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# THE PRO-t-CON PROJECT

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THE DEVELOPMENT OF A SYSTEM FOR  
CONTINUOUS PROCESS IMPROVEMENT USING  
PRO-t-CON PROCESS OPTIMISATION  
SOFTWARE AT AEP FILMPAC LTD.



A thesis submitted to the Faculty of Technology and Engineering, Massey  
University, in partial fulfilment of the requirements for the degree of  
Master of Technology  
In  
Quality Systems.

Paul Kenneth Moynagh

October 2000.

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## ABSTRACT

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This project details the work done to develop a methodology for process improvement at AEP Filmpac in Auckland, New Zealand. The company had purchased a process optimisation software package called Pro-t-con which they intended to use to improve the operating conditions for each product on each machine in the plant. Early use of the Pro-t-con software produced a number of questions as to its ability to optimise processes as effectively as expected. Thus research was done to test the effectiveness of the package and analyse its strengths and weaknesses. The results of this work suggest that Pro-t-con although very easy to use is limited in its ability to effectively optimise processes. Statistically it lacks the rigor of Classical and Taguchi design of experiment methods and cannot resolve processes with interactions or non-linear factors.

At the outset of the project the plant did not possess a system for suitably storing and retrieving machine set-up information, thus any improvements made to the settings one day would not be available for use the next time that product was run. Consequently in order to longitudinally develop process settings it was also necessary to develop a setting sheet system to support the process improvement initiatives.

The combination of a methodology for continuously improving processes and one for actually undertaking experiments to exploit such a process produced a coherent 10 step method for general process improvement. This method was used successfully on a variety of processes at plants in Auckland and Sydney.

## DECLARATION

I declare that this is my own, unaided work. It is being submitted in partial fulfilment of the requirements for the degree of Master of Technology at Massey University. It has not been submitted before for any degree or examination in any other University.

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Paul Kenneth Moynagh

This

Twentieth day of October 2000

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# 1.0 - INTRODUCTION

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The flexible packaging industry is very competitive. AEP Industries is the second largest manufacturer of flexible packaging products in Australasia. In order to compete effectively in a competitive commodity market it is necessary to not only be better than the competition in the present, but also be better at getting better for the future. There are many initiatives that promote the improvement of a company's competitive advantage, one of the most important of these is continuous processes improvement .

The management of AEP Filmpac understood this concept and on the recommendation of AEP Industries International, purchased a process optimisation software tool called "Pro-t-con". The intention was to apply Pro-t-con to a variety of Filmpac's manufacturing machines in order to identify optimal operating conditions and thus improve their processes. Pro-t-con came highly recommended by various European plants within the AEP group where it had made significant improvements to their processes in terms of throughput and quality.

This work reports on the development of a system to support Pro-t-con and investigates the suitability and effectiveness of Pro-t-con within AEP Filmpac in Auckland.

## 1.1 WHY PRO-T-CON?

The Management of AEP Filmpac identified an urgent need to improve the manufacturing efficiency of their operation. A substantial investment in new equipment was made during 1997 and 1998, however despite restructuring the company to simplify aspects of the manufacturing operation, the potential of these new investments was not realised. A process optimisation software tool called "Pro-t-con" was thus purchased with the view of applying it to each product on each manufacturing machine to identify optimal operating conditions. Pro-t-con came highly recommended by various European plants within the AEP International group where it had helped them to make significant improvements to their processes in terms of throughput and quality. It was expected that

the software would enhance the competitive position and long term viability of the company by helping to exploit its machinery constraints more effectively.

GS Technology marketed the Pro-t-con software worldwide and approached AEP Filmpac regarding its purchase. Steve Tilly from GS Technology thus visited Filmpac and gave a demonstration of the software on Machine 9. He spent three days organising and conducting experiments with 35 micron Palletfast stretch cling film and achieved a significant improvement in the machine's output through the study. This confirmed the value of Pro-t-con for Filmpac and they thus undertook to purchase it.

### 1.2 AIMS

The aims of this research are to

- 1) Develop a system for applying PRO-t-CON process optimisation software to the AEP Filmpac plant.
- 2) Analyse the performance of the software and system.
- 3) Make suggestions for the future development of the system and software.

### 1.3 OBJECTIVES

- 1) Define the necessary systems and procedures required to achieve a substantial and permanent improvement in the current machine operating conditions and to enable continuous improvement to take place
- 2) Demonstrate, on selected machines, a significant increase in plant output potential through application of the ideas developed in (1).
- 3) Demonstrate, on selected machines, the potential of the systems defined in (1) to reduce variation in machine output and quality.
- 4) Improve product quality and consistency on the companies' key products.

The establishment of a system for continuous improvement will help to reduce variation between runs of the same product and longitudinally develop the company's variety of products. This will make it more difficult for competitors to enter such markets and ensure that as customer expectations rise so too does the company's ability to satisfy

them.

A significant increase in output and quality will allow Filmpac to re-evaluate their products in terms of their competitive dimensions i.e. cost, time, quality and flexibility. A reduction in process variation will enable better planning of resources and make it easier to reliably meet customer demands.

The achievement of the above objectives will help the company to maintain and grow their competitive advantage over other manufacturers in an aggressive market.

#### 1.4 THESIS STRUCTURE

The literature review follows this section and discusses issues relevant for achieving the project's aims. A brief methodology section follows to describe the project's approach and introduce the three key areas of work.

- 1) A 10 step approach to process improvement,
- 2) The development of a setting sheet system for documenting and saving machine settings.
- 3) An analysis of the Pro-t-con software.

The project then comes together again for an overall discussion and conclusions.

## 1.5 BACKGROUND

AEP Industries NZ Ltd. is a division of AEP Industries Australasia and operates plants that produce a wide range of flexible packaging products. Blown film extrusion, flexographic printing, laminating, and bag converting processes are utilised in these plants.

### 1.1.1: COMPANY HISTORY

#### *Alex Harvey Industries (AHI)*

Filmpac was started in the early 1970's as part of what was then AHI. An amalgamation of fledgling plastic film manufacturing companies was put together on a new site in Mt Wellington, Auckland, to form a powerful new company to take advantage of the growing demand for flexible packaging. AHI Plastic Film Company was born, flexible packaging was coming of age and waxed paper was a thing of the past. The company very quickly became a producer of a wide range of products centred on bread packaging, agricultural films, packaging for New Zealand's primary produce such as meat and butter and a broad range of industrial packaging products, such as shrink and stretch cling films.

#### *Borden*

Through the various mergers and acquisitions that took place, the company grew to be the largest and most diversified film manufacturing plant in New Zealand. In 1990 Borden, an American based company founded on the food industry, acquired the flexible packaging division of what was then Printpac UEB.

#### *AEP*

In late 1996, AEP Industries Inc. purchased the worldwide packaging group from a troubled Borden. Three specialised plants were set-up in New Zealand as separate divisions.

**Filmpac** focussed on polyethylene and PVC films for general packaging. The emphasis was on extrusion with flexographic printing and bag making to support it.

**Flexipac** specialised in printing with strong bag converting capabilities. A small extrusion operation supported their laminating requirements.

**Liquipac** specialised in producing a range of pouches for packaging liquids.

Similar operations were also set up in Sydney and Melbourne to make up the Australasian group.

#### 1.1.2: COMPETITORS

The flexible packaging industry in New Zealand is extremely competitive. This is particularly so in the polyethylene films sector that Filmpac operates in. Due to the relatively low cost of entry and the flexibility of film manufacturing, printing and bag converting processes, it is relatively easy for small companies to enter the market. With a single extruder, printing press and bag machine a wide range of products can easily be produced.

#### 1.1.3: SALES INITIATIVES

Filmpac has pursued a strategy of being the market leader in many high volume sectors of the flexible packaging market. In many of these sectors, Filmpac has secured the business of the market leaders and the secondary suppliers, often with sole supply contracts.

Many of Filmpac's customers are subsidiaries of large multinational organisations. As such, these companies have access to international benchmark pricing. The "commodification" of packaging in most cases sees it viewed as a pure expense and an area of focus for companies to cut cost. Over capacity in the flexible packaging industry, results in most manufacturers being eager to fill this capacity, thus packaging manufacturers are easily played off against each other by their customers.

#### 1.1.4: COMPANY PERFORMANCE

The following graphs (Figs 1 to 5) show details of the last six years of actual results and a projection for the year 2000.

