventory control.
- Ability to monitor throughput of raw materials.
- Materials accountability.

The following section describes aspects of:

- Storage.
- Conveying.
- Drying.
- Blending.
- Recycling.
- Control.

Storage of raw material is dependant upon the volume of raw material throughput. Raw material suppliers have varied methods of supplying raw materials (HUSKY 1980, PAGE 86) as shown in table 2-9.

<table>
<thead>
<tr>
<th>THROUGHPUT (TONNES PER MATERIAL PER COLOUR)</th>
<th>STORAGE METHOD</th>
<th>DELIVERY METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 50</td>
<td>BAGGED (25 Kg)</td>
<td>PALLETISED</td>
</tr>
<tr>
<td>50 to 500</td>
<td>BULK CONTAINERS (Octabins)</td>
<td>PALLETISE</td>
</tr>
<tr>
<td>500 &amp; ABOVE</td>
<td>SILO</td>
<td>BULK CONTAINER</td>
</tr>
</tbody>
</table>

Table 2-9 Various types of raw material supplies.
There are so many types of conveying that only a short summary can be given. Key factors when selecting material conveying systems (HUSKY 1980, PAGE 90) include:

- Processing rate of material at each moulding machine.
- Type of material to be conveyed & its form.
- The bulk density of the material.
- Horizontal & vertical conveying distances.

The systems available include:

- Negative(vacuum) systems.
- Positive(pressure) systems.
- Vacuum & pressure combination systems.
- Pneumatic venturi systems.
- Vacuum hopper loaders(air or vacuum or electric).

There are 2 reasons for drying raw materials before processing.

Firstly, hygroscopic materials such as ABS, PC, PA & PET absorb moisture from the ambient air into the core of the granule (WANDAHL 1982, PAGE 2) (HUSKY 1980, PAGE 109). This moisture can cause various defects when moulded. Undried or semi-dried ABS can exhibit (WANDAHL 1982, PAGE 4) (FOWLER 1992):

- Silver(mica) surface streaks.
- Delamination.
- Brittle product.
- Inconsistent production.
- Blemish, surface marks around gate.
- Contribute to poor weld lines.

When undried PC is moulded, not only do some of the above defects appear but the impact properties are greatly reduced, e.g. within 21 hours storage (at 23°C & 50% relative humidity) the impact strength has been reduced to 15% of its original value (WANDAHL 1982, PAGE 4). Drying of PC in a dehumidifying dryer at 120°C for 2-3 hours obtains full recovery of impact properties.
Secondly, it is also necessary to dry non-hygroscopic materials. Condensation occurs during storage & transportation & surface moisture is formed on the surface of the granule (WANDAHL 1982, PAGE 2) (HUSKY 1980, PAGE 109).

There are various types of drying systems as shown in table 2-10.

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>DRYING SYSTEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OVEN WITH FAN</td>
</tr>
<tr>
<td>COST</td>
<td>UNDER £1000</td>
</tr>
<tr>
<td>DRYING EFFICIENCY VARIES WITH AMBIENT*</td>
<td>YES</td>
</tr>
<tr>
<td>TIME DRY ABS</td>
<td>3-4 HOURS</td>
</tr>
<tr>
<td>MOUNTING</td>
<td>MOBILE OR STATIC</td>
</tr>
</tbody>
</table>

Table 2-10 Comparison of drying systems.

An oven is suitable where small quantities of raw material needs to be dried but the drying efficiency is affected by the relative humidity of the air which if greater than 4 grams/ Kg will cause difficulties in drying (WANDAHL 1982, PAGE 13). The raw material is usually placed in trays & therefore the granules near the top of the tray will dry first which means that only thin layers will ensure consistent drying of material. A circulating air fan is usually fitted to aid drying.

Hot air systems work on the principle of drying the granules by forcing air through a hopper of raw material & recirculating this air. Drying efficiencies of hot air systems are also affected by humidity of ambient air.
The most efficient drying systems are dehumidifying dryers which use the same forced air circulation principle as hot air systems but the circulated air is passed through a dessiccant bed to remove air moisture. As the dessiccant bed becomes saturated a secondary bed is being dried (charged). Switching from saturated to unsaturated dessiccant bed is controlled by microprocessor which ensure consistent drying. Other methods of drying are available such as the use of vented barrels as detailed earlier in this section.

Some manufacturers offer predried materials which are enclosed in vacuum sealed bags, but the risk of damage during transportation & storage would necessitate some form of drying if the predried sealed container was punctured.

There are 3 main areas of blending in an injection moulding facility:
- Colouring.
- Re grind.
- Additives.

Blending has received significant discussion over the past 10 years as it can remove much of the work carried out by compounders. Compounders would normally supply raw material which has been processed with a pre-blend, i.e. blended (colour & additives), extruded, cooled (water bath), chopped (granulator) & sieved. This eliminates the needs for most blending on-site with the exception of regrind. There are disadvantages to compounded material in that it requires more storage space. The potential cost & inventory reduction of using on-site blending means that equipment manufacturers are continually developing more advanced blending equipment to overcome some of the difficulties associated with on machine blending i.e. inconsistent metering & mixing (HUSKY 1980, PAGE 98).

Colour blending can be done using various forms of pigments, e.g. dry powder, liquid colour & colour concentrate (granule). Due to the difficulties in handling powder & liquid colour, colour concentrate or masterbatched granules has become the most popular method of colouring.

There are two methods of metering masterbatch granules. These are:
- Volumetric (by volume).
- Gravimetric (by weight.)
Volumetric type blending equipment is most readily available & is cheaper than gravimetric equipment. There are difficulties with volume blending, where variation in masterbatch granule particle size, variation in bulk density between additive & polymer, static electricity & vibration can all cause layering & separation (LEE & McKAY 1992). If colour is not a critical feature of the moulding then volumetric dosing is quite suitable with dosing rates at 4-5% masterbatch to base raw material. Usually a paddle mixer is fitted to aid blending.

Where metering rates are as low as 1% & colour is required to be consistent from batch to batch then gravimetric blending is recommended. There are various types:
- Batch proportioning.
- Sequence weighing of volumetric additive & polymer.
- Continuous gravimetric blending of all ingredients.

The accuracies that can be achieved with the latter type can be 0.25% of feedrate (LEE & McKAY 1992).

There are various additives that can be added to aid processing & improve the final moulding. These include (HUSKY 1980, PAGE 108):
- Antimicrobials (inhibit bacteria).
- Antistatics.
- Blowing agents (release a gas to expand polymer).
- Catalysts & hardeners (reinforcement).
- Fillers (talc, glass fibres)
- Impact modifiers.
- Lubricants (easier processing).
- Stabilisers (ultraviolet light & heat).
- Surfactants (dispersion of pigments).

The dosing equipment available for blending the above additives & regrind is similar to equipment used in colour blending.
Recycling & reclamation is an important issue in today's world where the minimal or even no impact upon the environment is being sought (OERTEL 1989). The key aspect when designing a process is reducing the level of physical waste that has to be disposed of. The source of most wasted material is:

- Inefficient tooling (% of scrap sprue & runners to good mouldings).
- Rejected mouldings.
- Material used in changeover (purging old material).

Having identified the source of the scrap, the first possible improvement is whether the scrap can be eliminated. Scrap due to inefficient tooling is quite difficult to overcome once the mould-tool has been manufactured & it is unlikely that a more efficient form of runner system (hot runner) can be incorporated. In most cases the tool cannot be modified & therefore a regrinding system is required.

Material scrapped during purging is almost certainly contaminated & therefore can only be disposed of.

Some mouldings cannot accept reground material due to a certain feature being critical in the end product e.g. impact properties & aesthetics. If reground material is acceptable within the product then there are various types of granulators available (cutting action varies with manufacturer):

- Manually or robotic (sprue picker) fed with vertical throat.
- Auger feed into cutting chamber to reduce jamming of rotor.

The location of granulator is also critical. Granulating next to the moulding machine can reduce contamination, drying & inventory of regrind as compared with centralised grinding (LITHERLAND 1990).

Safety & noise aspects on granulators has been traditionally difficult problems to overcome. Manufacturers have now developed slow rotational speed granulators that reduce noise levels to within legal limits. The design of granulators that are safe to use has been one of the major concerns of the plastics industry & a code of practice has been published (BPF 1981).

Once the material has been reground then the regrind can be reintroduced (proportioned) with the virgin raw material as discussed in an earlier section on blending.
The latest raw material handling systems can incorporate a remote control panel with touch screen technology allowing all parameters of the system to be interrogated, e.g. throughput, temperatures & dosing rates for additives etc.

A final note on material handling is that even with the most sophisticated handling system, contamination cannot be ruled out. In particular, metal objects have to be prevented from entering the barrel of the injection moulding machine. Metal separators are available (KILLINGER 1989) but also low cost magnets placed in the material path will avoid very expensive damage to injection unit components.

2.1.5 MOULD-TOOLS

The project requirements did not include investment in new mould-tooling therefore a summary will be given on areas applicable to the project.

The most common type of tooling is the 2 plate tool (Figure 2-9).
There have been two paths of development from the 2 plate tool (Figure 2-10) (PYE 1989, PAGE 445).
Figure 2.10 Developments within mould-tooling (PYE 1989).
The manifold nozzle was developed in the early period of injection moulding to allow individual impressions of a standard 2 part mould to be fed from the underside. The manifold nozzle is external to the mould-tool & is basically an extension of the injection unit.

The hot runner was developed from the manifold nozzle. The hot runner unit is mounted within the structure of the mould-tool & has to be suitably insulated from the rest of the mould. Temperature control of hot runners is usually remote or integrated within the controls of the moulding machine (PYE 1989, PAGE 445).

The underfeed or 3 plate mould-tool allows underfeed of the component. During moulding cycle the mould-tool separates in 2 sections & the sprue & runner are ejected separately from the components.

The insulated runner was developed directly from the underfeed type when it was found that certain materials can be moulded without removing the runner by keeping the two front section latched together. This technique is possible only because the polymer exhibits good insulating properties (PYE 1989, PAGE 445).

The only problem with the insulated runner type mould-tool was that the gate would freeze if the cycle was interrupted. To minimise this effect, localised heating can be introduced by incorporating a heater probe element in the centre of the melt flow path.

Most of the mould-tool designs are still in current use & the optimum type can be selected on the basis of (PYE 1989, PAGE 447):
- Complexity of component.
- Method of feed & gating allowed (underfed not critical to aesthetics).
- The reduction of waste material per shot (no sprue or runner).

There are specialist applications. One such mould-tools was manufactured in a stack configuration, with 4 parting lines allowing 4 times the output of a conventional tool but with the same clampforce. The mould-tool was designed with thermal & rheological balanced cavities using CAD & required a unique melt transfer system (BPR 1991d).
The number of cavities is determined at the design stage & is calculated on:

- Quantity output each year.
- Utilisation of the full clampforce of the machine.
- Physical size of component.
- Complexity of component.

Increasingly mould design incorporates simulation of melt flow within the mould runner system(AUSTIN 1991). The main reason for using simulation is to minimise residual stress & avoid warpage & sink marks.

The level of residual stress in transparent components can be checked using polarising sheets. For opaque components a reversion test is used whereby a family of circles are drawn on the moulding. The moulding is then placed in an oven at a specified temperature. The major & minor axis of the ellipses are then measured(AUSTIN 1991, PAGE 11).

The effect of moulding conditions(mould & melt temperature & fill time) can be simulated at the design stage & their effects minimised to produce an optimum filling pattern(AUSTIN 1991, PAGE 17). Software programs are available to predict pressure, temperature, shear rate, shear stress & cooling time. The use of CAD software helps to decide on(AUSTIN 1991, PAGE 30):

- Number of gates.
- Positions of gates.
- Flow pattern.
- Runner design.

One good example of the benefits of CAD is in the design of family mould tools. Family mould tools are specialised in that several different sizes of components are manufactured in a single moulding cycle. The critical aspect of designing a family tool is to obtain identical rate of cavity filling. Identical runner & gate dimensions would produce overpacked(warped) small components & underpacked(sink marks or short shot) large components. The runner & gate system needs to be redesigned to allow small & large components identical filling & packing(AUSTIN 1991, PAGE 57).
The true benefit in the use of computer simulation in the design of mould tools makes the difference between a difficult moulding process or a small processing window (i.e., range of processing conditions) to a tool with a well designed runner system which can be moulded with a large processing window.

There are various types of gates design, some of which require the component to be degated after moulding while others can be automatically degated upon ejection.

The design of component to be moulded also dictates the complexity of tool. Various re-tractable cores & ejection mechanisms (mechanical, air or hydraulically operated) require special consideration when selecting the injection moulding machine.

Mould cooling is important as it is significant to the moulding cycle & therefore the cost of the component. As the melt enters the mould, it cools rapidly to a temperature at which it solidifies sufficiently to retain the shape of the cavity. Having too low a mould temperature can greatly affect the filling or the properties of the final moulding & usually a compromise is reached (PYE 1989, PAGE 180).

The operating temperature for a particular mould will depend on:
- Type & grade of material being moulded.
- Length of flow within the cavity.
- Wall section of the moulding.
- Length of the feed system.

Sometimes it is advantageous to use a slightly higher temperature than is required to fill the cavity, as this tends to improve the surface finish of the moulding by minimising weld lines, flow marks & other blemishes (PYE 1989, PAGE 180).

The cooling channels are designed in the tool to give an even cooling across the moulding surface. The cooling channels are usually unconnected & a circuit is usually formed by connecting flexible pipework to the open ends by means of suitable connectors. This is an important point if toolchange time is to be reduced that no errors are made in connecting this pipework. Usually incorporating standard backplates fitted with manifolds can eliminate the need for manual connection.
Equipment for mould cooling needs to be considered in advance with mould temperatures above 95°C requiring an oil medium while below this temperature water systems are sufficient.

Another difficult area of interface between tool & machine is the ejection system. There are various types of hydromechanical ejection systems:
- Single bar ejection plate in centre of platen.
- Multi bar ejection plate for large mould tools (equaly spaced).

Various methods are available for connecting the above:
- Non-tied ejection, spring return.
- Tied ejection, manual connection of threaded bar.
- Tied ejection, automatic coupling from machine controls.

Single bar ejector plate can incorporate an automatic coupling of ejector while the multi ejection is more difficult & can only be done manually. The coupling of the ejection is very often overlooked & a changeover time can be increased by 15 minutes for a multi ejection plate system & within a few seconds if an automatic coupling is available.

Automatic ejection coupling almost certainly requires the use of standard lengths of ejector rod protruding from the tool to obtain a reference datum so that it can controlled by the main injection moulding machine controls.

Traditionally the procedure for mould clamping was to locate the tool on the fixed platen by the tool register ring (standard size). The mould tool could then be firmly clamped to the fixed platen & a similar procedure undertaken for the tool on the moving half of the platen (PYE 1989, PAGE 71). When trying to reduce the setup time then safe tool changes are required. Developments in tool changing systems have adopted the use of standard backplates which are clamped to the tool & the accuracy of backplate to tool is set once at the initial set-up & every subsequent mould-tool change doesn't require resetting (re-registering the tool to the moulding machine). The mounting of cooling water, electrical, air & hydraulic connections by a manifold onto the backplates means that the procedure of mould-tool changing becomes safe, repeatable & quick.
2.1.6 TOOL HANDLING

The development of tool handling equipment is particularly important to safe & quick change over of tools in an injection moulding process (SHINGO 1985). The reason for quick changeovers is that the concept of SMED (single minute exchange of dies) can be achieved. As well as selecting the most suitable equipment for tool handling there are many practical solutions that require little cost to achieve SMED e.g quick clamps & tools at workstation (SHINGO 1985).