**Figure 1: Sales Tonnes**

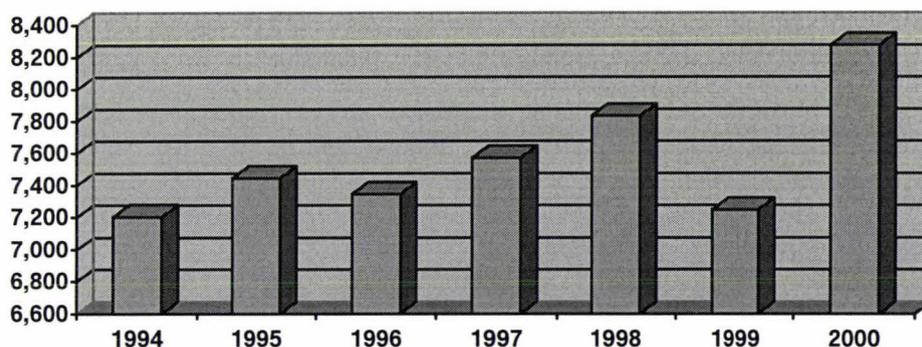


Figure 2: Sales Revenue - \$000

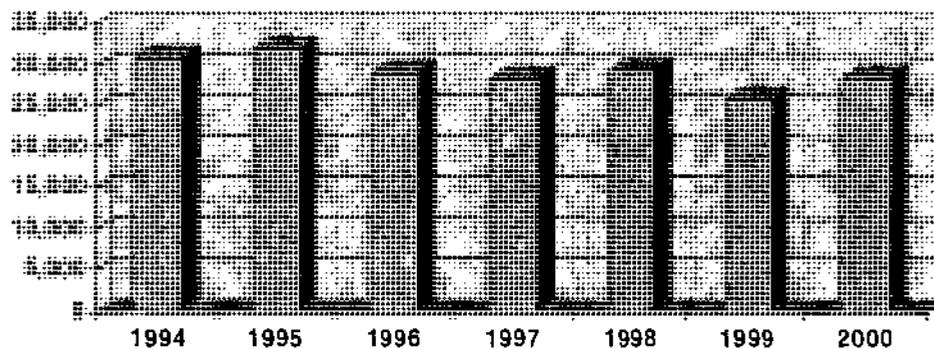


Figure 3: Capital Expenditure - \$000

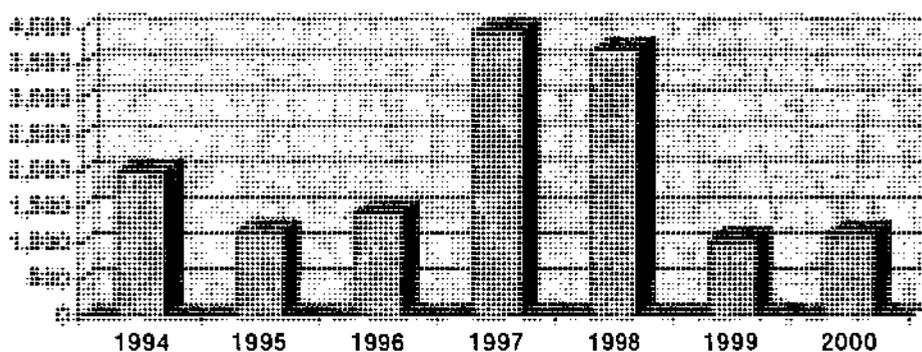


Figure 4: Total Employees

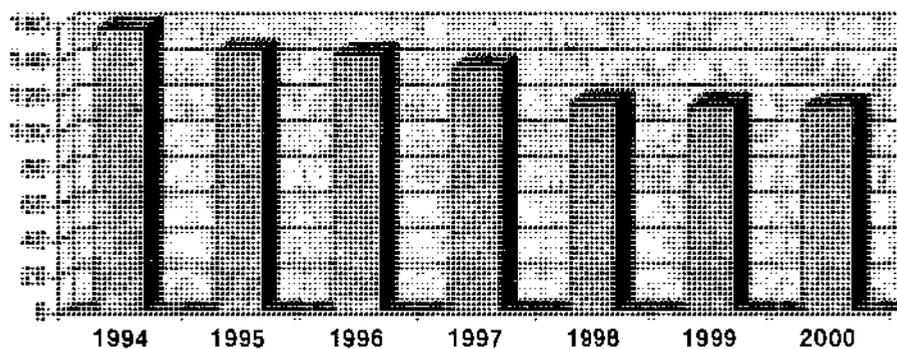


Figure 5: Operating EBIT - \$000

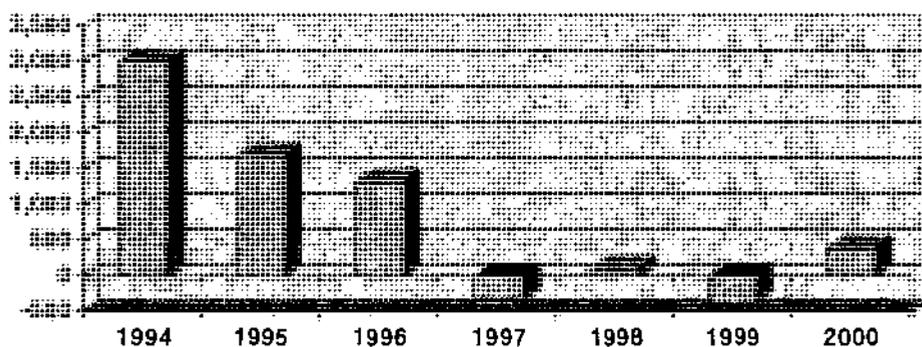


Figure 5 shows a rapid decline in profitability from 1994 to 1997, this was due to significant increases in raw material costs that were not passed on to customers due to competitive pressures. The company began to downsize and simplify their business while aiming to increase the volume of product made.

#### 1.1.5 MACHINERY

Filmpac Auckland is divided into three sections, Extrusion, Printing and Conversion. The extrusion facility consists of nine machines that vary considerably in their capabilities. Two of these machines are three layer co-extrusion lines and the capital spent in 1998 was for the purchase of Machine 1 from Maachi in Italy. This high output line is used to make much of the company's bread, form-fill-n-seal and lamination films. The other seven blown film extruders are mono-layer lines and vary in their use from high output industrial films to low output lamination films. Low Density, Linear Low Density and High Density Polyethylenes are used in these machines which are generally accompanied by a regrinding "Exact" unit for reprocessing trim. Corona treaters are included in six lines to produce a printable surface on the film. Six lines have Weighbatch gravimetric dosing systems and much of the pelletised raw materials are distributed to the machines through a silo system.

The printing facility consists of two high-speed flexographic printing presses (Uteco and Comexi). The eight colour Uteco press was purchased in 1997 to improve the performance of the printing facility as the demand for high quality printing increases. A microdot mounting machine was purchased in 1999 to improve the plate mounting process.

The conversion facility consists of a variety of machines for making bags, perforating, slitting and sealing. Two high speed Amplas Wicketers and one old FMC Wicketer are the backbone of the bread bag manufacturing operation. Two Gunters allow sealing and perforation of anything from rubbish bags to mattress covers. The slitter enables a wide extruded roll to be slit into narrower rolls for use in various products.

Scrap product is recycled and reused in a variety of low specification products.

#### 1.1.6: WORK FORCE

The work force at Filmpac consists of a variety of skill levels, generally extrusion and conversion operators can be described as unskilled to semi skilled with varying levels of experience and ability with their specific machines. It was decided that the present experienced operators were incapable of running Machine 1 efficiently so a recent initiative in extrusion has been to employ qualified electricians to operate this new co-extrusion line and do small electrical jobs,. This has freed up these experienced operators for other machines and for training the new electrician operators. Printers are trade qualified, there being two per shift, help is provided by semi skilled print assistants.

The extrusion supervisor manages up to nine operators on an extrusion shift and helps with machine set-ups and problems. Supervisors have historically been promoted from good/experienced operators however recently a new supervisor was appointed from outside the company with no experience in the industry in an effort to broaden the knowledge base. Conversion is run by team leaders who also operate machines and Printing is run by the trade qualified team leaders who also run one of the machines. The plant manager oversees all these.