Various methods are available for transporting tools which vary from forklifts, mobile tables & hoists. Each can be manual, semi-automated or fully automated. Forklifts are not recommended for the difficult tool manouevring required as any breakdown of communication between operators can easily lead to an accident (HUSKY 1980, PAGE 30).

Some difficulty can be experienced when vertically loading large mould-tools in between the platens. Where the tool is physically larger than the distance between tiebars, then the mould-tool has to be rotated or brought into position horizontally by means of a mobile table.

The 2 main types of handling systems are shown in figure 2-11.
Figure 2-11 Vertical & horizontal mould-tool handling.
2.1.7 COOLING SYSTEMS

The areas requiring cooling are:
- Mould.
- Moulding machines.
- Mould cooling systems.
- Mould temperature controllers.

Nearly all mould tools require cooling with the exception of short life & prototype tooling where cooling is omitted. Cooling is usually achieved by passing a suitable medium (water or oil) to remove heat from the cavity area. Heat dissipated through the mould tool by conduction is transferred to the circulating fluid & the heat removed by chillers or water cooled heat exchangers. The rate of heat removal is a major factor in achieving the required standard of final moulding & can contribute to up to 80% of the cycle time (HUSKY 1980, PAGE 118).

There are two methods of calculating the rate of heat removal:
- Detailed calculation.
- Empirical data (HUSKY 1980, PAGE 118)

For the purpose of this thesis detailed calculations are not required as information is readily available by manufacturers.

Empirical data relies on some basic assumptions being made. Calculation of chiller capacity is done neglecting losses of heat to the air & injection moulding machine. The quantity of heat that must be removed from the mould to cool the plastic melt can be determined from a heat content (enthalpy) graph for the respective polymer. The heat input of the mould heaters (if used) should be included in the calculations. The sizing of circulation pump, chilled water piping & reservoir. Additional heat removal from the chilled water is required to offset the heat gained caused by the circulating pump & heat transfer through the piping & reservoir. Heat load is usually given from experience.

Once the total heat load has been calculated then the chiller system can be selected.

Chilled water is usually at a temperature of between 10-16°C.
To ensure turbulent flow, flowrate of chilled water is 150 litres/minute per mould-tool. Circulating pump pressure to be 75 PSI to overcome pressure losses in the moulds & piping. Well insulated chilled water piping & reservoir minimises the heat gain from ambient air within the plant.

Cooling towers can be used for supplying cooling water to injection moulding machines directly or through intermediate systems (water cooled chillers & MTC). The cooling of injection moulding machines relates to the maintaining the hydraulic fluid at a temperature between 46-52°C (HUSKY 1980, PAGE 133). All open cooling systems such as cooling towers require a suitable water treatment to protect people from legionellae & equipment from a build up of corrosion, mineral substances & organic growth (HUSKY 1980, PAGE 139).

Chillers are self contained refrigerators with reservoirs & circulating pump to supply cooling water to the mould. Chillers are available either air cooled or water cooled & can be either sited at each moulding machine or located at a central point with distributed feed.

Where a cooling requirement exists for more accurate temperature control &/or the temperature exceed 95°C (oil medium) then a MTC (mould temperature controller) is interfaced between the cooling system & the mould. The size requirements are difficult to calculate & usually is based upon previous experience (HUSKY 1980, PAGE 131).

2.1.8 PRODUCT HANDLING
The requirement for companies to continually improve on the costs of their products to remain competitive means that there is an emphasis upon automating manual processes. Reasons include:
- The increasing costs of labour above profit (HUSKY 1980, PAGE 60).
- The aspect of eliminating dull & repetitive costs.
There are so many types of handling systems (Table 2-11) that only a brief summary can be given here. Product handling includes:

- Any finishing operations before packing.
- Shape of component, i.e. can it be stacked or does it require individual packaging.
- Standard of moulded component, i.e. key features of component, any gauging requirements, checks on aesthetic finish such as colour.
- Volume & batch size govern the speed of handling i.e. can the handling device be within or less than existing moulding machine cycle.
- Is it capable of handling a range of components.

<table>
<thead>
<tr>
<th>HANDLING METHOD</th>
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<td>PICK &amp; PLACE</td>
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<td>ROBOTS</td>
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</table>

Table 2-10 Product handling methods.

2.1.9 SERVICES & LAYOUT
There are services that must be distributed to various parts of the injection moulding machine & ancillary equipment. These include compressed air, water, electric (power & lighting), air conditioning, ventilation & heating.

Compressed air is required for:
- Mould-tools during ejection stroke.
- Conveying of materials (material handling).
- Secondary operations.
- General maintenance requirements.
Water is required for various areas of the injection moulding machines & the interface with the mains water is quite critical & bye-laws have to be adhered to.

Electrical power for a small number of machines can usually be accommodated with the existing supply to the factory but if the installed power (KW) for each individual moulding machine & ancillary equipment is added & multiplied by the power factor then the total KVA can be calculated. The power factor ideally should be 1 & it is defined as the phase difference between the voltage & current sinusoids with either the current curve lagging or leading the voltage. The power factor is dependant upon the nature of the load & not upon the generator (generating company). Thus if the power factor is 1, power is equal to VA. The effect of power factor can be quite significant & electrical supply companies do all they can to improve the power factor of their loads either by installation of capacitors or special machines or by the use of tariffs which encourage consumers to do so (HUGHES 1981, PAGE 325).

Another aspect to consider is diversity factor which reduces the total power required. As injection moulding machines have varying power demands throughout the moulding cycle then the total KVA demands can be reduced according to local electricity supply codes (HUSKY 1980, PAGE 172).

It can now be proven (HUSKY 1980, PAGE 150) that lighting systems & their effectiveness can contribute substantially to:
- Increased productivity.
- Improved quality control.
- Reduced scrap.
- Safe working environment.
- Improved employee moral.
- Better control of housekeeping.

There are various types of lighting:
- Incandescent.
- Fluorescent.
- High intensity discharge (mercury-vapour, metal-halide, high pressure sodium lights).
Exact requirements can be termed:
- Luminocity.
- Lumen maintenance.
- Electrical characteristics.
- Construction.
- Light distribution.
- Shielding.
- Spread.
- Colour.
- Life.
- Cost.

Air conditioning, ventilation & heating requirements also contribute towards high levels of machine & labour productivity (HUSKY 1980, PAGE 160). The recommended year round operating conditions are 21-24°C & 45-50% relative humidity. Ventilation is specific to the polymer being processed & careful planning must ensure that planned changes in legislation can be accommodated easily. Heating is not so much a source of difficulty as injection moulding machines are heat sources themselves, but any heat extracted from air cooled chillers can be re-distributed to heat other parts of the factory.

The planning of the layout is crucial & has significant impact upon the effectiveness of the operation. Objectives of plant layout should include (HUSKY 1980, PAGE 182):
- optimum material flow.
- efficient use of floor space.
- optimum labour productivity for the level of automation selected.
- allow for future expansion without disturbing existing production.

In order to simulate the various options, the use of computer aided design can rapidly develop the optimum layout (OPEN UNIVERSITY 1986, UNIT 7, PAGE 6). Once the requirement has been finalised for the layout & various services, a decision is made on the method of relaying the services to the various equipment. Various distributions include (HUSKY 1980, PAGE 204):
- Overhead.
- Floor level.
- Below the floor (service tunnel & trench)
2.1.10 BUILDINGS

Only a brief consideration of buildings can be made & areas of importance:

- The foundations or floor slab supporting the injection moulding equipment needs to be designed to accept the load.
- Floor should be sealed to inhibit dust & resistance to penetration of oil.
- Any trenches & tunnels should be suitably constructed to accommodate all the required services (HUSKY 1980, PAGE 227).
- Roof insulation.
- The installation of fire protection devices (HUSKY 1980, PAGE 231).

2.1.11 MAINTENANCE

The equipment required for maintaining an injection moulding facility can be quite considerable. If an existing maintenance function exists then much of the diagnostic equipment will already exist. The following is an additional list for maintenance of mould-tools:

- Clean area.
- Stripping table for tools.
- Turnover jig for rotating tools from vertical to horizontal.
- Hand tools for polishing cavities.
- Access to inhouse or external facilities for major work, spark eroder, lathes, millers, surface grinder.
- Service hoist.
- Inspection equipment.
- Storage area for spares.
2.2 Materials.

This section looks at the developments (table 2-12) of the plastic materials that are now commonly used in injection moulding.

<table>
<thead>
<tr>
<th>MATERIALS</th>
<th>KEY</th>
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Table 2-12 Developments of injection moulding materials.

Polymers consist of atoms of various elements linked together to form monomers which are multiplied to form long chains. Due to the inherent number of links an atom can make to another atom (valency of an atom) various structures can form with single, double or triple bonds. This is further complicated by the non-planar nature of the molecules where atoms bonded to one another have bond angles (BRYDSON 1990, page 5). An example of two polymers which are specific to the project are shown in the following diagram (figure 2-12).
The development of polymers began with natural occurring materials such as rubbers & synthetic materials like Bakelite in the last century (OPEN UNIVERSITY 1984a, UNIT 1). In the above example the plastic are PS, SAN & ABS which is 3 different monomers polymerised together. The basic elements carbon, hydrogen & nitrogen form the basic building blocks of each monomer. How the monomers are linked together control the physical properties of the final polymer. Traditional polymers like PE, PP, PVC & PS are limited in application particularly for engineering use by virtue of their low melting or glass transition temperature. The introduction of aromatic rings (Benzene) stiffen the chain structure, increase the glass transition temperature & resistance to burning (OPEN UNIVERSITY 1984a, UNIT 1, PAGE 15).
The alloying of metals to improve properties is quite common. The increasing demand for improved properties in plastics to meet specific application such as increased toughness is achieved by polymerisation of 2 or 3 different monomers(copolymerisation). Blending of two polymers is quite difficult but the process known as copolymerisation gives the option of many possible chain structures from block copolymers, alternating copolymers & random(ideal) copolymers(OPEN UNIVERSITY 1984a, UNIT 1, PAGE 31). Rigid thermoplastics have examples of widely used copolymers such as ABS, HIPS & SAN. HIPS & ABS are graft polymers where the side chains are deliberately introduced to improve the toughness of the materials. ABS has butadiene monomer grafted onto the styrene-acrylonitrile chains which increases the toughness properties over the polystyrene homopolymer or styrene-acrylonitrile copolymer. When stress is applied the material surface forms a "craze" which is due to the polybutadiene particle stretching to create voids which allow the material to absorb large amounts of energy.(THE OPEN UNIVERSITY 1984a, BROADCAST BOOK, PAGE 5). HIPS is a low rubber content styrene polymer grafted to polybutadiene & may be regarded as an intermediate polymer between PS & ABS. The principle of rubber toughening is now common for a range of other polymers e.g. PA, PC & PP.

While plastics are based upon polymers, polymers are not necessarily plastics e.g. some polyesters can be plastics, rubbers, fibres, surface coatings or adhesives. For the purpose of this project only plastics such as ABS and SAN etc. are further considered.

2.2.1 PLASTICS
There are two types of plastics, thermosetting & thermoplastic, and they are distinguished by their inability or ability to reversible softening after heating & cooling.

Thermosets are defined as polymers which become irreversibly hard on heating or by addition of special chemicals(THE OPEN UNIVERSITY 1984a, UNIT 1, PAGE 9). The hardness is a chemical change known as curing which makes this type of plastic impossible to recycle unless used as a filler. The curing process cross-links chains of molecules to form a hard structure. The particular disadvantage to thermosets is the specialized equipment required for moulding and the inability to regrind the material except for fillers.
Thermoplastics however are plastics which are capable of reversible softening after heating & cooling (THE OPEN UNIVERSITY 1984a, UNIT 1, PAGE 9).

2.2.2 THERMOPLASTIC
A further evaluation thermoplastics can be broken down into the molecular structure, properties & processing.

There are two main types of thermoplastics, amorphous & crystalline. The two forms of thermoplastics can be easily recognised when they contain no additives, amorphous structures being transparent while semi-crystalline structures are translucent or opaque. The following diagram (Figure 2-13) shows the arrangement of molecular chains within the two structures. An amorphous molecular structure is random while a semi-crystalline structure has a locally ordered arrangement similar to that of crystalline solids (BRYDSON 1990, PAGE 8).

Figure 2-13 Molecular chain structure of thermoplastics at various states.
When cooled, molten high molecular weight amorphous materials pass through a rubbery state (where the molecular chains move by rotating their bonds) to a glassy state (where the molecular bonds do not have the ability to move). The transition between rubbery and glassy state is termed the GLASS TRANSITION TEMPERATURE, $T_g$.

Semi-crystalline thermoplastics on cooling show a change from viscous to a rigid semi-crystalline structure depending upon molecular weight. When heated a temperature is reached whereby crystallinity disappears, this is called the CRystalline Melting TEMPERATURE, $T_m$. On cooling crystallisation occurs between $T_m$ and $T_g$ and is dependent upon the rate of cooling (high rate/little crystallinity etc). Crystalline polymers shrink more on cooling due to their more ordered structure. An amorphous polymer would shrink in the order of 0.5% whilst a crystalline polymer shrinks in the order of 1-6%. This influences the design of mould tools and rate of mould cooling during processing.

Comparison of various manufacturers polymers is difficult as various manufacturers have their own methods of tests. To overcome this the British Standards Institution have published a standard for the acquisition and presentation of comparable data for basic properties of plastics (BS7008 1988a/b). A complete list of properties are shown in table 2-13.