Because of the continuous nature of the extrusion process the plant must be run 24 hours a day 7 days a week. Filmpac has recently changed from a complicated mixture of 12 and 8-hour shifts to having all production staff on a 12-hour, two days on, two nights on, four days off shift structure. This requires that there be four shifts in each department and enables machines to be run more consistently without the need for significant overtime during busy periods.

#### 1.1.7: WORK ORDER SYSTEM

Jobs are raised by customer service and sales staff in relation to customer requirements. This information is passed on to the planner who raises a work order and plans the product for a specific machine. Work order information is retrieved from MFG. Pro, the company's accounting system, and a work order developed. Work-orders contain important information for running a job including end use, product dimensions, material and specification details. The work-order print system is a "front end" used by operators and supervisors on the floor for printing out the work orders they are to complete for the day. The system is easy to use and requires only that the user type in the pending

work order number.

Runs vary significantly in length but generally the longer the run the better, as set-up costs become a lower proportion of the total. Often however sales staff promise a product without consultation with production, this causes an otherwise reasonable job to be interrupted so that the new one can be done. Consequently production is characterised by shorter than optimal run lengths and day to day planning. Also as many products can be made on a variety of the machines and these machines vary in their output, the time taken to complete an order can vary significantly.

Over one thousand products exist and these are identified by individual item codes. In many cases products are exactly the same in many dimensions but, for example, a change in width or roll length will require a new item code.

#### 1.1.8: A TANGLED WEB OF KNOWLEDGE

In the manufacturing area of AEP Filmpac many operators have a note book of settings and tips for running specific products to help them next time these products are run. They tend to protect this information, as there is a feeling that it ensures their continued employment. Anecdotes of operators who have struggled for hours to start up a machine exist. Occasionally skilled operators are phoned up in the middle of the night to dictate machine settings over the phone so another shift can get a job going. As there is no documentation to suggest how the product should be run This produces the situation is that machines are set differently each time they are run, an obvious special cause that increases variation in the final product.

Operating staff skill levels are limited, particularly in the area of line optimisation. Staff training has mostly focussed on the primary job functions of operating machines rather than on process optimisation and increasing the throughput of the process. Due to limited formal training and traditional empirical learning styles, the understanding of process fundamentals and their cause and effects is low. Consequently the settings used by operators to set up jobs are often far from optimal. No guidelines exist for the development of these settings and it is up to the operator to set it the way he feels is best. Depending upon the operator this might mean at a low output and unless the supervisor realises that the machine is under less than optimal conditions, that is the way it will stay.

Figure 6: Variation in output between runs of the same product (Machine 9)

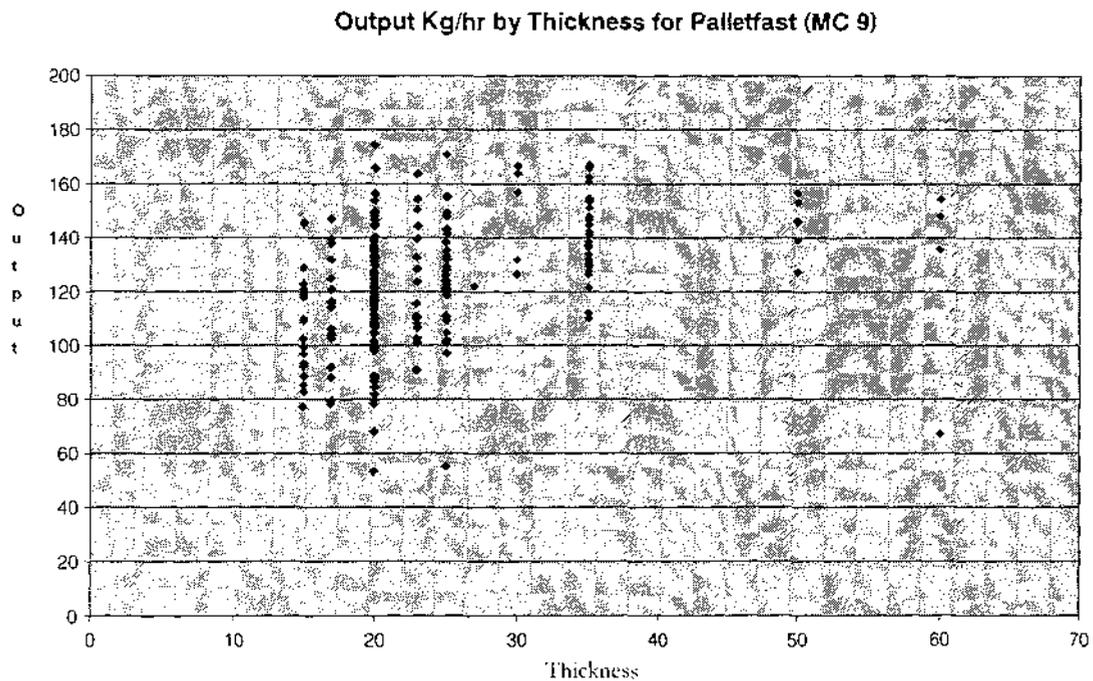


Figure 6 shows a worrying problem with the output from Machine 9. It can be seen from the graph that production rates vary from 80kg/hr. to 170 kg/hr. Machine 9, unlike all other machines in the plant, runs only one type of product (Palletfast stretch cling film (SCF)) and should therefore be relatively stable in its output. The variation in actual machine output seen above is likely to be due to a number of factors including: machine settings, operator ability, running problems, job changes and probably also reporting errors. This variation makes it very difficult to plan how long each job will take, to estimate the cost of the job and to guarantee the quality of the product. Such things frustrate customers, the planning department and the operators themselves as the decisions based on this poor information produce inaccurate plans, frequent job changes, poor quality and missed deliveries.

Such factors contribute against Filmpac's new machinery reaching its full potential.

# 2.0-LITERATURE REVIEW

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## 2.1 RESEARCH STRATEGY

The tasks detailed in the research aims suggest a variety of areas to discuss within this literature review. These are

- 1) The factors that influence the success of process improvement projects in industry.
- 2) The different methods for process improvement in industry.
- 3) The tools available for process optimisation and experimentation in industry.
- 4) Methods for objective analysis of the Pro-t-con software/method and the process improvement system developed in 2 above.

The crux of areas one and two was to review papers that made suggestions for improving manufacturing processes, implementing process change, developing systems for process maintenance, the effect such change has on manufacturing staff and how to get their support. All to enable the development of a suitable system for applying Pro-t-con at Filmpac.

Area three involved a discussion of the options available to industry for experimentation and optimisation of their machinery and an analysis of how these options fit into a process of continuous improvement. The focus was on the usability of these techniques, the information they gave and the number of experiments necessary to get this information.

Many authors suggest that a thorough knowledge of the system to be improved is essential to experimental efforts, therefore research into the blown film extrusion process was also undertaken.

When aiming to improve a process or system it is important to be able to measure its performance before and after the work. Consequently research was done into methods for measuring the effect of such an initiative on the company.

## 2.2 IMPLEMENTATION OF PROCESS IMPROVEMENT INITIATIVES.

Consistent factors in businesses include; [Statistical Methods for Quality, 1997]

- 1) There are customers.
- 2) The value chain consists of interconnected processes.
- 3) Improving the value chain processes is fundamental to being competitive.

The International Quality Study of Management Practices, having examined many different management practices, found only three to have universal benefit across all the industries studied. [Mahlen, 1993] These were:

- 1) Widespread deployment of the organisation's strategic plan.
- 2) The use of formal programs for supplier certification.
- 3) The use of process improvement practices.

Since this project is interested in the development and application of a process improvement strategy within AEP Filmpac, research into the factors that influence the success of such initiatives in manufacturing plants was deemed necessary.

Some of the most poignant comments from the reviewed articles are presented below.