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</tr>
<tr>
<td>HARDNESS</td>
<td>*</td>
</tr>
<tr>
<td>COST</td>
<td>*</td>
</tr>
<tr>
<td>OPTICAL</td>
<td></td>
</tr>
<tr>
<td>FRICTION</td>
<td></td>
</tr>
<tr>
<td>DIMENSIONAL STABILITY</td>
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</tr>
<tr>
<td>MOULD SHRINKAGE</td>
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</tr>
<tr>
<td>LUBRICATING</td>
<td></td>
</tr>
<tr>
<td>WEAR</td>
<td></td>
</tr>
<tr>
<td>APPEARANCE</td>
<td></td>
</tr>
<tr>
<td>OPTICAL</td>
<td></td>
</tr>
<tr>
<td>SURFACE FINISH</td>
<td></td>
</tr>
<tr>
<td>COLOUR &amp; COLOUR RETENTION</td>
<td></td>
</tr>
<tr>
<td>SCRATCH RESISTANCE</td>
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Table 2-13 Basic list of properties applicable to plastics.
## PROPERTIES CONTINUED

<table>
<thead>
<tr>
<th>THERMAL</th>
<th>TEMPERATURE OF DEFLECTION UNDER BENDING</th>
<th>BS7008</th>
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<tr>
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<td>VICAT SOFTENING TEMPERATURE</td>
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</tr>
<tr>
<td></td>
<td>THERMAL CONDUCTIVITY</td>
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<td></td>
<td>THERMAL INSULATION</td>
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<tr>
<td></td>
<td>SPECIFIC HEAT CAPACITY</td>
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<tr>
<td></td>
<td>TEMPERATURE OPERATING RANGE</td>
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<tr>
<td></td>
<td>RESISTANCE TO THERMAL AGEING</td>
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</tr>
<tr>
<td>FIRE</td>
<td>IGNITIBILITY</td>
<td>*</td>
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<td></td>
<td>FLAMMABILITY</td>
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<tr>
<td>ELECTRICAL</td>
<td>DIELECTRIC DISSIPATION FACTOR</td>
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<tr>
<td></td>
<td>RELATIVE PERMITTIVITY</td>
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<tr>
<td></td>
<td>VOLUME RESISTIVITY</td>
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<tr>
<td></td>
<td>SURFACE RESISTIVITY</td>
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<tr>
<td></td>
<td>ANTI-STATIC PROPERTIES</td>
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<tr>
<td></td>
<td>TRACKING RESISTANCE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ELECTRIC STRENGTH</td>
<td>*</td>
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<tr>
<td></td>
<td>ELECTRIC INSULATION</td>
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<tr>
<td></td>
<td>FLEXURAL MODULUS</td>
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</tr>
<tr>
<td></td>
<td>FLEXURAL STRENGTH</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>TENSILE CREEP MODULUS</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>TENSILE CREEP STRENGTH</td>
<td>*</td>
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<td></td>
<td>ELONGATION AT BREAK</td>
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<tr>
<td></td>
<td>IMPACT STRENGTH</td>
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<td></td>
<td>CREEP LATERAL CONTRACTION RATIO(POISSONS)</td>
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<tr>
<td></td>
<td>CREEP RUPTURE TIME</td>
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<td></td>
<td>DYNAMIC SHEAR MODULUS</td>
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<td>SHEAR LOSS FACTOR</td>
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<td></td>
<td>DYNAMIC FATIGUE</td>
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</tr>
<tr>
<td></td>
<td>FRACTURE TOUGHNESS</td>
<td>*</td>
</tr>
<tr>
<td>RHEOLOGICAL</td>
<td>MELT FLOW RATE</td>
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</tr>
<tr>
<td></td>
<td>VISCOSITY NUMBER</td>
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<td></td>
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<td>*</td>
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<tr>
<td>ENVIRONMENTAL</td>
<td>CHEMICAL RESISTANCE</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>ENVIRONMENTAL STRESS CRACKING</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>SOLUBILITY &amp; DIFFUSIVE TRANSPORT</td>
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</tr>
<tr>
<td></td>
<td>LIGHT/UV RADIATION</td>
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<td>VIBRATION DAMPING</td>
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<td></td>
<td>SOUND ABSORPTION</td>
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</tr>
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<td></td>
<td>OXIDATION</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WATER ABSORPTION</td>
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</tr>
<tr>
<td></td>
<td>EROSION BY SAND/WIND/RAIN</td>
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<td></td>
<td>ATTACK BY FUNGI/BACTERIA/INSECTS</td>
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</tr>
<tr>
<td></td>
<td>OZONE</td>
<td></td>
</tr>
<tr>
<td>HAZARDS</td>
<td>TOXICITY OF ADDITIVES</td>
<td></td>
</tr>
<tr>
<td>PROCESSING</td>
<td>CHOICE OF PROCESS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>METHOD OF ASSEMBLY</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FINISHING &amp; DECORATION</td>
<td></td>
</tr>
<tr>
<td>ECONOMIES</td>
<td>MATERIAL COSTS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CAPITAL COSTS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OPERATING COSTS</td>
<td></td>
</tr>
</tbody>
</table>

Table 2-13 continued.
At Rexel Engineering a range of thermoplastics and a few thermosets are used in the manufacturing of stapling machines as listed in the following table (Table 2-14). Selection of materials for particular applications were carried out approximately 10 years ago and there has been little change since for most products.

<table>
<thead>
<tr>
<th>POLYMER TYPE</th>
<th>NAME</th>
<th>APPLICATION (STAPLING MACHINE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMORPHOUS</td>
<td>ABS/SAN (BLEND)</td>
<td>Covers, bases and cover knobs.</td>
</tr>
<tr>
<td></td>
<td>PC</td>
<td>Tacker sideplates and handles.</td>
</tr>
<tr>
<td></td>
<td>ABS</td>
<td>Covers, bases and cover knobs.</td>
</tr>
<tr>
<td></td>
<td>HIPS</td>
<td>Low cost covers and bases.</td>
</tr>
<tr>
<td></td>
<td>EVA</td>
<td>Soft feel cover knobs, base pads.</td>
</tr>
<tr>
<td>SEMI-CRYSTALLINE</td>
<td>POM</td>
<td>Steadies and carriers.</td>
</tr>
<tr>
<td></td>
<td>PA66</td>
<td>Spacers.</td>
</tr>
</tbody>
</table>

Table 2-14 Thermoplastics used in today's stapling machine.

Material selection is very important in the design of products. There are many process & end product criteria which must be satisfied to some extent although in most cases a compromise is achieved. The consideration of these criteria must begin early on in the design process otherwise late changes can occur expensive modifications to tooling or even the production process e.g. plastics have various shrinkage rates & any tooling modifications by substituting an amorphous material for a semi-crystalline material will involve welding up cavities or even a new tool.

To aid the designer a computer based plastic materials selection system has been developed (RAPRA 1989). The database is user friendly allowing the designer to weight particular properties depending upon the end product application & desired production process. There are approximately 70 material properties to select & a database of 90 generic polymers. The database exceeds 350 different types of polymers when various fillers & processes are included. The designer is able to compare different polymers & make an initial selection. Final specification of polymer & grade can then be agreed with the raw material manufacturer.
Manufacturers also have polymer databases (GRACE 1989) & these are available to the designer but are limited to the polymers supplied by the individual manufacturer. Further developments by a group of manufacturers have introduced a database called "CAMPUS" (computer aided material preselection by uniform standard) which allows designers to compare polymer specifications from many of the major manufacturers (GRACE 1989).

2.2.3 PROCESSING
There are many processing routes which can be selected. The main criteria for selecting the required process in most cases is the volume of product & the opportunity it gives to recover the high initial capital investment. The following figure compares the various process routes available (figure 2-14).

Figure 2-14 Various processing routes for primarily thermoplastics (OPEN UNIVERSITY 1984).
Polymers are available from large polymer manufacturers in many different grades (hundreds) from various different process routes. The most important distinguishing characteristics are structures & molecular weight (THE OPEN UNIVERSITY 1984a, UNIT 1, PAGE 33). The copolymer grades offer greater toughness over a wider temperature range at the expense of stiffness e.g. ABS. Applications are more demanding than homopolymer & each polymer is available in several different melt flow grades (MFI). MFI is inversely related to molecular weight i.e. high MFI grades correspond to low molecular weight. High molecular weight polymers possess the best physical properties e.g. high molecular weight PP (low MFI) used in safety helmets & pipe fittings (THE OPEN UNIVERSITY 1984a, UNIT 1, PAGE 34).

The various types of additives are summarised as follows: -
- Pigments
- Lubricants
- Plasticisers
- UV & heat stabilizers
- Fire retardants
- Anti-static agents
- Bio-degradeable agents
- Fillers
- Anti-oxidants
- Blowing agents
- Special applications, plating

The ability to colour plastics is a great advantage but the development of pigments which are cadmium & lead free has meant that increasingly the pigment cost can be up to 20% of the raw material cost.

Lubricants are of two types, external & internal. External lubricants prevent sticking of molten polymer to processing equipment. Internal lubricants are designed to aid flow (BRYDSON 1990, PAGE 12).

Plasticisers make a polymer mass flexible e.g. plasticised PVC (BRYDSON 1990, PAGE 12).

Stabilizers are added to reduce the effect of UV & heat e.g. PVC (BRYDSON 1990, PAGE 12).
Fire retardants are for particular applications such as automotive under-bonnet applications.

Anti-static agents used for electronic components.

Bio-degradeable agents used where the product will be reduced to basic elements on disposal.

Fillers can be inert (e.g. whiting/china clay in PVC) or re-inforcing fibres (e.g. glass fibre & carbon fibre) (BRYDSON 1990, PAGE 12).

Anti-oxidants to reduce the effects of oxygen on ageing & at elevated temperatures e.g. polyethylene & polypropylene (BRYDSON 1990, PAGE 12).

The availability of blends has increased over the last few years e.g a simple blend of ABS & SAN (ratio 2:1 by weight) will improve the surface gloss, PC & ABS (ratio 1:1 by weight) improves impact & temperature resistance. In principle, a blend is a physical mixture of different polymers e.g. PC & ABS. It is different from a copolymer where the different monomers may be found on the same polymer chain. A blend may be expected to have quite different properties to a copolymer (BRYDSON 1990, PAGE 12).
2.3 METHODS.

Methods are ways of doing things or procedures. Most companies introduce methods when required to do so by law, or on the basis that it is "best industrial practice". Methods which affect the injection moulding facility are shown in table 2-15.

<table>
<thead>
<tr>
<th>METHODS</th>
<th>KEY</th>
</tr>
</thead>
<tbody>
<tr>
<td>:...LEGISLATION</td>
<td>:...HASAWA(HEALTH &amp; SAFETY AT WORK ACT)</td>
</tr>
<tr>
<td>:...BEST PRACTICE</td>
<td>:...HEALTH &amp; SAFETY</td>
</tr>
<tr>
<td>:...WORK STUDY</td>
<td>:...PRODUCT COSTING(FINANCE)</td>
</tr>
<tr>
<td>:...SYSTEMS</td>
<td>:...TECHNIQUES</td>
</tr>
<tr>
<td>:...PREVENTATIVE MAINTENANCE</td>
<td>:...SPC(Statistical Process Control)</td>
</tr>
<tr>
<td>:...LOW INVENTORY CONCEPTS</td>
<td></td>
</tr>
</tbody>
</table>

Table 2-15 Legislative & best practice methods.

2.3.1 LEGISLATION

Methods that are requirements of legislation can either be made by Parliament(statute) or by a minister of state(regulation) & both carry the full force of law(BRYDSON 1990, PAGE199)

There are also codes of practices which have been approved by the HSC(Health & Safety Commission). These are not legislative but can be used in legal proceedings.
There are two particular statutes that apply to injection moulding:

METHODS-LEGISLATION-HASAWA

Within the HASAWA there are several regulations & approved code of practices which have been introduced which are applicable to processes such as injection moulding. They include:
- Control of Lead at Work 1980.
- Control of Substances Hazardous to Health 1988.

Specific situations include the use of lead compounds in the pigment formulation (yellows & reds) can require specialist personal protective equipment to be worn. The removal of lead in pigments is now becoming possible as raw material suppliers develop new pigments using organic elements. The elimination of a hazardous substance should be the best solution as compared with using personnel protection.

Control of substances hazardous to health or COSHH (HSE 1990) requires employers to:
- Assess the risk of exposure to hazardous substances.
- Outline precautions to be taken.
- Introduce & maintain control measures to prevent or control risk.
- Where necessary monitor the exposure & carry out health surveillance of workers.
- Inform, instruct & train employees.

There is also further requirements placed upon manufacturers, importers, & supplier of substances to provide adequate information about any risks to health when it is being used, handled, processed, stored, transported or during disposal (HSE 1990).
COSHH also applies to hazards created by micro-organisms which can be present in cooling systems such as cooling towers & chillers (DUBOIS 1990) (CRONER HASAWA 1992, LEGIONAIRRES DISEASE). Also cadmium compounds are used in stabilizers for plastics (CRONER HASAWA 1992, CADMIUM POISONING).

The noise regulations now specify action levels starting at exposures to noise at 85dB(A) for a whole working day. Obviously the first action is to eliminate or specify new equipment that operates at noise level less than 85dB(A).

The Fire Precautions Act (DAWS 1989) is primarily intended for the:
- Secure the safe escape of occupants from a building.
- Means of fire fighting.
- Means of giving warning of fire.

The FPA requires premises to have a fire certificate where more than 20 people are employed to work at any one time & also where explosive or highly flammable materials are present in certain quantities (DAWS 1989). With the introduction of a new process, certifiable premises will require:
- An electrical fire alarm system complying to BS5839.
- Maintenance of the means to escape.
- Instruction & training of staff.
- Testing & maintenance of alarm systems.
- Maintenance of fire fighting equipment.
- Keeping of records.

General fire safety requirements are imposed by means of a fire certificate issued by the Fire Authority. An exception to this are where the processes involved are particularly hazardous or where there are very large quantities of explosive or highly flammable substances stored. These premises may require fire certificates issued under the Fire Certificates (Special Premises) Regulations 1976 (DAWS 1989).
2.3.2 BEST PRACTICE

Modern manufacturing methods include the necessity for safe working practices. The HASAWA lays down the responsibilities for both employer & employee & the outworking of this legal requirement in safe systems of work in the plastics processing industry (BPF 1990). The real target of safe working practices is to cut down on illness, injury, accidents & damage.

The combinations of injection moulding with high temperature melts, high forces (clamp), automatic movements, cutting actions (granulators) & noise (granulators, hydraulic pumps) means that special consideration has to be given to achieve a safe working environment. The British Plastics Federation, HSE & BSI have published several codes of practice & related documents which elaborate on safe working practices for:

- Safe systems of work in the plastics processing industry (BPF 1990).
- Eyebolts PM/16 (CRONER HASAWA 1992, PAGE 65).
- Safe working with overhead cranes PM/55 (CRONER HASAWA 1992, PAGE 66).
- Specification for hand operated chain blocks (BS 3243 1990)
- Guide for the use & maintenance of non-calibrated round steel lifting chain & chain slings.
- Lifting slings (BS6166:PART 3 1988).

The latter document refers to the British & European standard which gives the technical safety requirements for the design & construction of injection moulding machines (BS6679 1985). In particular additional guarding introduced by the moulding department should also comply with this standard.
The British Plastics Federation & the Fire Protection Association have published many useful documents with regard to fire, in particular:
  - Planning programme for the prevention & control of fire in the plastics processing industry(BPF & FPA 1979)

One concern with regard to fire is that large quantities of raw materials should be stored away from heat sources such as moulding machines. The recommendation is to store raw materials in storage area which is adequately protected by a sprinkler system. This is not always practical but having the opportunity to consider a new facility allows time to incorporate these safe working principles.

Work study has been highly practised within industry & has gained best practice status within manufacturing companies. There are many facets to work study & these include:
  - Organisational structure, the systematic & critical analysis of organisational structure & relationships in order to make improvements(BS3375:PART1 1984).
  - Method study, the system recording & critical examination of ways of doing things in order to make improvements(BS3375:PART 2 1986).
  - Work measurement, the application of techniques designed to establish the time for a qualified worker to carry at a defined rate of working(BS3375:PART 3 1985).
  - Work performance control, the application of work measurement techniques with other information to the appraisal of results & payment for work(BS3375:PART4 1985).

Many of the terms used in work study are explained in a further standard(BS3138 1979).