*"Top management support affected implementation results" [Sanchez, 1996]*

*"The existence of a champion to defend the project increases the probability of success" [[Sanchez, 1996]]*

*"Training reduces resistance to change and makes workers better prepared to solve problems that arise, ...those firms that invested more training hours per worker achieved a higher increase in production flexibility." [[Sanchez, 1996]]*

*"... it is very important to promote early worker participation during automation because opposition to technological change reduces productivity and can jeopardise the new technology. Worker opposition to automation disappears when the workers who are affected by the automation are consulted or bought into the process before hand". [Sanchez, 1996]*

*"Focus, accountability, involvement and response to performance are key to getting staff to buy into a project that affects them. What gets measured gets done." [Brooks, 1995]*

*"The new line jobs are direct labour plus a variety of indirect duties... data recording, data analysis and problem solving." [Schonberger, 1986]*

*"Consider the change in self-concept when an operator who has always just chunked out parts takes on data recording duties. Recording disturbances is what managers and technicians have always done. The operator thinks; maybe I am now a part of the management and technical operation of this place." [Schonberger, 1986]*

*"The most successful programs put the responsibility and leadership in the hands of the machine operators. The results are as follows: Machine set-up is transformed from skilled to unskilled work; the set-up persons value shifts from manual skills to mental and problem solving skills." [Schonberger, 1986]*

*"As organisations adapt to SPC, as well as other changes, they will encounter the natural resistance to change of management and non-management personnel. Organisations with a long-term perspective will have a better chance of overcoming this resistance" [Keys and Reding, 1992]*

*"Using shop floor data collection to monitor production and improve planning can result in significant reductions in lead times and work in progress. For more fundamental gains, the task for manufacturing managers is to make improvements in the production process itself - cutting out stages, making machines more efficient or reducing the time it takes to switch the line from one product to another being obvious examples. Recent research by Custom Micro Products suggests that using shop floor data collection can help in the effort. Accurate information from the shop floor is the base of successful process improvement". [Anon, 1999]*

A major issue that appeared in the reviewed articles was that support from the people who were to be most affected by the change had to be gained early. Authors differed in their approach to gaining this support, this is likely to be due to the differing environments such studies were done in. They did however agree that training in the new way and involvement in its design were critical to successful change. Support from upper management and the existence of a project champion to defend the project were considered extremely important. These concepts are supported by the suppliers' recommendations for the introduction of Pro-t-con and are known by them as the "Pro-t-con Culture Change". [Lo 1999]

It was clear from the outset that the major barriers to implementation of a process improvement system at Filmpac were likely to be of a people and organisational nature. Consequently employee involvement and participation in the optimisation and data collection sides of the project were deemed essential. Thus the development of a

comprehensive system for collecting and analysing data was an early focus. The model proposed by Upton 1998b was helpful in this regard. The Pro-t-con user manual details useful suggestions for encouraging the Pro-t-con culture change and recommends the following ingredients as essential for success of Pro-t-con endeavours. [Lo 1999]

- The process is capable of achieving each target on its own or achieving some targets in groups
- Approval and commitment from Management
- A Project Team Approach, involving planning, operating & QC personnel
- Detail planning of timing, target setting, resource- people & equipment
- Adequate resources available for Study
- Basic knowledge of process set-up
- Equipment and process in standard running conditions (Very Important)
- Accurate gauges and instrumentation for data collection
- Well defined quality standards
- Good collection of derivative values for process confirmation
- Carefully conducted trial
- Carefully conducted validation trial
- A report and recommendation for further improvements

Practical considerations relevant to the AEP Filmpac plant were the most important factors in the design of an approach to using Pro-t-con for process improvement there. However the suggestions detailed above and found throughout the articles were used heavily in guiding the design. This is covered in further detail in section 3

## 2.3 PROCESS IMPROVEMENT METHODOLOGIES

In order to design a methodology for applying Pro-t-con to the manufacturing plant at AEP Filmpac it is important to understand some of the methods proposed and used by others for process improvement. Authors present process improvement systems that vary in their level of discussion from the management of an overall continuous improvement culture to the actual process of experimentation. Most approaches however involve planning, analysis, design and implementation phases for obvious reasons.

Many of those proposed utilise various tools or techniques such as Design of Experiments (DoE), Statistical Process Control (SPC), Quality Function Deployment (QFD) or fish bone diagrams. However they often ignore the fact that scientific knowledge development is basically an iterative learning process where each study builds upon the knowledge of those that went before. It helps to view the process of improvement in terms of knowledge development and therefore follow such a progression in this type of work.

### 2.3.1: EIGHT STAGES OF KNOWLEDGE

Barnes 1997b discusses eight stages of knowledge that a company may go through in understanding their processes and uses a case study on Nabisco biscuits to illustrate them. The stages are

- 1. Complete Ignorance.** No knowledge of the variables that affect the response and one considers all variation to be random. May not even know how to measure the response itself.
- 2. Awareness.** Begin to build a list of the factors that one believes could affect the process. (e.g. ingredients, baking time, weather etc)
- 3. Learn to Measure Key Variables.** Begin to measure the variables that one thinks may affect the response. (e.g. time baking using a watch, measure ingredients using cups, count the number of strokes used in mixing etc.)
- 4. Control the Mean.** Knowing how to measure the key variables it follows that one will attempt to control them in order to control the response. E.g. have a countdown timer to tell you when to take the cookies out of the oven, standardise measuring cup size etc.

**5. Process Capability and a Recipe.** Work on reducing the variation in key variables and document a process that gives reasonable results i.e. write down a recipe and maintain control of all the variables. Cookies should then become more consistent.

**6. Process Characterisation.** Conduct a series of experiments to discover how certain variables affect the response so that if a customer wants a sweeter or a lower fat cookie one knows which variables to change.

**7. Know Why.** Develop knowledge of the interactions between input variables and the response as well as the strength and direction of these relationships. Build a model of the process to predict what effect changes in certain variables will have on the cookie. E.g. you know how much less sugar to put in for the desired reduction in cookie sweetness.

**8. Complete Knowledge.** Since there are infinite secondary variables it is impossible to have perfect knowledge of a process. It is however practical to say that one has reached stage eight when you have a model which will predict output characteristics to 10% of the tolerance band for changes in inputs across a 2:1 range, including all interactions.

The 8 stages of knowledge development detailed above suggest a stepwise process of improvement in them self. It may theoretically be possible to skip stages 4 and 5 in a rush to know why a process behaves as it does. However without instilling the disciplines involved in these middle stages it is easy for the developed knowledge to be lost, and for the process fall back to stage 3. The total approach described above ensures that improvements that are made to the process are maintained over the long term.

### 2.3.2: A SEVEN STEP METHOD OF PROCESS IMPROVEMENT

An example of an improvement methodology presented by Brydone et al [Statistical Methods for Quality, 1997] is the following 7 Step Method of Process Improvement

- 1) Define Project.
- 2) Define current situation – (flowcharts, focus groups).
- 3) Analyse the causes – (fish bone diagrams, data collection).
- 4) Determine possible solutions and implement them.
- 5) Measure results.

- 6) Make sure any improvements are ongoing – (SPC, documentation).
- 7) The future, can more improvements be made?

This is a general method that resembles the Plan Do Check Act (PDCA) cycle. It could be used at any of the 8 stages of knowledge detailed above however it is most suited to knowledge development at stages 5,6 and 7. It adds to the 8 stages of knowledge by asking whether further improvements can be made and thus turns back upon itself to form a loop that encourages continuous improvement.

### 2.3.3: UPTON'S 4 LEVELS OF INVOLVEMENT

Upton 1998b, describes process improvement in terms of 4 levels of involvement, these are discussed below with the inclusion of a preliminary step, level 0.

#### ***Level 0. Establish Process Measurement Methods and Document the Process.***

This step involves recording information on the process settings and outputs and is important for analysing where the process is and what variation is present in it. This is the beginning of process knowledge and takes it up to level 3 of the 8 stages detailed by Barnes i.e. learn to measure key variables.

#### ***Level 1. Reposition the Process in a Local Region***

The information recorded on process settings can be used to establish the present operating envelope. From this a stable operating point can be developed using a best guess method or an optimisation package such as Pro-t-con. The best settings are then fixed in place and reduced variation within the process due to changes in operating conditions should be experienced. The performance of the previous best settings should now be the average. This extends process knowledge to level 4 or 5 of the 8 stages of knowledge, lifting the average performance of the process and reducing its variation.

#### ***Level 2. Explore and Pursue the Boundary of the Existing Process***

Conduct experiments to gain an understanding of the greater processing region and explore its boundary. Use this information to help optimise the process for its current configuration. Pro-t-con, Design of Experiments etc. are useful for this. This is known as the exploitation of a constraint [Goldratt 1992] and involves development of process

knowledge up to level 8.

***Level 3. Reconfigure the Process to Elevate or Break Constraints.***

In exploring the process boundary a constraint or constraints are often discovered to be keeping the process from better performance. In order to improve the process further it is necessary to break these constraints. This is known as the elevation of a constraint [Goldratt 1992] and involves developing new knowledge of the elevated process boundary.