In todays manufacturing most of the above techniques are applied but in particular the goal of most injection moulding facilities is to operate within very constant cycle times & to carry out any additional operations within this time(degating or inspection). Therefore the measurement techniques are not employed to evaluate people but the whole process. Obviously, calculation of cycle times & other key aspects(set-up times & utilisation) will define the final cost of the moulding.
Traditionally, product costing uses absorption costing methods to recover the costs of overheads & depreciation (PRIMROSE & LEONARD 1986). There are also aspects such as capital allowances which have an affect upon financial costing (INLAND REVENUE 1973).

A great deal of interest has been shown towards "quality" in the past decade. It began with quality control & now is emphasised as a total concept for continually improving businesses i.e Total Quality Management.

The definition of quality varies but it implies the achievement of a standard for product or service that the customer (internal or external) will be satisfied with. To achieve this level of customer expectation, systems & techniques have been introduced.

Many companies are now accredited with an approved quality system (BS5750:PART1 1987). This British standard (BS5750) has an equivalent European (EN29000) & International (ISO9000) standard & is the basis by which the customer can initially evaluate a supplier's capability. The supplier is expected to have a documented quality system & to display a commitment to continually review & improve its processes. Customers are continually wanting to improve their profitability & see that a supplier with an external audited quality system can build a partnership around continual improvement.

FMEA or rather Failure Mode & Effect Analysis has been implemented predominantly in the area of product design but can be used anywhere to identify potential difficulties with a new or existing product or process. It is a means by which a small or large group of people can critically analyse & prevent failure by considering potential failure modes from their experience. Once a particular failure mode has been identified, it can be rated by a risk number & recommended actions can be made to reduce or if possible eliminate the effect of that failure mode.
Techniques such as statistical process control is now commonplace within leading companies. This method relies on the process operator continually monitoring their process, evaluating whether the process is in control, & knowing when to take corrective action when the process begins to deviate. Many would reduce this important concept to the operator filling in charts to satisfy management. What SPC really does is to allow the operator full responsibility to control their process & being confident that the product or service is what the "customer" requires.

The measurements can be done on the product or a better way is for the process to monitor key parameters that dictate the quality of the end product(WINDSOR-SHAW 1991). There are often difficulties measuring components immediately after moulding in that shrinkage will continue to occur as the component cools. This cooling can occur for many hours(FRANKEN 1990), but stability in materials such as ABS can be within 1-2 hours. The alternative to this is to experiment at obtaining the required standard of moulded component by varying parameters(preferably one at a time). When defective components are produced then the parameter can be noted. This parameter can then be monitored to ensure that the components being produced are not defective. Unlike the measurement of a sample of moulded components, measurement of process parameters can be done with each process cycle. Statistical process control is now incorporated within many injection moulding machine controls & gives the benefit of measuring specified parameters(table 2-16) after each moulding cycle. This does not totally eliminate inspection of the moulded part but can increase the level of confidence that the moulding is free of defect. Ultimately, SPC reduces the level of defects by continually reducing process variation that cause defects.
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TYPE</th>
</tr>
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<tbody>
<tr>
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<td>HOLDING</td>
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<td></td>
<td>MOULD MOVING HALF</td>
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<td>AREA UNDER ACTUAL PRESSURE CURVE</td>
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<td>SPEED</td>
<td>INJECTION</td>
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<td>SCREW</td>
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<td>INJECTION STROKE</td>
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<td>POSITION</td>
<td>CHANGEOVER</td>
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<tr>
<td></td>
<td>SCREW</td>
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<tr>
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<td>MOULD OPEN</td>
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<td>MOULD CLOSED</td>
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<td>AMBIENT</td>
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<td>SCREW</td>
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</tbody>
</table>

Table 2-16 Examples of process parameters being used for SPC (GOLDSMITH 1990).
Maintence or rather preventative maintenance has been mentioned earlier as an important factor to ensure that the expected lifetime of the equipment can be realised. This is best done on a computerised system whereby regular servicing & calibration of equipment can be initiated & data can be kept of the services made.

There has been such an abundance of terms designated to computerised or automated processes that it might be beneficial to review the current practice (Table 2-17).

<table>
<thead>
<tr>
<th>ABBREVIATION</th>
<th>EXPLANATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNC</td>
<td>COMPUTER NUMERIC CONTROL (STAND ALONE PROCESS WHICH CAN OPERATE WITH MINIMAL INTERVENTION &amp; CAN INCORPORATE AUTOMATED TOOL CHANGING &amp; MATERIAL HANDLING i.e MACHINE MACHINE TOOL)</td>
</tr>
<tr>
<td>CAD</td>
<td>COMPUTER AIDED DESIGN (COMBINATION OF CAPD &amp; CAMSD)</td>
</tr>
<tr>
<td>CAM</td>
<td>COMPUTER AIDED MANUFACTURE (COMBINATION OF CAPP &amp; CAPI)</td>
</tr>
<tr>
<td>FMS</td>
<td>FLEXIBLE MANUFACTURING SYSTEMS (CONTROLS SEVERAL DNC, CNC, NC, MATERIALS TO &amp; FROM WORKSTATIONS &amp; REPORTS STATUS)</td>
</tr>
<tr>
<td>FMM</td>
<td>FLEXIBLE MANUFACTURING MODULES (STAGE IN BETWEEN CNC &amp; FMS)</td>
</tr>
<tr>
<td>MRP</td>
<td>MATERIAL REQUIREMENT PLANNING</td>
</tr>
<tr>
<td>MRPII</td>
<td>MANUFACTURING RESOURCE PLANNING (FULLY INTEGRATED SYSTEM FOR PLANNING &amp; CONTROL)</td>
</tr>
<tr>
<td>CIM</td>
<td>COMPUTER INTEGRATED MANUFACTURE (USE OF COMPUTING &amp; COMMUNICATIONS HARDWARE &amp; SOFTWARE TO PLAN, COORDINATE, MONITOR &amp; CONTROL THE THE TOTALITY OF MANUFACTURING ACTIVITIES WITHIN A COMPANY)</td>
</tr>
<tr>
<td>CM</td>
<td>CELL MANUFACTURE (SEVERAL DIFFERENT WORKSTATIONS ARE INTEGRATED INTO ONE CELL WITH A ROBOTIC OR LINE MATERIALS HANDLING)</td>
</tr>
<tr>
<td>AMT</td>
<td>ADVANCED MANUFACTURING TECHNOLOGY</td>
</tr>
<tr>
<td>CAPE</td>
<td>COMPUTER AIDED PRODUCTION ENGINEERING</td>
</tr>
<tr>
<td>CAST</td>
<td>COMPUTER AIDED STORAGE &amp; TRANSPORT</td>
</tr>
<tr>
<td>CAPP</td>
<td>COMPUTER AIDED PROCESS PLANNING</td>
</tr>
<tr>
<td>CAE</td>
<td>COMPUTER AIDED ENGINEERING (COMBINATION OF CAD &amp; CAM)</td>
</tr>
<tr>
<td>DNC</td>
<td>DIRECT NUMERIC CONTROL (GROUPS OF CNC MACHINES CONNECTED THROUGH SUPERVISORY CONTROL)</td>
</tr>
<tr>
<td>CAPD</td>
<td>COMPUTER AIDED PRODUCT DESIGN</td>
</tr>
<tr>
<td>CAMSD</td>
<td>COMPUTER AIDED MANUFACTURING SYSTEMS DESIGN</td>
</tr>
<tr>
<td>CAPI</td>
<td>COMPUTER AIDED PROCESS INSTRUCTION</td>
</tr>
<tr>
<td>CAQA</td>
<td>COMPUTER AIDED QUALITY INSTRUCTION</td>
</tr>
<tr>
<td>CAPM</td>
<td>COMPUTER AIDED PRODUCTION MANAGEMENT (COMBINATION OF CAPI, PRODUCTION PLANNING, MONITORING &amp; CONTROL SYSTEMS, &amp; MAINTENANCE PLANNING &amp; CONTROL SYSTEMS)</td>
</tr>
<tr>
<td>AGV</td>
<td>AUTOMATED GUIDED VEHICLE</td>
</tr>
<tr>
<td>AMD</td>
<td>AUTOMATED MATERIALS DISTRIBUTION</td>
</tr>
</tbody>
</table>

Table 2-17 List of main developments in computerised & automated systems within manufacturing (OPEN UNIVERSITY 1986, UNIT 2 & 3).
Latest injection moulding machines are similar to CNC machine tool equipment but there are differences:

- Tooling for injection moulding machines are manufactured for a particular moulded component & the costs are prohibitive for duplicate mould-tools. This can cause major difficulties when failure of mould-tools occur.
- Developments in machine tools include automated material handling, but this is still seen as being an additional extra for injection moulding machines & is difficult to integrate.

The application of FMS to injection moulding is still at an early stage & will take some time to develop standardisation mould-tools which can incorporate possibly insert type cavities & materials handling can be fully integrated to allow many different types of components to be produced.

One of the key areas companies have targeted for improvement since the mid 1980's is reducing the level of inventory & its associated costs. Let us now consider various aspects of inventory:

- What is inventory?
- Why is it a disadvantage to have inventory?
- How does inventory exist?
- How can inventory be reduced or even eliminated?

Firstly, what is inventory?

Inventory exists as unused material before a process or as non-shipped product after a process, e.g:

- Raw materials.
- Work in progress.
- Finished parts.
- Finished goods.
Why is inventory a disadvantage to a company?
- The value of inventory can depreciate.
- Inventory requires handling, storage & administration which are additional to manufacturing costs & therefore non-value adding.
- Inventory increases documentation.
- Inventory ties-up vital money that a company needs to re-invest in new products & processes.
- Inventory exaggerates demand in production schedules.
- Inventory frequently incurs obsolescence costs.
- Difficult to isolate defective components where large inventory exists.
- Inventory is a hindrance to product improvements & new product introductions.

How does inventory exist?
Western manufacturing philosophy was based upon producing goods just in case they were needed to ensure that production continued at all costs no matter what happened e.g scheduling failures etc. The only way to achieve this was to have inventory between each process where production might be interrupted (ILLINGWORTH 1985). These interruptions include:
- Set-up time.
- Lack of balance between processes.
- Machine & equipment breakdowns.
- Waiting for delivery of materials, e.g supply from another country.
- Quality checking & waiting for an inspector.
- Audit of finished product.
- Concession or rectification of defective product.
- High absenteeism.

Other reasons included:
- Process scheduled to overproduce to allow for rejects incurred at next processes along the supply chain. This could be as much as 20%.
- Management & financial measurements were based upon high utilization of new equipment to recover the capital investment, i.e processes continued to produce even though demand did not exist.
- Inventory was generated for special sales promotions or the introduction of a new product.
The traditional solution to reduce the effect of these interruptions was to manufacture to a batch quantity (usually several weeks forecasted demand).

How can inventory be reduced or even eliminated?
Many methods have been used to reduce inventory. These include:
- MRPII.
- OPT (Optimised production technology).
- CM.
- FMS.
- JIT.

Many companies have now installed MRPII type systems & have reduced their inventory. OPT is concerned with material flow & how bottlenecks (any resource whose capacity is equal to or less than the demand placed upon it) may be eliminated (GODFREY & STRUTHERS 1985). Cell manufacture reduces inventory by linking processes physically together & balancing each of the sub-processes. FMS links several cells (doesn't have to be physically) together & is designed to build a complete product with one set of components & to be flexible enough to change-over to make variants within one cycle. Most of the above methods are capital intensive & possibly try to solve the effect rather than looking at the root causes of inventory i.e MRPII replaces complex manual planning but the complexity can be caused by inefficient design of product for manufacturing, e.g lack of standard components & design for manufacture using principles such as product mushroom design.

Finally several companies have implemented JIT with considerable inventory reductions, e.g Hewlett Packard achieved 60-80% inventory reductions on 4 different sites (CHALLIS 1987). The question that must be asked, what is JIT?

The philosophy of JIT centres around the elimination of waste (MASKELL 1987). Waste is defined as any activity performed within a manufacturing company which does not add value to the product. Examples of waste are inventories, material handling, quality problems, queues, delays, long leadtimes & unnecessary clerical & accounting procedures. The continuous elimination of waste is brought about by changes in every aspect of the manufacturing process.
A JIT manufacturing plant aiming for these ideals would achieve (MASKELL 1987):

- Elimination of WIP by reducing batch sizes to 1.
- Elimination of raw material inventories by the suppliers delivering direct to the shop floor just in time for use.
- Elimination of scrap & rework by an emphasis on total quality control.
- Elimination of finished goods inventories by reducing leadtimes so that all products are made to order.
- Elimination of material handling costs by re-design of the shopfloor so that materials & sub-assemblies move directly between adjacent workstations.
- Elimination of wasteful clerical activities & delays by critical examination of the usefulness of these activities.

The combination of these concepts bring about JIT, & the end result of JIT are radical improvements in true productivity & more products of higher quality getting to the customers more quickly at a lower cost (MASKELL 1987).

Let us now consider how JIT methods apply to injection moulding. Batch sizes are usually governed by the set-up time which is usually significant as seen in table 2-18.

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>MINUTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>STOP MACHINE</td>
<td>-</td>
</tr>
<tr>
<td>DRY NEW MATERIAL (MINIMUM)</td>
<td>120</td>
</tr>
<tr>
<td>MOVE PRODUCT HANDLING EQUIPMENT</td>
<td>10</td>
</tr>
<tr>
<td>DISCONNECT SERVICES TO MOULD TOOL</td>
<td>10</td>
</tr>
<tr>
<td>REMOVE TOOL FROM MOULDING MACHINE</td>
<td>10</td>
</tr>
<tr>
<td>PREPARE NEXT TOOL (EJECTOR BAR &amp; SERVICES)</td>
<td>10</td>
</tr>
<tr>
<td>PLACE TOOL IN MOULDING MACHINE</td>
<td>10</td>
</tr>
<tr>
<td>RECONNECT SERVICES</td>
<td>10</td>
</tr>
<tr>
<td>MOVE PRODUCT HANDLING EQUIPMENT</td>
<td>10</td>
</tr>
<tr>
<td>RESET MOULDING MACHINE PARAMETERS</td>
<td>10</td>
</tr>
<tr>
<td>PURGE OUT OLD MATERIAL &amp; FEED DRIED MATERIAL INTO HOPPER</td>
<td>10</td>
</tr>
<tr>
<td>MOULD UNTIL INITIAL SAMPLES ARE CORRECT</td>
<td>10</td>
</tr>
<tr>
<td>INSPECT INITIAL SAMPLES &amp; FINE TUNE PROCESS AS REQUIRED</td>
<td>20</td>
</tr>
<tr>
<td>OBTAIN CONCESSION OR RECTIFY TOOL IF DEFECT EXISTS</td>
<td>10</td>
</tr>
<tr>
<td>BEGIN NEW MOULDING RUN</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL:</td>
<td>250</td>
</tr>
</tbody>
</table>

Table 2-18 Breakdown of activities & times in a typical mould-tool change for an injection moulding machine.
The above table takes the worst case situation, normally improvements can be made by scheduling or knowing what the customer requires in the next production period, i.e. leadtime. The most difficult problem has been the reduction of set-up times so as to be able to run smaller batches (ROCKWELL 1988). Measures that have been used to reduce set-up times include (ROCKWELL 1988):

- Better layout.
- Better information before changes.
- Coding tools for easy identification.
- Providing spare tool location, & tool spares.
- Standardised tools.
- Tool handling equipment, rollers & quick clamping.
- Jig & fixtures for on-the-spot inspection.