***Level 4. New Process/Radical Redesign.***

At some point it may be decided that the process is not capable of performing as required no matter how much work is done to it. It is necessary then to access a superior boundary through a radical redesign of the old process or through the purchase of a new one. The process of knowledge development therefore begins again.

This is a powerful framework for process improvement as it encourages companies to iteratively learn about their processes and utilises the well regarded Theory of Constraints (TOC) concepts [Goldratt 1992] in levels 2, 3 and 4. It is useful for management decision making by helping them to understand the different levels at which an improvement project could be approached. Management's decision making process may pose the following questions.

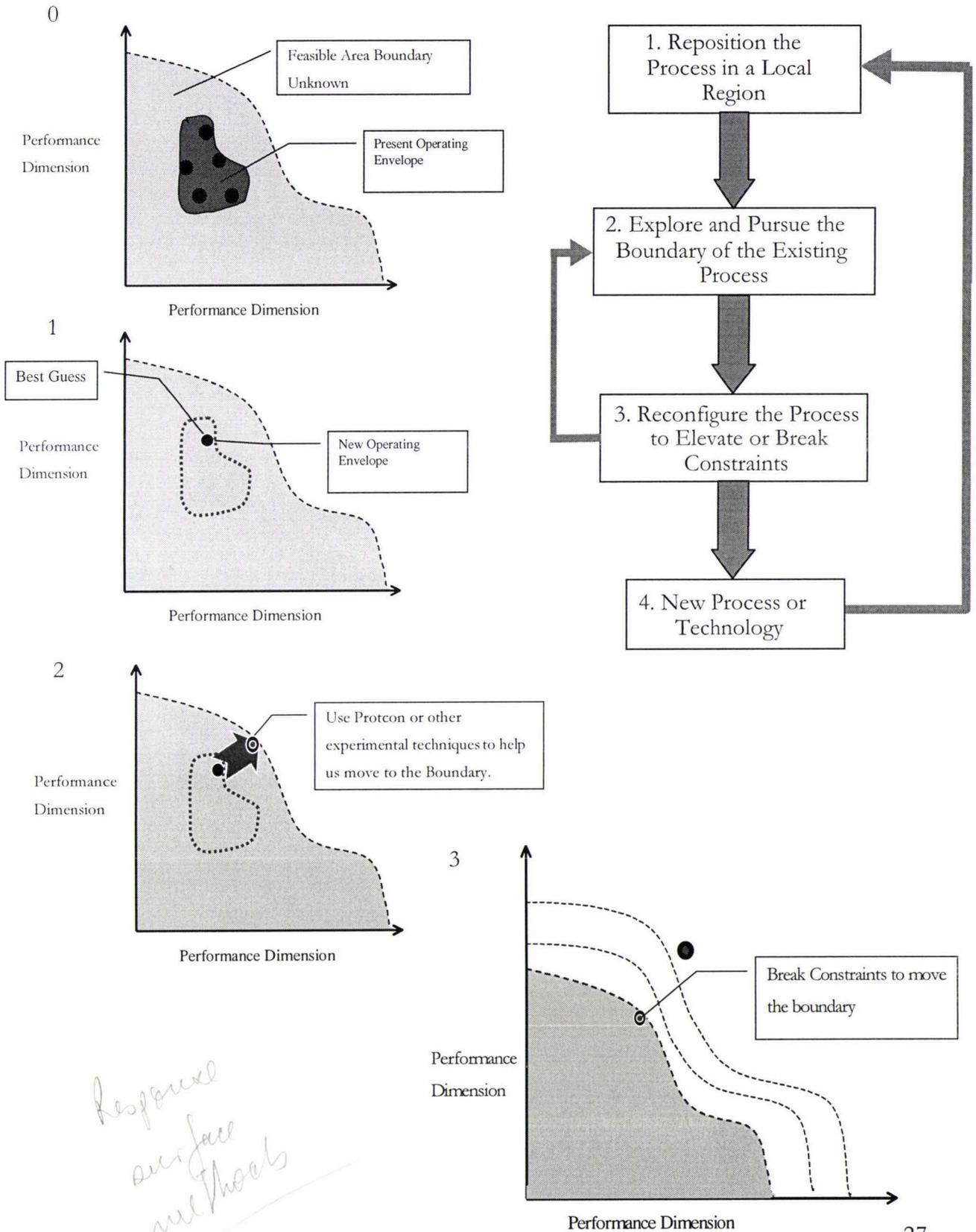
- 1) Has the limit of what the process can achieve through experimentation been reached? Has it been exploited fully?
- 2) How may the process be reconfigured to access a new performance boundary?
- 3) Is it possible to develop a new process to achieve the same task more effectively?

The danger is in either abandoning a process which holds significant potential for exploitation or in fighting too long to improve an existing process that has no further capability. A balanced approach is necessary to ensure the right decisions are made in a timely fashion.

The above levels are presented graphically in figure 7.

Figure 7 was adapted from Upton 1998b and was very helpful in conceptualising the methodology for process improvement at Filmpac

**Figure 7: Upton's Levels of Process Improvement**



*Response surface methods*

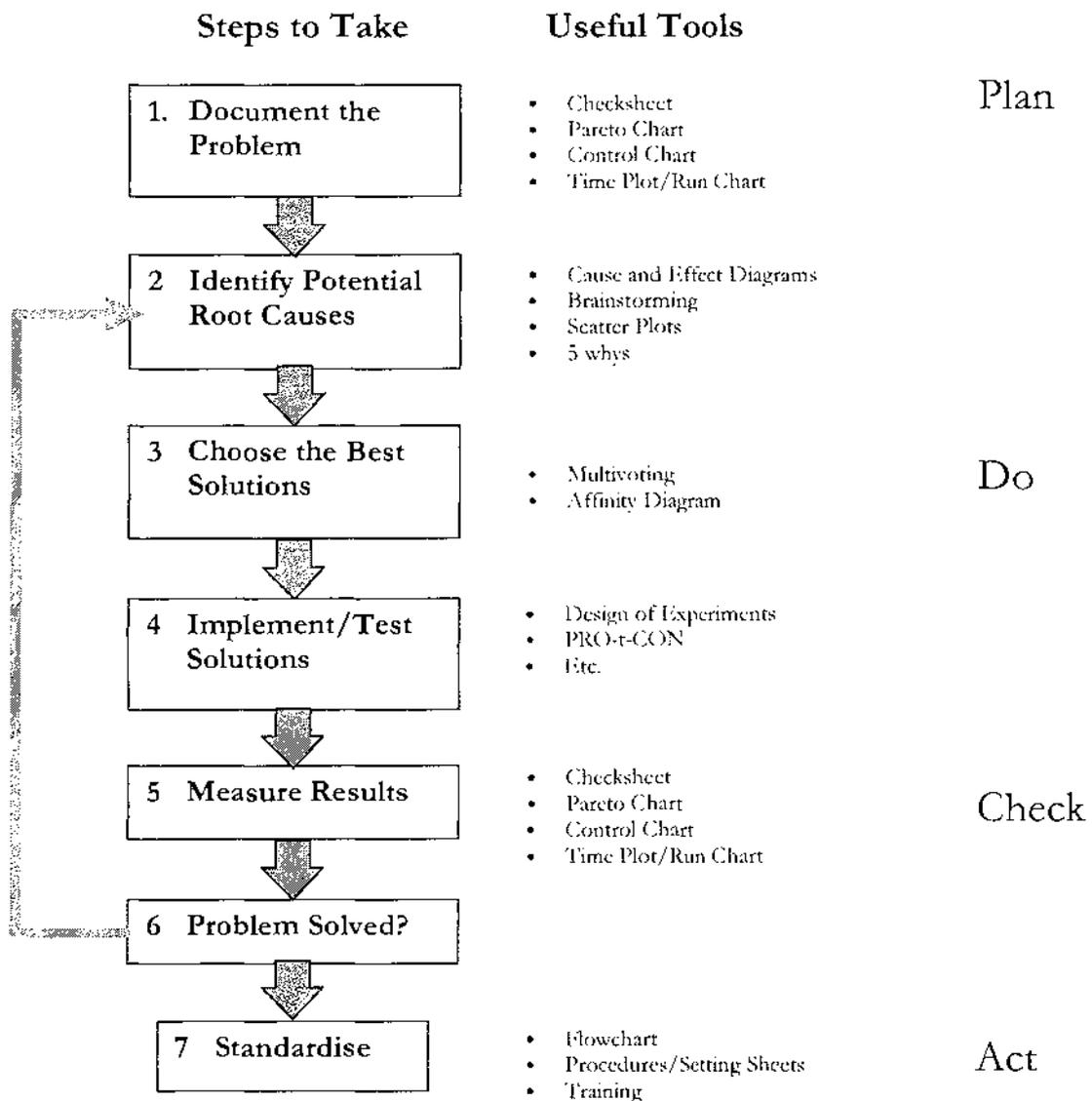
2.3.4: FLOW CHARTS FOR PROCESS IMPROVEMENT AND PROBLEM SOLVING

Adapted From Hoerl and Snee 1995 [Statistical Methods for Quality, 1997]