Specifically to injection moulding (SHINGO 1985):

- Standardised mould-tool heights.
- Standardised mould-tool clamping positions.
- Spare injection unit hoppers.
- Use of purging agents.
- Quick-couplings for mould-tool services.
- Pre-heating of mould-tool.

The JIT concepts outlined above were to be the main guiding methods in the design of the injection moulding facility at Rexel Engineering.
2.4 People.

A very important area is that of how people (table 2-19) act within a process as this determines the effectiveness of a process.

<table>
<thead>
<tr>
<th>PEOPLE</th>
<th>KEY</th>
</tr>
</thead>
<tbody>
<tr>
<td>:...JOB FUNCTIONS &amp; ORGANISATIONAL STRUCTURE</td>
<td>... Developments relevant to the project.</td>
</tr>
<tr>
<td>:...SKILLS, KNOWLEDGE &amp; TRAINING</td>
<td>:...ATTITUDE</td>
</tr>
</tbody>
</table>

Table 2-19 Key aspects of people within a process.

There are certain functions that have to be carried out & have to be made the responsibilities of certain jobs e.g changes to injection moulding machine settings to overcome moulding defects should be carried out by a certain qualified job role. Also there are reporting relationships & formal communication channels that need to be defined. The steps (HUSKY 1980, PAGE 246) are as follows:

- Identify job functions.
- Assign job responsibilities.
- Establish reporting relationships.
- Document the organisational structure.

Obviously, having defined the job functions & organisational structure it is necessary to define the skills, knowledge & possible training requirements in advance. When introducing new manufacturing methods then the timing of training is crucial. Too early the training will give no time for the person to apply the new found knowledge while too late will mean that bad habits will have been taught & will be difficult to change (WILLOWS 1985). The introduction of JIT methods requires teamwork, education, particularly of supervisors, operators, flexibility of work practices & suitable terms & conditions which are acceptable to both employee & employer.

Training of people is a very important aspect when introducing a new technology into a company but there are well proven courses & interactive computer simulation package for injection moulding prepared by the Plastic Processing Industry Training Board (now the British Plastics Training Association) (BPTA 1989) (BPTA 1991).
With the introduction of any change into a company the attitudes of people towards change is very important to the successful completion of that change(WILLOWS 1986, PAGE 53). The involvement of management, employees, & unions at an early stage, even though the project may be unsuccessful later means that communication can begin as early as possible & that any difficulties can be given the opportunity of being solved. People are very reluctant to change(forced) without having some kind of advanced input.
2.5 Information.
If we return to the process in figure 2-1 we can see that any deficiency in the inputs will have a consequential deficiency in the output, therefore it is necessary to obtain correct information at the right time for safety & correct manufacture. The basic categories of information are shown in table 2-20.

<table>
<thead>
<tr>
<th>INFORMATION</th>
<th>KEY</th>
</tr>
</thead>
<tbody>
<tr>
<td>:...SHALL KNOW</td>
<td>... DEVELOPMENTS RELATED TO THE PROJECT</td>
</tr>
<tr>
<td>:</td>
<td>:</td>
</tr>
<tr>
<td>:...SHOULD KNOW</td>
<td>:</td>
</tr>
<tr>
<td>:</td>
<td>:</td>
</tr>
<tr>
<td>:...NICE TO KNOW</td>
<td>:</td>
</tr>
</tbody>
</table>

Table 2-20 Key information categories.

Information can be classified into three distinct areas; shall know basis, should know basis, & nice to know basis. Information that shall be known is that relating to statutory requirements such as acts of law(seection 2.3.1) & can include:
- A statement of the company's health & safety policy.
- A reporting procedure for health & safety matters.
- Emergency drills.
- Adequate information on how to carry out the job safely.
- The requirements of personal protection.
- Data sheets on hazardous materials.
- How to carry out equipment safety checks.

Information that should be known is that relating to good business practices(seection 2.3.2) & can include:
- Process procedures.
- Drawings of components.
- Standards of components.
- Route card information, i.e quantities required at certain times.
- Process information for each set-up.
- Quality instructions for inspection methods.

Information that is nice to know is not specific to the process but may be beneficial for the employee alone i.e information of other types of injection moulding.
2.6 Transformation.

Having now defined each of the inputs as in figure 2-1, the final action is to transform these inputs into the required outputs which in the case of injection moulding is products & completed documentation. This is the basis of the injection moulding process & is shown in flowchart(figure 2-15).

Figure 2-15 A typical injection moulding process, transformation of inputs into outputs.
3.0 FEASIBILITY OF CONCEPT

The methodology used in the development of a manufacturing process such as injection moulding is shown in figure 3-1. The following chapters elaborates on this methodology, which has been used extensively in the introduction of new manufacturing systems (OPEN UNIVERSITY 1986, UNIT 8). This chapter considers the basic concept of the project and its development through the concept problem stage.

Figure 3-1 Relationship of the manufacturing system development process to the general systems methodology (OPEN UNIVERSITY 1986).
3.1 Corporate, marketing and manufacturing strategies.

The corporate objectives within the Group, Acco-Rexel Holdings, was concerned with maintaining and improving levels of growth, profit and return upon investment. These corporate objectives were translated into a marketing strategy and a manufacturing strategy.

The marketing strategy included the following:–
- Products, markets & segments.
- Range of products.
- Mix.
- Volumes.
- Standardisation versus customisation.
- Level of innovation.
- Leader verses follower alternatives.

The markets for stapling products are worldwide & can be divided into the home market(UK) & the export market. Rexel's range of products manufactured at Rexel Engineering are listed in the following table (Table 3-1).

<table>
<thead>
<tr>
<th>PRODUCT FAMILY:</th>
<th>PRODUCT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stapling machines</td>
<td>Mini staplers (Bambi, Mini 10)</td>
</tr>
<tr>
<td></td>
<td>Desktops (utilising the popular 56 staple)</td>
</tr>
<tr>
<td></td>
<td>Hand pliers (desk top, medium/heavy duty)</td>
</tr>
<tr>
<td></td>
<td>Heavy duty staplers (for stapling large number of sheets)</td>
</tr>
<tr>
<td></td>
<td>Tackers (includes light, medium and heavy duty models)</td>
</tr>
<tr>
<td></td>
<td>Specials (longarm, automatic electronic, staple extractor)</td>
</tr>
<tr>
<td>Wire products</td>
<td>A range of staples to be used with the above machines.</td>
</tr>
<tr>
<td></td>
<td>A range of paperclips.</td>
</tr>
<tr>
<td></td>
<td>Coloured drawing pins.</td>
</tr>
</tbody>
</table>

Table 3-1 Rexel Engineering's range of products.
The mix of products that is required for each market does vary substantially, e.g. the French/Italian markets prefer pliers to desktop stapling machines. The volume of each stapling product line can range from 10,000 per year to 1,000,000 per year dependent upon each market’s requirement. A pocket machine such as the Bambi peaked near a million machines during the late eighties whereas the heavy duty pliers might reach a 10,000 per year sales quantity.

There is an objective to standardise the product range to a standard range of colours & finishes within, but there is also a market for customisation. Customers are offered a service whereby a standard stapling machine may be printed upon using hot foil printing, ink pad printing, screen printing and/or customers’s logo’s inserted within the mould tool.

The level of innovation within the stapling product market has been relatively low, but new developments in the area of electronics and materials (e.g. plastics) has encouraged new innovative designs, i.e. electronic & disposable stapling.

Rexel has identified that the future survival of the company is based upon being the leader in the manufacturing of stapling products. This has been considered possible only if its products are market leaders.

Having considered the marketing strategy the next step is to consider how products win orders in the market place. Each of the following criteria can be considered important when purchasing a stapling machine (not ranked in any order):

- Product quality (function, reliability, maintainability).
- Delivery (speed and reliability).
- Colour range.
- Product range.
- Design leadership.
- Service backup.
- Price.
Each customer will categorise each of these criteria into two main groups, qualifying & order winning. Two examples are given in table 3-2.

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>CUSTOMER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Qualifying</td>
<td>Design leadership</td>
</tr>
<tr>
<td></td>
<td>Service backup</td>
</tr>
<tr>
<td></td>
<td>Product range</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Order Winning</td>
<td>Product quality</td>
</tr>
<tr>
<td></td>
<td>Delivery</td>
</tr>
<tr>
<td></td>
<td>Price</td>
</tr>
</tbody>
</table>

Table 3-2 Two examples of customer selection criteria for the purchase of products.

When a customer compares products from many suppliers a process of elimination is often used to find the most suitable product for their particular needs. This begins with the comparison of basic features that are considered a minimum that the product must have; termed "qualifying" criteria. If products pass the minimum qualifying requirements then the customer must consider preferred features being offered by manufacturers and these are termed "order winning" criteria. These order winning criteria are quantifiable. Product quality can be considered as the functional aspects of the product such as operation, lifetime & reliability. Delivery can be measured in terms of period and reliability. Price is usually considered if product quality and delivery are identical. Customer 2 has fewer order winning criteria & makes a choice on price alone assuming that all the qualifying criteria have been met.

There is a continuous move by product manufacturers to excel in product quality and delivery in order to obtain a competitive edge over others. This allows companies to influence pricing based upon perceived product value.
The manufacturing strategy is concerned with process choice and infrastructure which complements the marketing strategy (OPEN UNIVERSITY 1986, MANUFACTURING STRATEGY SET BOOK). The process choice could include both batch and line manufacture. The emphasis is upon batch manufacture for stapling machine components & line manufacturing when assembling finished products.

The infrastructure emphasises a management style where business & people are important factors. There is a high level of specialist manufacturing support required for batch & line manufacture which includes departments such as Design Engineering, Production Engineering and Quality Engineering.
3.2 Analysis of existing system.
In order to establish the current situation & to monitor the future success of the project, an initial study was made of the existing component supply system. The existing system could be described diagrammatically with consideration of aspect such as system boundaries, inputs, outputs, & the external environment as in the following diagram(Figure 3-3).

Figure 3-3 Supply system for Rexel stapling products.
This diagram describes the supply system of Rexel stapling products to the respective markets. The overall boundary is Rexel while sub-boundaries are Rexel Engineering and Company A respectively. Inputs include suppliers of components & raw materials. Outputs include the distribution of stapling machines to the markets. This diagram satisfies the definition of a system. (OPEN UNIVERSITY 1986, UNIT 1, PAGE 12).

Within the overall "Rexel" controlled boundary there exists the sales, distribution and marketing functions & Rexel Engineering's manufacturing boundary. In order to satisfy customer requirements for products with a delivery of 2 days at 95% reliability (e.g. customer 1 example in table 3-2), inventory of finished goods valued at £600,000 of stapling machines were held at distribution, equivalent to a 6 week supply. An analysis of margin by product revealed that 80% of total gross margin and 60% of total stock was associated with a few high volume stapling machines as shown in the following diagram (figure 3-4).

Figure 3-4  Pareto analysis of high margin products with main type of plastic used for key component.
Having outlined the supply system the next step was to consider the inventory at each customer supplier boundary. The quantity and value of work in progress and raw material inventory for internally manufactured parts was relatively low due to the manufacturing leadtime of 2 weeks. Bought out components could be subdivided into two categories:

- Low value components, leadtime 6 weeks, packaging, springs, fasteners etc.
- High value components, leadtime 6 weeks, plastic components supplied by Company A.

The typical value of stocks of plastic components in 1989 was £60,000, of which HV/HV components accounted for 60%, £36,000. Inventory levels are normally calculated with reference to forecast demand. This usually leads to plastic components which are surplus to requirements, termed obsolescence costs. The value of this obsolescence costs was approximately £3000 per year and could be eliminated by the adoption of a low inventory policy otherwise known as small batch manufacturing.

A sub-boundary of Rexel Engineering was Company A who supplied nearly all plastic components for Rexel's stapling machines. The 6 week delivery leadtime was caused by a number of factors:

- A distance of 250 miles existed between Rexel Engineering & Company A. This obviously restricted supply & communication.
- A 10 injection moulding machine facility which had received no capital investment for at least 10 years.
- The manufacturing strategy was based upon large batch manufacture. Similar orders were grouped together in order to reduce number of set-ups. Consequently a 6 week leadtime existed & inventory of finished goods/packaging valued at £20,000 were held at the company.

The analysis of the existing system revealed that a leadtime reduction for HV/HV components from 6 weeks to 1 week could result in better customer service along the supply chain. The value of potential inventory which could be released due to this improved customer service was estimated to be between £122,000 and £378,000,(ACCO-REXEL 1990, APPENDIX 4).
3.3 Objectives, constraints and performance criteria.

In section 3.2, the existing system for the supply of plastic components was described, which resulted in high inventory levels within the business. Therefore the objective of the project was:

"To increase customer satisfaction and confidence by a reduction in the leadtime on critical plastic components used for the manufacture of high volume stapling machines"

The local customer was a reference to the assembly department at Rexel Engineering & critical plastic components refer to the HV/HV plastic components. The constraints that existed were as follows:

- Support of Group to achieve the objective.
- Gaining support and involvement from employees at Rexel Engineering to achieve objectives.
- Being able to breakdown the overall task into manageable sub-tasks that could be tackled by teams from conception right through to implementation.
- A 2 year time period to complete project within Teaching Company programme.
- The availability of capital funds.
- The availability of funding for development.

The performance criteria and targets set to measure the objectives are listed in the following table (table 3-3).

<table>
<thead>
<tr>
<th>PERFORMANCE CRITERIA:</th>
<th>TARGET:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of components:</td>
<td>To attain existing Rexel</td>
</tr>
<tr>
<td></td>
<td>Engineering standards.</td>
</tr>
<tr>
<td>Delivery leadtime &amp; reliability:</td>
<td>1 week/ 95% reliability.</td>
</tr>
<tr>
<td>Component costs:</td>
<td>Costs to remain at current levels.</td>
</tr>
</tbody>
</table>

Table 3-3 Performance criteria & targets for project.

Having defined the objective, the constraints and criteria by which the success of the project could be measured, the next stage was to consider the routes available to achieve the objective.
3.4 Routes to objectives.

There were several routes available to satisfy the objective set in section 3.3. These included:-

- **DO NOTHING** (To continue to obtain components from Company A).
- **INVESTMENT** (To invest in new equipment at Company A, Company B, or at Rexel Engineering).
- **LOCAL SUPPLY** (To consider a supplier in South Wales).

**DO NOTHING**

In February 1990 the plant and machinery assets (table 3-4) at Company A were valued at £37000.

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>MODEL</th>
<th>CLAMP FORCE (TONNES)</th>
<th>AGE (YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Engel</td>
<td>150</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>Engel</td>
<td>250</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>Engel</td>
<td>250</td>
<td>20</td>
</tr>
<tr>
<td>1</td>
<td>Metalmeccanica</td>
<td>150</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>Herbert</td>
<td>150</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>Edgewick</td>
<td>45</td>
<td>20</td>
</tr>
<tr>
<td>1</td>
<td>Austen Allen</td>
<td>7.5</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 3-4 List of moulding machines at Company A.

Deliveries on average were completed within 6 weeks from order. The company employed 45 staff in 1990, most of whom had many years experience in the plastic injection moulding field. Nearly all the senior management were near the age of retirement and the site premises were leased for a limited number of years.