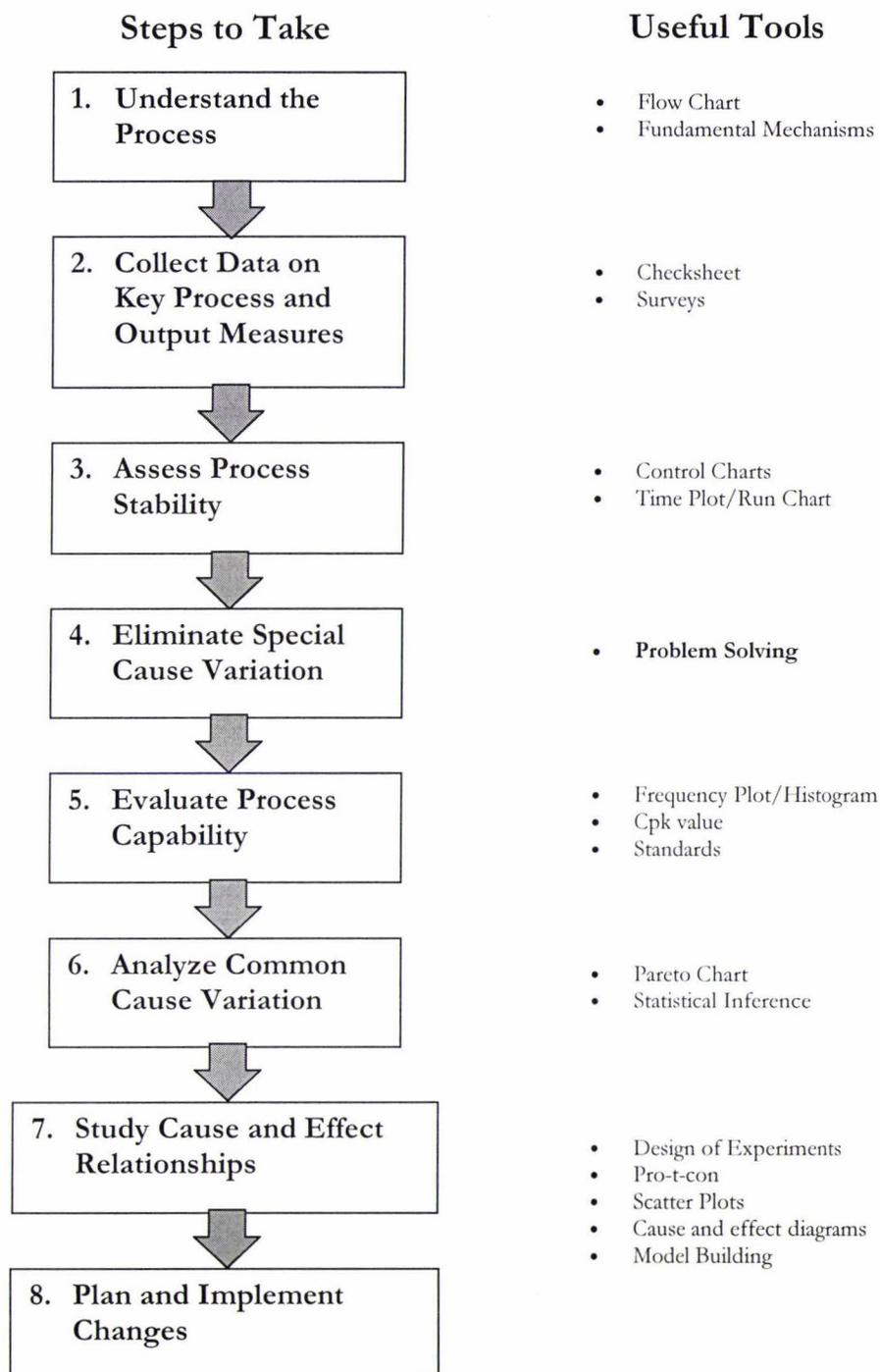
The Flow Charts in figures 8 and 9 are typical of the process improvement and problem solving strategies used in practice. They work well because they

- 1) Emphasise work as a process,
- 2) Separate the two steps to reducing process variation i.e. the elimination of special cause variation and the analysis of common cause variation.
- 3) Promote a cycle of constant learning.
- 4) Incorporate the principles of the PDCA Cycle.

Figure 8: A 7 stage Flow Chart for Problem Solving



**Figure 9: An 8 Stage Method for Process Improvement**



The suggestion of tools to use at each stage is a useful element of the two methods. Although the problem solving flow chart in fig 8 suggests a cyclical method of constant learning the process improvement method in fig 9 seems to omit this important element. Fig 9 also fails to explicitly encourage the maintenance of improved process settings deemed necessary by Barnes. However the cyclicity and process maintenance of the problem solving method and the focus on data and analysis of the process variation in

the process improvement method combine to suggest a strong and useful overall process improvement method.

### 2.3.5: GOLDRATTS FIVE STEPS

Goldratts five steps for process improvement Goldratt 1992

- 1) Identify the constraint.
- 2) Exploit the constraint.
- 3) Subordinate resources to the constraint.
- 4) Elevate or break the constraint.
- 5) Go back to step one but don't allow inertia to cause another constraint.

Goldratts five steps concentrate attention on the factors that are constraining a process from better performance. Goldratt, then, provides less of a detailed method than others, suggesting a similar type of guiding approach to that of Upton and recommending that process improvement should begin by exploiting constraints i.e. the process should be "optimised". However it also acknowledges that it may not be possible to achieve the desired results without breaking (elevating) the constraint altogether. It suggests a cyclical approach that encourages continuous improvement but does not suggest specific tools to use in defining, exploiting or elevating constraints. Barnes's 8 stages of knowledge and the other experimental methods such as proposed by Pro-t-con, Taguchi and Hoerl and Snee fit into the first 3 steps of Goldratts 5 steps above, as methods which enable the exploitation of constraints.

### 2.3.6: PRO-T-CON METHODOLOGY

The suggested Pro-t-con process optimisation method is as follows.

- 1) Brainstorm with operators, technical etc to develop a process recording sheet that includes all factors and responses i.e. all inputs and important outputs from the process.
- 2) Develop process measurement methods e.g. 1-5 nominal scale.

- 3) Conduct experiments and record data from the process.
- 4) Enter the experimental running conditions and their quality/output characteristics into Pro-t-con.
- 5) Define variables as controllers, derivatives (co-variates) and resultants in Pro-t-con.
- 6) Define the targets of the optimisation study including their order of priority in Pro-t-con.
- 7) The software performs the optimisation and gives the optimal settings and expected results.
- 8) Perform a confirmatory run to check that the optimal settings achieve the expected results.

The method revolves around the Pro-t-con software and its capabilities, the end result being a setting sheet to run the machine to in the future. It is a very simple methodology that is applicable wherever the development of a set of “optimal” settings is being attempted. In terms of the 8 stages of knowledge it, using the software, involves development of knowledge up to stages 6 and 7 but could also be used for development of a recipe at stage 4. This is discussed in further detail next in sub section 2.4.

### 2.3.7: TAGUCHI 8 STAGE PROCESS

Taguchi proposes a method for process improvement that focuses on first reducing process variation (making the process more precise) and second making the process more accurate. This is due to the emphasis on the cost to society of variation suggested by Taguchi’s loss function.

Taguchi 8 stage process improvement methodology. Antony et al. 1999a

- 1) Set Objectives.
- 2) Select quality characteristic or response.
- 3) Identify control, noise and signal factors.
- 4) Choose an orthogonal array design.

- 5) Prepare experiments.
- 6) Run experiments.
- 7) Statistical analysis and interpretation of results.
- 8) Perform a confirmation run.

This methodology is specific to Taguchi but similar to those suggested by Barnes and Antony and compares well with the methodology recommended by Pro-t-con above. It is involved with the process of knowledge development at levels 6 to 8 and fits into the previous methodologies wherever experimentation is necessary. A variety of tools exist for knowledge development through experimentation and these are discussed in detail in sub section 2.4.

#### 2.3.8: SUMMARY

The methods discussed above suggest that the following aspects of process improvement are important for the design of a method for implementing Pro-t-con at Filmpac.

- 1) Emphasise process improvement as a knowledge creation and development process.
- 2) Process improvement initiatives should include stages that ensure improvements are ongoing, i.e. include maintenance stages that involve process documentation and measurement.
- 3) An iterative approach to process improvement promotes a continuous search for improvement opportunities.
- 4) Begin process improvement initiatives by optimising/exploiting the current process.
- 5) Consider process redesign and constraint breaking exercises only when sure that the process is incapable of achieving the necessary performance in its current configuration.

## 2.4 STATISTICAL TECHNIQUES FOR PROCESS OPTIMISATION

A major element of the methods described above was the use of statistical methods to aid in the process improvement initiatives. Research into techniques such as Classical, Taguchi and Shainin Design of Experiments, Statistical Process Control, and Response Surface Methodologies has thus been conducted to help compare these methods with Pro-t-con. This research will enable a fuller understanding of the options and approaches available to experimenters and help in the design of experiments so that they may be compared. Analysis of the way in which improvements were demonstrated due to the reviewed articles will suggest methods to employ for a similar task at Filmpac.

A normal approach to a process optimisation project might be to use Design of Experiment (DoE) techniques in order to help understand and optimise processes. A few descriptive quotes are presented below.

- \* *“Experimental design involves making purposeful changes to the inputs or factors of a process to observe the corresponding changes in outputs or responses. A process is defined as some combination of machines, materials, people, environment and measurement which when used together perform a service, produce a product, or complete a task. Experimental design is a scientific approach which allows the researcher to better understand a process and determine how the inputs affect the response.” [Barnes 1997b].*
- \* *“The Classical tools start with fractional factorials and end with evolutionary optimisation (EVOP). The Taguchi methods use orthogonal arrays (inner and outer) in “tolerance design,” employing analysis of variance and signal to noise for statistical evaluation... All three approaches (Shainin methods included) are far superior to conventional SPC, which attempts to solve chronic problems by means of control charts—a total waste of time. All three approaches are also far superior to old fashioned experiments, taught in universities and widely practised by engineers in which one variable at a time is varied, with all other variables kept rigidly constant. Besides the inordinate amount of time necessary for such experimentation, the central experimental weakness of this approach is the chronic inability to separate main effects from interaction effects.” [Bhote, 1991]*
- \* *“DoE required that we interrupt production on the machine involved in the experiment for a lengthy period. A typical experiment involves a matrix with 12 different set-ups, each of which required changing seven different parameters. It could easily take several*

*days to run this experiment to conclusion. The level of guesswork and up-front planning also made it difficult to justify continued use of DoE.” [Litsikas, 1995]*

- \* *“Because Sequential Process Optimisation (SPO) (the software that Arrow Molded plastics chose to use) works in process and doesn’t require machine down time, Arrow Plastics scheduling department is also pleased. Jobs don’t have to be interrupted; thus the company can realise the productivity and costs savings of tooling a mold once, instead of several times.” [Litsikas, 1995].*
- \* *“Pro-t-con is applicable to any continuous process as “every process is only a combination of process variables influencing a combination of product variables”. Providing you can measure variables, it is possible to establish the relationship between them and optimise the process with the Pro-t-con technique”. [Lo, 1999]*
- \* *“A modelling system for all types of plastics processing uses actual production data to optimise parameter settings...Protcon calculates relationships between a large number of variables, in order to show if and how the process can be controlled. One expert who has “test driven” the package says it could have “profound significance” in process modelling. The program will calculate the importance of given machine parameters on given part parameters” [Mapelston, 1994].*
- \* *“Every process, no matter how well controlled, still has opportunities for improvement by a Pro-t-con Study. The improvements could be in output, better quality and better knowledge of the process for engineering improvements.” [Lo, 1999]*
- \* *“Another less widely acknowledged method of process optimisation, known as response surface methodology, is endorsed by many statisticians as a technique for modelling complex manufacturing processes with a minimal number of experiments.” [Brinkley, 1993]*

A fundamental paradigm of Pro-t-con is that *“every process is only a combination of process variables influencing a combination of product variables” [Lo 1999]*. So providing inputs and outputs can be measured, the process can be optimised. A variety of other methods for discovering the effects of a processes inputs on its outputs exist and these include DoE, RSM, Taguchi and Shainin techniques. However some of the people involved in the articles quoted above seem to have had problems using these methods as they can require a significant knowledge of statistics, a large number of experiments and often interruptions to production. The suggestion is that Pro-t-con does not suffer from

such problems and is thus more easily used in an industrial setting. These issues shall be discussed further, during this section.

#### 2.4.1: CLASSICAL DESIGN OF EXPERIMENTS (DOE)

*“Classical experimental design is a scientific approach which helps the researcher to determine how the inputs affect the response”. [Barnes 1997b]*

Two level factorial experimental designs involve analysing  $k$  factors in  $n$  observations with each factor at two levels. This is a useful technique for analysing a process for its factor effects and allows the provision of independent (orthogonal) assessments of the effects of each factor under study as well as the interactions between factors. The number of experiments or treatment combinations necessary ( $t_c$ ) for a two level factorial experiment is  $t_c = 2^k$  so for four factors it is necessary to do  $2^4 = 16$  experiments. This number can be reduced through fractionalisation of the design but this comes at the expense of the information about interactions between factors. The above equation then becomes  $t_c = 2^{k-p}$  where  $p$  is the fractionalisation element so  $2^{4-1} = 8$  experiments could be done if the effect of the four way interaction was not deemed important. DoE is designed so that the analysis is more powerful in terms of the ratio of number of experiments necessary and the information resulting from these experiments than from a "non-designed" data set. The Plackett Burman screening experiment is designed to give a processes single factor effects with the minimum number of experiments. It is often used for reducing a large number of variables down to a smaller number of important ones for more in depth analysis. It ignores interaction and non-linear effects and is thus questionable in terms of its predicative value.

DoE work is often supported by statistical data analysis that may involve model building by regression, Analysis of Variance (ANOVA) and further in depth analysis of the important factors and their interactions/non linearity's.

Many books exist on the topic of experimental design, however the major text consulted in this review was an accumulation of knowledge from many of these into a set of course notes for Industrial Analysis Techniques 1997, a paper provided by Massey University Department of Production Technology. This text covered a variety of the options available to experimenters.

A number of papers were reviewed that also discussed DoE. Antony [3] discussed a series of suggestions for making industrial experiments more successful that compare well with those found in Barnes [4,5]. Brinkley [9] presents a case study on the combination of DoE and SPC for improved quality discussing the option of Response Surface modelling for process optimisation, another important option available to industry. Litsikas [25] presents a short article discussing the reasons that Arrow Molded Plastics dumped DoE for another methodology called Sequential Process Optimisation (SPO). The suggestion was that SPO was more user friendly than DoE as it required less interruptions to production and was easier to implement. She lists the benefits of SPO over DoE as 1) Significantly reduced machine down time, 2) Facilitates reaching optimal combinations, 3) Last minute changes not as overwhelming, 4) Reduced scrap and 5) Verification of theories and opinions. This is similar to what the Pro-t-con operations manual suggests are Pro-t-cons benefits over DoE. Unfortunately no further information was found about SPO.

The power of DoE to develop information and knowledge about processes is seldom questioned. It is however often seen as difficult to implement, as it requires significant prior planning and can involve a large number of experiments. It is generally for the use of capable engineers, statisticians and scientists and requires significant training in its application.

#### 2.4.2: RESPONSE SURFACE METHODOLOGY (RSM)

Response surface techniques are special cases of the previously discussed DoE methods and are used when curvature is suspected in the response. The objective is to provide empirical contour diagrams of how factors under the control of the experimenter influence the response. They give more information about the effect of factors on the response and consequently require significantly more experiments. The main options available are Three Level, Central Composite and Box Behnken Designs[Barnes, 1997b]. Because RSM techniques require so many experiments they are usually undertaken with a small number of variables i.e. when it is known which variables are significant and the interest is in a fuller understanding of how they affect the response.