**INVESTMENT—COMPANY A**

Investment at Company A was one of the more obvious routes to satisfy the objective. Introducing the latest technology into a company that already had a good background in injection moulding would be advantageous but the factory was old & lacked headroom for tool handling equipment.

**INVESTMENT—REXEL ENGINEERING**

The level of investment required at Rexel Engineering was unknown until an initial study could be undertaken. This study would consider the components being manufactured, the capacity requirements, allowances for set-ups, tool sizes and the necessary infrastructure.
Investment at Rexel Engineering would have to include training and education for many employees. There were a few employees with past plastic moulding experience which included areas such as tool maintenance, supervision and management.

**INVESTMENT–COMPANY B**

Company B had a moulding facility of nineteen injection moulding machines. The size of moulding machines varied from 90 to 250 tonnes clamp force. The main products were high volume components with little variation in colour or material. The company had received new investment with government grants in the early 1980’s to supply many of the Acco-Rexel group of companies with plastic components. The very nature of its operation was of large batch manufacturing with infrequent mould-tool changes due to the standard nature of the product.

**LOCAL SUPPLY**

Many injection moulding companies were situated within South Wales. Fierce competition existed between these suppliers to recover the high cost of capital equipment involved in injection moulding. This was obviously an advantage to a prospective customer but usually lower first year component prices were not realistic of the true cost of manufacture. Prices would usually increase in subsequent years to recover the loss made in obtaining the initial orders. The frequent movement of mould-tools should be avoided as far as possible in order that a sound supplier/customer partnership could be built up.
3.5 Technical and financial modelling of each route.
Each of the alternative routes outlined in section 3.4 were considered from a technical and financial perspective.

DO NOTHING
In 1990, Company A's component prices for its customers rose by between 8-11%. The necessary price increases were requested to obtain breakeven point as the company was operating on a non-profit making basis. No further price increases could be born by the customer & it was expected that a further downturn in sales due to the recession would occur increasing costs even further. Company A was expected to incur a loss. With the ever increasing burden of machine breakdown this option was only becoming intolerable.

INVESTMENT—COMPANY A
The management at Company A Plastics determined that the minimum level of investment required was as follows(table 3-5):

<table>
<thead>
<tr>
<th>YEAR</th>
<th>QUANTITY</th>
<th>SIZE (CLAMP)</th>
<th>COST £</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>1</td>
<td>150 tonnes*</td>
<td>110000</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>60 tonnes</td>
<td>50000</td>
</tr>
<tr>
<td>1992</td>
<td>1</td>
<td>150 tonnes*</td>
<td>110000</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>60 tonnes</td>
<td>50000</td>
</tr>
<tr>
<td>1993</td>
<td>1</td>
<td>150 tonnes</td>
<td>110000</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>60 tonnes</td>
<td>50000</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>7.5 tonnes</td>
<td>10000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>490000</td>
</tr>
</tbody>
</table>

Note
* : Machines required to produce HV/HV components.

Table 3-5  Capital investment required at Company A.

The above investment plan included additional equipment to replace all existing moulding machine which manufacture all components. The major limitation with the above investment was that the objective of 1 week delivery was considered not practical to achieve due to the distance between Company A & Rexel Engineering. A leadtime of 4 weeks at 95% reliability was considered more practical.
There were other difficulties with Company A's approach in that the management would prefer not to look at reducing set-up times but to consider increased capacity to be the way to solve the supply difficulties. Reducing leadtimes with smaller batch sizes by investment in quick set-up equipment was considered to be impractical & difficult to justify. The investment in equipment would require reducing tool, colour & process setting times by using standard tool backplates, hydraulic clamping, & tool data automatic retrieval and set-up methods. Even the development of closed loop control was considered an unjustifiable expense. The proposed method of recovery of capital was by straight replacement of existing equipment. With the increased efficiency of the latest machines it was expected that only seven machines would be required.

INVESTMENT—REXEL ENGINEERING

The required level of investment was obtained by carrying out a full feasibility study. This study was completed with the aid of a computer using a standard spreadsheet software package(AMSTRAD 1989). The analysis involved the following key elements:

- A flowchart for the model(figure 3-5).
- Some basic assumptions(table 3-6).
- Input data(table 3-7).
- Results of initial simulation runs(table 3-8)(figure 3-6)(figure 3-7).

The purpose of using the model was to ascertain the the following:

- Confirm that the basic assumptions were correct for small batch manufacturing methods.
- Number of components required to be produced.
- Number of tool changes.
- Number of colour/logo changes.
- Total capacity required and the required level of machine utilization.
- Number of machines required, type of facility required and infrastructure.
- The financial viability of the proposal.
Figure 3-5 Flowchart of a computer simulation for justifying an injection moulding facility.
<table>
<thead>
<tr>
<th>ASSUMPTION</th>
<th>VALUE</th>
<th>REASON FOR CHOICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Number of tools</td>
<td>20</td>
<td>Tooling for HV/HV components.</td>
</tr>
<tr>
<td>- Assembly reject level</td>
<td>6%</td>
<td>Past experience.</td>
</tr>
<tr>
<td>- Tool change time (minutes)</td>
<td>30-45</td>
<td>As existing supplier.</td>
</tr>
<tr>
<td>- Colour/logo time (minutes)</td>
<td>15-30</td>
<td>As existing supplier.</td>
</tr>
<tr>
<td>- Machine available time</td>
<td>5days/24hours/3shifts</td>
<td>High temperature process(200-300°C) requiring continuous operation.</td>
</tr>
<tr>
<td>- Machine downtime</td>
<td>15%</td>
<td>Allowance for routine preventative maintenance.</td>
</tr>
<tr>
<td>- Change sequence</td>
<td>1st-Tool 2nd-Logo</td>
<td>All component variants are manufactured off a few tools or colour.</td>
</tr>
<tr>
<td>- Machine running times</td>
<td>Costed times</td>
<td>These were supplied by existing supplier.</td>
</tr>
<tr>
<td>- Assembly loading</td>
<td>Current</td>
<td>Existing line flowrates used.</td>
</tr>
<tr>
<td>- Material costs</td>
<td>Current</td>
<td>As existing supplier.</td>
</tr>
<tr>
<td>- Direct labour costs</td>
<td>1man/m/c</td>
<td>As existing supplier.</td>
</tr>
<tr>
<td>- Finish labour costs</td>
<td>Current</td>
<td>As existing supplier.</td>
</tr>
<tr>
<td>- Depreciation level</td>
<td>7years</td>
<td>Standard company policy.</td>
</tr>
<tr>
<td>- Government grant</td>
<td>14.6%</td>
<td>Regional grant available.</td>
</tr>
<tr>
<td>- Additional overhead at Rexel Engineering</td>
<td>Various</td>
<td>Includes 3 technicians, toolroom, and maintenance.</td>
</tr>
<tr>
<td>- Stock reduction:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier/components</td>
<td>50-80%</td>
<td>Reduced leadtime</td>
</tr>
<tr>
<td>Rexel Eng/components</td>
<td>50-80%</td>
<td>Reduced leadtime</td>
</tr>
<tr>
<td>Rexel/machines</td>
<td>20-80%</td>
<td>Reduced leadtime</td>
</tr>
<tr>
<td>- Other benefits</td>
<td>Costs</td>
<td>Reduced costs due to less obsolescence, material handling and transactions.</td>
</tr>
</tbody>
</table>

Figure 3-6  List of assumptions made in the simulation model.
<table>
<thead>
<tr>
<th>INPUTS</th>
<th>VALUE</th>
<th>REASON FOR CHOICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Data available</td>
<td>Historical</td>
<td>Actual past demand on a particular product/component.</td>
</tr>
<tr>
<td></td>
<td>Forecast</td>
<td>Forecast data is available for monthly deliveries but is adjusted for stocks.</td>
</tr>
<tr>
<td>- Data type</td>
<td>Yearly/monthly/weekly/daily.</td>
<td>Yearly/monthly schedules are a good indication of global capacity requirements while weekly/daily schedules introduce the variability that exists indicating the true capacity requirements.</td>
</tr>
<tr>
<td>- Random input</td>
<td>--------</td>
<td>This was not considered due to the availability of above data &amp; the confidence that the data was representative of true demand.</td>
</tr>
</tbody>
</table>

Table 3-7 Input data for product sales schedule used in the simulation model.
<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Confirm assumptions</td>
<td>None of the assumptions in table 3-6 were changed at this stage, although during development trials, tool/colour/logo change times were improved.</td>
</tr>
<tr>
<td>- Capacity requirements</td>
<td>13000-44000/day (daily schedule, historical) 771000/month (weekly schedule, historical)</td>
</tr>
<tr>
<td>- Tool changes</td>
<td>3-6/day (weekly schedule, forecast) 3-9/day (daily schedule, historical)</td>
</tr>
<tr>
<td>- Colour/logo changes</td>
<td>12-15/day (weekly schedule, forecast) 30-33/day (daily schedule, historical)</td>
</tr>
<tr>
<td>- Machines required/</td>
<td>4/60% (daily schedule, forecast, figure 3-6) 3/70% (weekly schedule, historical, figure 3-7)</td>
</tr>
<tr>
<td>effective utilization</td>
<td>2/80% (yearly schedule, historical)</td>
</tr>
<tr>
<td>- Investment required</td>
<td>To support a 2, 3, 4 machine facility the level of investment required was obtained from equipment suppliers.</td>
</tr>
<tr>
<td>- Project viability</td>
<td>A cost breakdown for each tool/component which included proportioning overhead, depreciation was prepared. The period for depreciation was spread over 7 years. Assuming no increase in component costs, a favourable government grant and the stock reductions envisaged then a payback within 2 years would make the project to be viable.</td>
</tr>
</tbody>
</table>

Table 3-8 Results gained from initial simulation runs.
Figure 3-6 Chart of daily capacity requirement for period 27th February to 5th April, 1989.
Figure 3-7 Chart of weekly capacity requirement for period week 14 to week 26, 1989.

The simulation model allowed for many of the key considerations to be modelled before further development expenditure on trials. The information and experience gained by using a simulation model allowed testing of the initial assumptions made. Further development trials were undertaken on those critical areas which were found to have a large effect on the investment plan. These development trials began in January 1990 & included:


The results from these trials (table 3-9) were then incorporated within the simulation model and a new set of results were obtained.
<table>
<thead>
<tr>
<th>DATE &amp; PARAMETER</th>
<th>IMPROVEMENT</th>
</tr>
</thead>
</table>
| **January 1990** (ACCO-REXEL 1990b) | - Clamp size: 150 tonnes clamp force acceptable for most tools.  
- Cycle rate: 44% improvement  
- Colour change: Light to dark 2 minutes, vice versa 8 minutes. |
| **April 1990** (ACCO-REXEL 1990c) | - Clamp size: 160 tonnes clamp force acceptable.  
- Cycle rate: 57% improvement.  
- Colour change: Light to dark 2 minutes, vice versa 5 minutes.  
- Tool change: Mobile manual tool tables not recommended for our heavy tooling, typically 750 Kg. |
| **May 1990** (ACCO-REXEL 1990d) | - Tool change: Vertical semi automatic tool change achieved within 9 minutes 40 seconds floor to floor (does not include preheating or component inspection) |
| **August 1990** (ACCO-REXEL 1990f) | - Tool change: Vertical manual tool change achieved within 13 minutes 30 seconds (does not include component inspection). |

Table 3-9 List of development trials & improvements.

The results of the simulation would indicate that 3 injection moulding machines were required (figure 3-6) (figure 3-7), but in the practical trials (table 3-9) many of the assumptions could be improved upon:

- Tool change time could be achieved comfortably within 30 minutes.
- Colour change achievable within 15 minutes.
- Cycle rate improvement of minimum 10% possible thus reducing the overall capacity requirements.

This meant that only 2 machines were required, as there was confidence that the above trials were typical for all the other 20 mould-tools.

The trials were conclusive that the size of injection moulding machine need not be greater than 160 tonnes clamp force & the size of the platens & distances between tiebars were adequate to accept the largest mould-tool being considered.
Taking the information obtained from both simulation & trials a provisional list of equipment was prepared for budgetary purposes (table 3-10).

<table>
<thead>
<tr>
<th>Qty.</th>
<th>Equipment</th>
<th>Budget £</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>MOULDING MACHINES:</strong></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>150 Tonne clamping moulding machines</td>
<td>161,000</td>
</tr>
<tr>
<td>2</td>
<td>Unmanned shift control</td>
<td>5,000</td>
</tr>
<tr>
<td>2</td>
<td>Quality graphics, SPC charts</td>
<td>13,000</td>
</tr>
<tr>
<td>2</td>
<td>Sockets</td>
<td>1,000</td>
</tr>
<tr>
<td>2</td>
<td>Printer</td>
<td>2,000</td>
</tr>
<tr>
<td>2</td>
<td>Set of spares</td>
<td>10,000</td>
</tr>
<tr>
<td>2</td>
<td>Hydraulic tool clamping</td>
<td>22,000</td>
</tr>
<tr>
<td>18</td>
<td>Tool adaptor plates</td>
<td>45,000</td>
</tr>
<tr>
<td>2</td>
<td>Mould temperature interface</td>
<td>4,000</td>
</tr>
<tr>
<td>1</td>
<td>Miscellaneous, valves, flowmeters</td>
<td>5,000</td>
</tr>
<tr>
<td>1</td>
<td>Training for operators, supervisors, etc.</td>
<td>10,000</td>
</tr>
<tr>
<td></td>
<td>Delivery and installation of equipment</td>
<td>6,000</td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL SPEND:</strong></td>
<td>284,000</td>
</tr>
</tbody>
</table>

|      | **MATERIAL HANDLING SYSTEM:**                                            |          |
| 11   | Bins                                                                      | 1,000    |
| 3    | Granulators                                                               | 12,000   |
| 3    | Mobile drying equipment                                                  | 32,000   |
| 1    | Miscellaneous                                                             | 1,000    |
|      | **TOTAL SPEND:**                                                         | 46,000   |

|      | **SERVICES AND ANCILLARIES:**                                            |          |
| 1    | Partitioning                                                             | 6,000    |
| 1    | Power and lighting                                                       | 17,000   |
| 1    | Hydraulic and mould cooling                                              | 12,000   |
| 6    | Mould temperature controllers                                            | 10,000   |
| 1    | Installation                                                              | 6,000    |
|      | **TOTAL SPEND:**                                                         | 51,000   |

|      | **TOOL HANDLING:**                                                       |          |
| 1    | Gantry                                                                    | 28,000   |
| 20   | Tool racks                                                                | 4,000    |
| 20   | Adapt tools onto standard plates                                          | 32,000   |
|      | **TOTAL SPEND:**                                                         | 64,000   |

|      | **PRODUCT HANDLING:**                                                    |          |
| 1    | Weighing equipment and tables                                             | 4,000    |
| 2    | Conveyor                                                                  | 4,000    |
|      | **TOTAL SPEND:**                                                         | 8,000    |
|      | **TOTAL SPEND:**                                                         | 453,000  |

Note: Approximately £340,000 of the above was likely to be affected by foreign currency (German or Austrian). Rate was fixed at 2.7DM to the £ for above analysis.

Table 3-10 Equipment list.
Briefly, much of the additional equipment for the moulding machine facility was considered necessary to reduce set-up time, e.g.

- Standardised backplates for each mould-tool.
- Electronic interface of mould temperature controllers to the injection moulding machine controls, so that manual setting was not required.
- Spare drying systems & containers to pre-dry the raw material.

**INVESTMENT—COMPANY B**

The management at Company B prepared an investment proposal which included an analysis of capacity requirements, capital equipment required, infrastructure and the method of transportation of finished components to Rexel Engineering. Differences between Rexel Engineering's proposal and Company B were as follows:

- Company B initially required equipment totalling £414000 which was less than Rexel Engineering, due to the availability of existing ancillary equipment.
- Company B would be capable of deliveries each week but transportation, packaging and customs clearance costs would be additional.
- Company B was eligible for 20% capital grants as compared with 14.6% at Rexel Engineering.
- Company B would continue to manufacture using large batch methods & therefore would hold stock of finished components ready for weekly despatch to Rexel Engineering.

The payback upon investment was between 1.4–2.5 years dependent upon the level of stock reduction at Rexel Engineering and Rexel. There were several technical difficulties in considering this investment:

- Supply of critical components could be affected by weather and transportation difficulties.
- Large batch manufacturing would incur stock holding of components with hidden quality defects.
- A continuous good communication would be required to avoid product stoppages at Rexel Engineering, i.e long distance between supplier & customer.
- Introducing new products and changes in design would be difficult.
LOCAL SUPPLY

Local injection moulding suppliers were asked to provide quotations for the supply of the HV/HV components. The result of this investigation was that component costs could be reduced by 5% overall, compared with an increase of 11% at Company A, & no change in component prices at both Company B & Rexel Engineering.
3.6 Evaluation & selection of optimum route.

The following table (table 3-11) compares each route against the project objectives.

<table>
<thead>
<tr>
<th>CRITERIA/TARGET /MEASURE</th>
<th>ROUTES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>COMPANY A</td>
</tr>
<tr>
<td>INVESTMENT REQUIREMENT</td>
<td>No</td>
</tr>
<tr>
<td>ACHIEVE REQUIRED COMPONENT QUALITY</td>
<td>Yes</td>
</tr>
<tr>
<td>DELIVERY (1 WEEK-95% RELIABILITY)</td>
<td>No(1)</td>
</tr>
<tr>
<td>COMPONENT COSTS DECREASED</td>
<td>No(3)</td>
</tr>
<tr>
<td>PAYBACK (YEARS)</td>
<td>(5)</td>
</tr>
<tr>
<td>OTHER BENEFITS</td>
<td>- Knowledge inhouse/group</td>
</tr>
</tbody>
</table>

(1) Estimated delivery 6 weeks/95% reliable.
(2) Estimated delivery 4 weeks/95% reliable.
(3) Increased component cost by 8-11% for year.
(4) Possible 5% below existing supplier costs.
(5) Payback not applicable as no investment required.
(6) Increased knowledge for design of new products, better control over new product leadtimes.
(7) No details available

Table 3-11 Comparison of each possible route.

DO NOTHING/INVESTMENT - COMPANY A

These proposals did not meet the objectives and targets set with regard to component cost and delivery respectively. With the added concern of the future uncertainty of the leased premises, this proposal was deemed not viable in the long-term.
INVESTMENT—REXEL ENGINEERING

This proposal met all the criteria & was financially viable. The main disadvantage was the introduction of a new technology to a site which had little previous knowledge of injection moulding. With the introduction of a new range of stapling machines & pliers there was an opportunity to gain complete control over development of new injection moulding tooling.

INVESTMENT—COMPANY B

This proposal also met the criteria set and was financially viable. The main disadvantage of this proposal was that delivery could be disrupted by weather.

LOCAL SUPPLY

This proposal also met the criteria set & was financially viable. The main disadvantage of supply through external sources was the possible loss of control. This control was essential if Rexel Engineering were to obtain supply of components on short leadtimes. The supplier would therefore also have to adopt small batch manufacturing methods in order to stay competitive on supply and price. Stockholding policies would ultimately increase component prices.

To conclude, the evaluation process began in August 1989 (and after several iterations), a capital expenditure request (CER) was submitted for £453000 to introduce a two injection moulding machine facility at Rexel Engineering. Capital approval was given in July 1990 from the ACCO World Corporation. The proposal to invest at Rexel Engineering by the parent company supported the policy of retaining plastics knowledge within the company. This would lay the foundation for the development of new plastic products at Rexel Engineering in the future.
4.0 DETAILED PLANNING, DESIGN AND IMPLEMENTATION.

As capital approval had been obtained this section now considers the subsequent planning, design and implementation stages.
4.1 Technical and financial planning.

The next step considered was the planning of each part of the implementation stage. The planning was simplified by the use of a computer software package (MICROSOFT) which could accept a large number of activities & relationships between these activities. Due to the very nature of these programs, long listing of computer paper can be generated to show critical paths etc. The real advantage of these programs are the simulations of change of circumstances & possibly ways of avoiding these situations, which might otherwise lead to a delay in the project. As these plans are usually large, an example of the kind of activities are shown in figure 4-1. The project management role should take into account not only achieving the budget but also the time taken to complete the project.

The following are a list of key activities that were planned to be undertaken:

- Equipment evaluation & ordering.
- Selection & training of personnel.
- Evaluation & approval of layout & services.
- Installation of services & equipment.
- Injection moulding approval trials.
- Delivery of main equipment.
- Installation, commissioning & familiarisation.
- Commissioning of tools.

Equipment evaluation had been done to a certain extent prior to capital approval, & an equipment specification was generated outlining Rexel Engineering’s main requirements. Quotations tendered were required to be valid for a few months to allow time to make a final selection of supplier. In the planning process, time had been allocated to visit each main equipment supplier to discuss their respective proposals. Selection of a supplier for the moulding machines was expected by the end of August 1990, while ancillaries were to be finalised by mid-September 1990.
Figure 4.1 Example of a typical schedule generated by computer software.
Selection & training of operators and technicians was planned. A specification needed to be drafted, outlining Rexel Engineering's specific workforce requirements and training plan. Preparing a specification, advertising positions, interviewing, selection and training employees was planned over a 4 month period. The completion date was projected as mid-January 1991 during the expected commissioning of the moulding machine facility.

Evaluation & approval of layout & services included the selection of an exact location for the injection moulding facility which needed discussion at management level. Final detailed layouts were to be completed using the Computer Aided Design system newly installed at Rexel Engineering. When the exact layout of facility had been agreed positions of ancillary equipment & necessary service ducts were decided prior to raising orders for installation contracts.

Installation of services & equipment required a period of 2 months. This would be enough time to clear the existing area & install the necessary services, refurbish the floor, & redecorate. It was planned that equipment such as chiller and overhead crane would be installed after completion of the floor. The above installation was expected to be completed by the end of December 1990.

Injection moulding approval trials were planned at the suppliers manufacturing site to view functional checks against Rexel's specification. It was planned to transport three of Rexel Engineering's mould-tools to the suppliers premises for the trial trial. The purpose of the trial was to simulate operating conditions at Rexel Engineering. Delivery of main equipment such as moulding machines and associated ancillaries was expected in mid-January 1991.

Installation, commissioning & familiarisation was expected to take two weeks with Rexel Engineering's employees being trained during commissioning period. Commissioning of tools would include a total of 20 selected tools which were planned to be introduced over a period of 5 months. The final date coincided with the completion of the Teaching Company Programme in mid-June 1991.

Completion of the project was expected at the end of Rexel Engineering financial year. This being the last day of November 1991.
4.2 Detailed Design

The detailed design would include a review of the original objectives set followed by a detailed specification of each component of the injection moulding facility. At this stage it would be pertinent to review the project's objective & targets (section 3.3 & table 3-11):

Objective:

"To increase customer satisfaction and confidence by a reduction in the leadtime on critical plastic components used for the manufacture of high volume stapling machines."

Objective measure of customer satisfaction:

1. To attain existing Rexel Engineering component quality standards.
2. Delivery leadtime within 1 week at 95% reliability.
3. Component costs to remain at existing levels.
4. Payback within 2 years for any capital invested.

Operational & financial requirements to satisfy above:

1. Frequency of set-up changes to achieve leadtime objective; logo and/or colour change (4 to 5 per 8 hour shift); tool change (1 per 8 hour shift).
2. Injection moulding cycle rate improvement (more than 10% across all 20 tools).
3. Set-up time improvement; tool change (less than 20 minutes); tool insert change for logo (less than 15 minutes); colour change (less than 10 minutes).
4. Reduction of component/packaging inventory (minimum £10,000) at existing supplier; component inventory (minimum £15,000) at Rexel Engineering; finished goods inventory at Rexel Ltd. (minimum £72000).
The detailed design was based on the trials and simulation results obtained during the feasibility stage. Key to the success of any project is the preparation of specifications. These specifications and work instructions included:

- Equipment specifications (ACCO-REXEL 1990e) detailing moulding machine, material handling, services, ancillaries, tool handling & product handling requirements.
- Employee specification (ACCO-REXEL 1990g) detailing manning levels, safety, skills and training required.
- Equipment and service layouts.
- Operating procedures.

The completion of these specifications concluded this stage of the project.
4.3 Implementation.

The schedule of planned activities has already been discussed and this section describes what actually happened and the reasons for any changes necessary. A summary of the equipment purchased & the project schedule are shown later in table 4-1 & table 4-2.

<table>
<thead>
<tr>
<th>QUANTITY</th>
<th>EQUIPMENT</th>
<th>BUDGET</th>
<th>NON-BUDGET</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MOULDING MACHINES:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>150 Tonne clamping moulding machines</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>2</td>
<td>Unmanned shift control</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>2</td>
<td>Quality graphics, SPC charts</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>2</td>
<td>Sockets</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>2</td>
<td>Printer</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>2</td>
<td>Set of spares</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>2</td>
<td>Hydraulic tool clamping</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>18</td>
<td>Tool adaptor plates</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>2</td>
<td>Mould temperature interface</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>1</td>
<td>Miscellaneous, valves, flowmeters</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>1</td>
<td>Training for operators, supervisors, etc.</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>1</td>
<td>Delivery and installation of equipment</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>1</td>
<td>Bi-metallic barrel &amp; hardened screw</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>1</td>
<td>Automatic oil filtration system</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>1</td>
<td>Trials at manufacturer</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td><strong>MATERIAL HANDLING SYSTEM:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Bins</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Granulators</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Mobile drying equipment</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Miscellaneous</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Small drying oven</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td><strong>SERVICES AND ANCILLARIES:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Partitioning</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Power and lighting</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Hydraulic and mould cooling</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Mould temperature controllers</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Installation</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Relocation maintenance department</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>High voltage transformer</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Decorating of new moulding area</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Replacement of exterior glass</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td><strong>TOOL HANDLING:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Gantry</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Tool racks</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Adapt tools onto standard plates</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Tool splitting table</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

Table 4-1 Summary of equipment purchased.
Capital approval was given by the ACCO World Corporation on the 27th July 1990.

Equipment, evaluation & ordering began in August 1990 with all the main selected supplier quoting for the supply of injection moulding machines. A matrix outlining our moulding machine requirements & each supplier proposal was prepared. Each supplier satisfied the basic qualifying needs and a rating system was adopted to compare additional benefits of each supplier. The choice of manufacturers of moulding machines were narrowed down to 3.

Two out of the three manufacturers offered excellent equipment packages but the third manufacturer was technically and financially superior by offering a larger platen size and greater discounts. The platen size on the third manufacturer's 160 tonne clamp moulding machine was almost equivalent to a standard 250 tonne clamp moulding machine. An order valued at £230,000 was placed with the third manufacturer for two injection moulding machines on the 10th September 1990. Savings against budget were achieved by a more favourable exchange rate of 2.89DM : £ as opposed to the budgeted exchange rate of 2.7DM : £. Additional equipment was purchased such as hardened screw assembly and oil filtration system & these were justified on the basis that filled materials could be processed & preventative maintenance.
<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>COMPLETION DATE</th>
<th>VARIANCE/REASON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital approval</td>
<td>End Jul90</td>
<td></td>
</tr>
<tr>
<td>Equipment, evaluation, ordering.</td>
<td>Mid Sep90</td>
<td>Two weeks delay/Negotiation with many equipment suppliers.</td>
</tr>
<tr>
<td>Workforce, selection, training.</td>
<td>Mid Jan90</td>
<td></td>
</tr>
<tr>
<td>Evaluation, approval of layout and services.</td>
<td>End Oct90</td>
<td></td>
</tr>
<tr>
<td>Installation of services and equipment.</td>
<td>End Dec90</td>
<td></td>
</tr>
<tr>
<td>Machine approval trials.</td>
<td>Mid Dec90</td>
<td>Eight week delay/delayed manufacture of moulding machines.</td>
</tr>
<tr>
<td>Delivery of main equipment.</td>
<td>End Dec90</td>
<td>Six week delay/as above.</td>
</tr>
<tr>
<td>Installation, commissioning and integration of people and equipment.</td>
<td>Mid Jan91 End Feb91</td>
<td>Six week delay/as above.</td>
</tr>
<tr>
<td>Commissioning of tools.</td>
<td>End Jun91</td>
<td>Thirteen week delay/tool introduction underestimated.</td>
</tr>
<tr>
<td>Closure of project.</td>
<td>End Nov91</td>
<td></td>
</tr>
</tbody>
</table>

Table 4-2 Summary of implementation schedule, planned versus actual.

Material handling & ancillary equipment were evaluated much in the same way as moulding machines. One manufacturer offered a complete package which was technically & financially superior to other suppliers. An order was placed with company on the 28th September 1990 for equipment valued at £72,000. Additional equipment such as a drying oven (to dry small quantities of raw material) was also purchased. This oven had been overlooked in the original capital request.
The loss of 2 weeks in evaluating the supplier proposals was offset by reduced delivery times. Once the orders had been placed for the main equipment, smaller items such as overhead crane for tool handling, inspection equipment and miscellaneous small items were ordered.

Selection of employees & training to satisfy Rexel Engineering's requirements (ACCO-REXEL 1990g) was carried out during November/December 1990. Positions for both operators and technicians were advertised internally at Rexel Engineering. The two technicians employed received a 2 week condition setting training course at the British Plastic Training Associated in Telford during November/December 1990. The two operators received 1 week basic processing training during January 1991. Transfer of employment for operators and technicians began in mid-February 1991 as commissioning of the injection moulding facility was progressing. This transfer was delayed by 1 month due to the delayed delivery of moulding machines.

Layout & services were evaluated & approved by Rexel Engineering's management. A layout drawing outlining various location & configurations was prepared on the Computer Aided Design (CAD) system. A presentation was made to the management outlining benefits and constraints of each configuration. This concluded with an area being allocated for the injection moulding facility within the existing component manufacturing block. Positions of various equipment were also detailed on the CAD system obtaining the optimum position with due consideration of process flow, fire regulations and safety legislation.

The necessary services included the following:
- Electrical power supply (high and low voltage).
- Lighting.
- Water and drainage.
- Compressed air supply.
- Chiller pipework.
- Duct work for air cooled chiller.

Using the detailed service layout drawing quotations for the various services were obtained. This was completed by the end of October 1990 as planned. The installation of services & equipment required an area already allocated to the maintenance department & to store work-in-progress from the press-shop.
The component stocks were re-positioned closer to the press-shop as space became available due to the ongoing JIT & stock reduction programme. The maintenance department was re-positioned nearby on an existing mezzanine floor area with greater maintenance storage area, new partitioning and new offices. This raised the profile of the maintenance department & as a consequence the move was completed in a weekend.

Having vacated the area, the next stage was to refurbish the floor surface and replace the existing bitumen base with an epoxy resin floor surface. The new floor surface was chosen to encourage a higher standard of cleanliness. Service ducts to carry power, cooling water services to the injection moulding machines were cast into the floor prior to its completion. This removed the clutter associated with normal injection moulding facilities.

High voltage services included the replacement of a 500 KVA and 300KVA with a new 1000 KVA transformer. This required a new power cable to be laid externally to the building and a new distribution board to be installed. Power was shut off to the company during Christmas shutdown 1990 to allow all the necessary power supplies to be reconnected. The cost of this transformer was additional to budget & necessary for the success of the project. This cost was recovered by savings made in other areas of the project.

The next stage included the repainting of walls and replacement of external window glass.

A 2 tonne overhead crane was installed in December 1990(APPENDIX C). This involved the positioning of eight vertical columns, horizontally spanned rails and finally the main span to which a hoist was attached. Installation of the overhead crane should have been a straightforward operation since such equipment is relatively commonplace. Unfortunately this was not the case. Rexel Engineering was dissatisfied with the installation as it was considered unsafe. A structural engineer was consulted who advised on major improvements. The supplier agreed eventually to complete additional base plate grouting, stiffening spans & extra webs which vastly improved its stability. The contract price for the supply of overhead crane/gantry was, in hindsight too low, as considerable modification of the equipment was required to achieve the specified operational level.
The supplier did comply with the detailed specification but further checks would have revealed a lack of experience in the design & manufacture of specialised overhead cranes.

An air cooled chiller was installed to cool injection moulding machine hydraulics & mould-tools. Chiller pipework was installed above each service duct & connected to the injection moulding machines by flexible hose. Due to the unexpected delay in the delivery of injection moulding machines, the above services and equipment were installed by the end of January 1991.

Additional small equipment were purchased which was overlooked in the initial capital expenditure request, but obtained through savings made in other areas of the project.

After a number of delays machine approval trials were conducted in Germany on the 7th & 8th February 1991. Delivery of the injection moulding machines was completed on the 14th February.

Installation, commissioning & familiarisation of people with the equipment began immediately with all the operators & technicians being involved even at the commissioning stage. Commissioning was carried out by an engineer from the manufacturer while a second engineer trained the operators & technicians. Commissioning & training was completed within 6 days but this period included commissioning and employee training by the material handling/ancillary equipment suppliers. The injection moulding facility was now functional with a single mould tool adapted for processing. The success of commissioning this new facility was due to the effort of individuals in the injection moulding department, maintenance department and respective suppliers.

The commissioning of the suite of 20 mould-tools was phased over a period of 6 months. Each tool had to be fitted with standard backplates & fittings. By September 1991, the introduction of mould-tools had reached:

- Reached full process capability (statistical)(1)
- Reached Rexel Engineering component standards(15)
- Awaiting order requirement after approval of initial setup(2)
- Obsolete(1)
- Tooling awaiting to be introduced(1)
In summary there were 16 tools which could manufactured components in-house & the remaining were all in various stages of introduction with the exception of 1(obsolete).

Closure of project was completed when the expenditure budget had been finalised and all outstanding invoices cleared which occurred in November 1991 as planned.
5.0 REVIEW OF OBJECTIVES, OPERATION AND FINANCIAL BENEFITS.

This chapter reviews the key measures of the success of the planning & implementation planning phases and is a summary of a report produced 1 year after the capital was approved (ACCO-REXEL 1991b).

The objectives set in section 4.2 did not change throughout the introduction of in-house injection moulding at Rexel Engineering.

A review of the operational benefits is shown in table 5-1.

<table>
<thead>
<tr>
<th>OPERATIONAL REQUIREMENTS</th>
<th>(1) Company A</th>
<th>(2) Target</th>
<th>(3) In-house actual</th>
<th>(4) Improvement (3) - (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of set-ups(5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- logo/colour</td>
<td>1</td>
<td>4/5</td>
<td>2</td>
<td>-2/3</td>
</tr>
<tr>
<td>- tool</td>
<td>1</td>
<td>1</td>
<td>1/2</td>
<td>0/1</td>
</tr>
<tr>
<td>% cycle rate improvement:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- across 20 tools</td>
<td>0</td>
<td>10</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>Set-up time improvement( minutes):</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>- logo</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>- colour &amp; tool</td>
<td>---</td>
<td>30</td>
<td>27</td>
<td>3</td>
</tr>
</tbody>
</table>

KEY
(2): Target set from simulation.
(3): Results from in-house injection moulding.
(4): Improvement (or otherwise), in-house against target.
(5): Per 8 hour shift, over 2 machines.

Table 5-1 Summary of operational requirements, actual versus target.

Table 5-1 shows that there has been an increase in activity in set-up time improvement due to reducing leadtime to 1 week. Let us now consider the financial benefits of the system (table 5-2)(table 5-3).
<table>
<thead>
<tr>
<th>COSTS/SAVINGS</th>
<th>YEAR</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital:</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>- Investment</td>
<td>(439)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>- Replacement saving</td>
<td>110</td>
<td>150</td>
<td>160</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>- Grant</td>
<td>0</td>
<td>64</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Non-recurring costs</td>
<td>(3)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Overhead costs/savings</td>
<td>0</td>
<td>(59)</td>
<td>(59)</td>
<td>(59)</td>
<td>(59)</td>
<td>(59)</td>
</tr>
<tr>
<td>- Fixed costs RE</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>- Savings</td>
<td>0</td>
<td>28</td>
<td>78</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Working capital</td>
<td>(332)</td>
<td>188</td>
<td>189</td>
<td>(49)</td>
<td>(49)</td>
<td>(49)</td>
</tr>
<tr>
<td>- Stock reduction</td>
<td>(332)</td>
<td>(144)</td>
<td>46</td>
<td>(4)</td>
<td>(53)</td>
<td>(102)</td>
</tr>
</tbody>
</table>

CASHFLOW NETT
CASHFLOW CUMULATIVE
Payback: 1 year 9 months
Internal rate of return: not-available
Nett present value: (48)

Table 5-2 Cashflow with pessimistic stock reduction.

<table>
<thead>
<tr>
<th>COSTS/SAVINGS</th>
<th>YEAR</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital:</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>- Investment</td>
<td>(439)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>- Replacement saving</td>
<td>110</td>
<td>150</td>
<td>160</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>- Grant</td>
<td>0</td>
<td>64</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Non-recurring costs</td>
<td>(3)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Overhead costs/savings</td>
<td>0</td>
<td>(59)</td>
<td>(59)</td>
<td>(59)</td>
<td>(59)</td>
<td>(59)</td>
</tr>
<tr>
<td>- Fixed costs RE</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>- Savings</td>
<td>0</td>
<td>28</td>
<td>296</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Working capital</td>
<td>(332)</td>
<td>188</td>
<td>407</td>
<td>(49)</td>
<td>(49)</td>
<td>(49)</td>
</tr>
<tr>
<td>- Stock reduction</td>
<td>(332)</td>
<td>(144)</td>
<td>264</td>
<td>215</td>
<td>166</td>
<td>117</td>
</tr>
</tbody>
</table>

CASHFLOW NETT
CASHFLOW CUMULATIVE
Payback: 1 year 4 months
Internal rate of return: 23%
Nett present value: 64

Table 5-3 Cashflow with optimistic stock reduction.
With regard to the above cashflow (table 5-2)(table 5-3) the following should be noted:

- The investment refers to the cost of installing 2 moulding machines at Rexel Engineering.
- The replacement saving refers to the saving in replacement of old equipment at Company A.
- Initial costs are a one-off cost with a new facility.
- Fixed costs are the overheads associated with a facility.
- Stock or inventory reduction is valued at £28000 for the first year.
- Further inventory reductions are expected at distribution site in the next year.

A payback was promising within the target of 1.8 years agreed with original capital submission.

Senior managers concluded in the interim audit review (ACCO-REXEL 1991b) that a future implementation plan was needed to introduce more injection moulding machines & mould-tools into Rexel Engineering.
6.0 Conclusion.
The original objective of this project was to improve customer (internal) satisfaction to the Assembly Department with regard to the supply of certain key plastic components.

This has been achieved by bringing together new injection moulding equipment, new methods, new materials & most importantly those people, who had the right attitude towards change.

Since the initial introduction of injection moulding inhouse to Rexel Engineering in 1991, there has been a growing emphasis upon inhouse plastic component manufacture & plastic technology, which includes:
- Full 3 shift working for 5 days a week.
- Bringing in-house of more mould-tools with other materials e.g PC, EVA.
- Additional 3 injection moulding machines installed.
- Doubling of mould-tools within the facility.
- Even more emphasis upon plastics within stapling products, e.g latest stapling machines & pliers.
- New mould-tools to manufacture these new products, replacing the initial 20 mould-tools introduced.
- New people employed with a new wealth of experience in plastics.

While many changes are being introduced into the injection moulding facility, the concepts that support JIT still continue to be used. The injection moulding facility still achieves similar set-up times & continues to operate with a 1 week leadtime, frequently giving the customer plastic components days or even hours in advance of requirement.

On a more personal note, the author considered that the decision to invest was left quite late, even after numerous capital requests and presentations; BUT this proved to be an opportunity for reflection & gave more time for computer simulation and development trials. The author also appreciated the availability of money for these very important trials. These trials proved conclusive that Rexel Engineering was capable of inhouse injection moulding.

One final note; plastics may seem the answer to many of our problems when designing & manufacturing products BUT PLASTICS BRING THEIR OWN SET OF PROBLEMS WHICH MAY TAKE MANY COSTLY MISTAKES TO LEARN FROM.
7.0 RECOMMENDATIONS.

The recommendations that follow are specific to Acco-Rexel Ltd, at Llangeinor, South Wales:

1. Acco-Rexel should continue to maintain the improvements in set-up time reduction gained within injection moulding by supporting education & training of employees.

2. Acco-Rexel could introduce small batch manufacturing as a strategy for reducing costs & introduce as an objective for all departments.

3. Acco-Rexel could begin a long term education of all employees & suppliers, starting at management level in the basic principles of small batch manufacturing & include within an employee induction programme.

4. Acco-Rexel could begin a long term education & training programme for all those involved in the design, specification, purchase of plastic raw materials and in the subsequent manufacture of components.

The above recommendations are not the sole responsibility of management but upon all those who are capable of actioning the above including the author in matters of education of others.

The author hopes that actioning some of the above will ensure that small batch manufacturing & plastic injection moulding technology will be maintained and improved upon at Acco-Rexel Ltd, for the long term survival of the company & its employees.
APPENDIX A

TEACHING COMPANY SCHEME (TCS)

Experts from higher education participate in projects which are central to companies' plans for strategic development. The project is carried out in the companies by young graduates (TC associates) under the joint supervision of academic & industrial staff.

The mission of the TCS is to strengthen the competitiveness & wealth creation of the UK by the stimulation of innovation in industry through partnerships between academia & business.

The objectives are:

- To facilitate the transfer of technology & the spread of technical & management skills, & to encourage industrial investment in training, research & development.
- To provide industry based training, supervised jointly by academic & industrial staff, for young graduates intending to pursue careers in industry.
- To enhance the levels of academic research & training relevant to business by stimulating collaborative research & development projects & forging lasting partnerships between academia & business.

The TCS is managed by the Teaching Company Directorate (part of Cranfield Institute of Technology) on behalf of:

- Department of Trade & Industry.
- Northern Ireland Department of Economic Development.
- Ministry of Agriculture, Fisheries & Food.
- Economic & Social Research Council.
- Department of the Environment.

The above is an extract from the Teaching Company magazine.
APPENDIX B

PHOTOGRAPHS OF TESTS & MODIFICATIONS COMPLETED TO A DESK TOP STAPLING MACHINE TO IMPROVE THE TORSIONAL STIFFNESS OF PLASTIC COMPONENTS (ACCO-REXEL 1991e).
DIAGRAM 1  TORSIONAL STIFFNESS TEST JIG

DIAGRAM 2  TORSIONAL STIFFNESS TEST JIG
DIAGRAM 3. BASES AND COVERS BEFORE AND AFTER MODIFICATIONS

DIAGRAM 4. BASES AND COVERS BEFORE AND AFTER MODIFICATIONS
APPENDIX C

PHOTOGRAPHS SHOWING VARIOUS ASPECTS OF THE INTRODUCTION OF INJECTION Moulding AT REXEL ENGINEERING (ACCO-REXEL), LLANGEINOR.
AUGUST 1990

TOP: TWO EXAMPLES OF MOULD-TOOLS USED IN THE MANUFACTURE OF COVERS & BASES.

BOTTOM: LARGEST MOULD-TOOL, 3 PLATE DESIGN.
OCTOBER 1990

TOP/BOTTOM: PLANNED MOULDING MACHINE LAYOUT.
NOVEMBER 1990

TOP/BOTTOM: WORK IN PROGRESS & MAINTENANCE DEPARTMENT BEING MOVED IN PREPARATION FOR INJECTION MOULDING.
DECEMBER 1990

TOP: SERVICE DUCTS BEING DUG.
BOTTOM: FLOOR AREA BEING SCARIFIED.
DECEMBER 1990

TOP: INJECTION MOULDING MACHINES UNDERGOING FUNCTIONAL TESTS.

BOTTOM: MAIN ASSEMBLY HALL AT MANUFACTURERS.
DECEMBER 1990
TOP/BOTTOM: NEW EPOXY RESIN FLOOR BEING COMPLETED.
DECEMBER 1990

TOP: INSTALLATION OF NEW 1000KVA TRANSFORMER.

BOTTOM: NEW POWER CABLE ROUTING.
JANUARY 1991

TOP: INSTALLATION OF CHILLER & OVERHEAD CRANE.

BOTTOM: INSTALLATION OF OVERHEAD CRANE.
FEBRUARY 1991

TOP/BOTTOM: OFFLOADING MOULDING MACHINES.
FEBRUARY 1991

TOP: INJECTION MOULDING AREA & NARROW ENTRANCE (BY VEHICLES) FOR MACHINES TO NEGOTIATE THROUGH.

BOTTOM: MOULDING MACHINE NEGOTIATING ENTRANCE INTO FACILITY.
APRIL 1991

TOP/BOTTOM: COMPLETED INJECTION MOULDING FACILITY.
April 1991

Top: Raw material storage & mobile dehumidifying dryer (in green).

Bottom: Tool maintenance table.
TOP: TYPICAL MOULD-TOOL BEFORE ADAPTATION TO STANDARDISED BACKPLATES.

BOTTOM: STANDARDISED WATER COUPLINGS.
APRIL 1991

CENTRE:  STANDARDISED BACKPLATES HYDRAULICALLY CLAMPED IN THE INJECTION MOULDING MACHINE PLATEN.
CENTRE: MOULD-TOOL ADAPTED TO BACKPLATES WITH WATER COOLING CONNECTED TO SERVICE COUPLINGS.
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