Brinkley 1993 discusses the combination of Response Surface Methodology, Taguchi,

DoE and SPC for improving quality. The primary goal of the study was to longitudinally minimise defect levels and variation. He discussed a methodology that involved the design of central composite and three level experiments to allow linear and non-linear effects to be estimated. Response surfaces were constructed and constrained optimisation was performed using GAMS-MINOS non-linear optimisation software to determine the optimal factor settings for implementation on the shop floor. Confirmation experiments were performed to verify the solution.

Because RSM techniques give so much information about the relationship between important factors and the response they are useful for optimisation and help in setting factors to achieve specific targets. They do however, like DoE, require the user to have a strong statistical background.

#### 2.4.3: TAGUCHI METHODS

Taguchi methods are an important part of the history of experimental design and are as much a quality philosophy as a quiver of tools to use for process improvement.

Taguchi advocates a two stage process for process optimisation that aims to reduce response variation and set the response mean. Firstly the factors that significantly affect the Signal to Noise Ratio (SNR) should be identified using a suitable combination of inner and outer orthogonal arrays and setting all factors that affect the SNR to the levels where the process has the lowest SNR. This reduces variation in the performance characteristic prior to shifting the mean to the desired target. The next stage is to select an adjustment factor that has little effect on the SNR but a large effect on the response mean and use this to shift the mean to the desired target. So first the process is made more precise and then more accurate. This methodology is discussed by Barnes 1997b and used by Antony et al. 1999a.

Barnes 1997a gives a comparison between Taguchi and DoE his conclusions are that.

- 1). Taguchi's design matrix is a special case of a DoE matrix.
- 2) Taguchi methods stress simplicity and are thus attractive to engineers.
- 3) Taguchi is often a good way to get started but for complex problems full use of DoE

is recommended.

4) Taguchi is considered to be 60 to 80% effective whereas classical DoE with Response Surface Methodology techniques are believed to be 80 to 100% effective.

5) Optimisation is done with an iterative approach in DoE whereas a true optimum is not really found with Taguchi.

Antony et al 1999a discusses the background, methodology and results observed using DoE and Taguchi Methods in an industrial setting. The aim being to identify critical factors affecting process variability and mean and to use this information to minimise process variability whilst achieving the desired mean. They detail an eight step Taguchi process which was discussed previously. Using this methodology their process capability (Cpk value) was improved from 0.534 to 1.69, clearly showing a significant improvement in the processes ability to reliably produce to specification. Using Taguchi's loss function analysis the estimated potential annual savings to the company due to the above improvement was £ 75000 through improved customer satisfaction, better reputation, reduced complaints and a greater market share.

#### 2.4.4. SHAININ METHODS

Bhote 1991 begins by discussing the strengths and weaknesses of Classical and Taguchi DoE against the methods used by Dorian Shainin. The suggestion is that although the classical and Taguchi methods of DoE are significantly better than "one factor at a time" experiments for understanding processes, the Shainin techniques are easier and more powerful than either. The main reason for this is that in order to analyse processes for a large number of factors with a reasonable number of experiments the experimental designs must be fractionalised and thus ignore possibly important interactions. A paper written by Shainin is included in appendix A and relates a case study about the danger of analysing processes with interactions using experimental designs that are not able to analyse for them. The conclusion being that this can produce misleading and spurious results.

He then presents and discusses seven techniques used by Dorian Shainin (i.e. Multi-Vari charts, components search, paired comparisons, variables search, full factorials, scatter plots and pre-control) for process improvement and analysis. And proposes that these

are easier to learn, cheaper, quicker, less complex, more statistically valid and more versatile than Classical and Taguchi DoE methods. He presents the following table.

**Table 1: A Comparison of Classical, Taguchi and Shainin Methods for DoE**

Characteristic	Classical	Taguchi	Shainin
<b>Principal Techniques</b>	Fractional factorials EVOP	Orthogonal Arrays	Multi-vari components search Paired comparisons, variables search, full factorials, B vs. C. Scatter plots
<b>Effectiveness</b>	Good in the absence of interactions (20 to 200% improvement) Poor if interactions are present (small gains; retrogression possible) Limited optimisation	Good in the absence of interactions (20 to 100% improvement) Very poor if interactions are present (minimal gains; retrogression likely) Very limited optimisation	Extremely powerful regardless of interactions (100 to 1000% improvement likely) Retrogression rare. Maximum optimisation.
<b>Cost/Time</b>	Moderate (8 to 50 experiments)	Moderate, if no interactions (8 to 36 experiments for inner array alone) High if interactions present (several trials of same experiment; 64 to over 300 experiments for inner and outer arrays combined).	Low (3 to 30 experiments)
<b>Complexity</b>	Moderate ANOVA required 3 to 5 days of training	High Inner and outer arrays multiplied S/N and ANOVA required 3 to 10 days of training.	Low Mathematics embarrassingly simple 1 to 2 days training.
<b>Statistical Validity</b>	Low Saturated designs, with confounding of main and interaction effects	Poor Highly saturated designs, with extreme confounding of main and interaction effects. S/N only effective if ratio of mean to standard deviation is constant The objective to make a design robust against noise factors is worthy, but the means to achieve this are poor. Nonrandomisation a glaring flaw.	High Clear separation of main and all low and high order interactions.
<b>Versatility</b>	Low Only two tools available	Poor Only one tool available	High 20 tools available to tackle a wide range of problems.

<b>Scope</b>	Requires hardware Main use in production	Can be used at design stage if formula governing input and output variables is known. Main use in pre-production	Requires hardware Can be used at prototype, pre-production and production stages.
<b>Ease of Implementation</b>	Moderate Statistical knowledge and computers required. Engineers discouraged by complexity.	Poor Statistical knowledge and computers required Engineers turned off by complexity and modest results.	High Minimal statistical knowledge required Engineers, production, direct labour, and suppliers gravitate to its use, encouraged by excellent results.

Bhote obviously feels strongly that the Shainin methods are better than either Taguchi or Classical DoE. However it is debatable whether he has been absolutely fair to either of the methods or if he has actually used either of them as heavily as he has obviously used the Shainin techniques. For example he mentions that classical DoE has only two tools available (fractional factorials and EVOP) however a variety of other methods exist such as Response Surface, Plackett Burman, Multiple Regression and Factor/Cluster Analysis that support the use of Classical DoE. Also Bhote includes the use of Full Factorial experiments on up to four factors in Shainin's methods. One might grant Bhote that DoE by itself is less powerful than the Shainin toolbox he suggests however a DoE approach involving the variety of tools suggested above seems at least as good.

Nonetheless he gives compelling examples of the use of Shainin DoE in industry and the text is thus very useful as a training manual for the use of these methods. His critique of Classical and Taguchi DoE techniques compares in terms of the ease of use of these methods with the quotes presented previously and the suggestions of Pro-t-con to come.

#### 2.4.5: STATISTICAL PROCESS CONTROL.

While Pro-t-con claims to use sophisticated algorithms for data analysis the drive of SPC is to keep things simple and aid in the plants decision making process and is generally part of a companies Total Quality Management (TQM) system. SPC algorithms are based on uncomplicated well known statistical techniques and formulae, available in many

textbooks. Its aim is to help people understand and reduce process variation and in itself offers little to the understanding of relationships between process variables. SPC can be considered a methodology for maintaining an optimised process rather than for gaining one. It therefore doesn't fit into the same family as Pro-t-con, DoE, RSM, Taguchi or Shainin for process optimisation.

Brinkley 1993 mentions that although they were able to "optimise" their process using DoE techniques they experienced difficulties in getting operators to co-operate and maintain the optimal settings. Their solution to this issue was to shift the operator's focus from constant adjustment of the process to maintaining the process at the optimal settings and aggressively monitor important process factors such as solder levels and flux quality. SPC helped them in achieving this. It could be used to achieve a similar result at Filmpac.

#### 2.4.6: PRO-T-CON

The best explanation of what Pro-t-con aims to do can be found in their marketing brochure [Appendix B].

"Pro-t-con determines optimised process settings against a set of targets using a real-process Mathematical Model. The Model is developed from the collection of process data within the operating window. Pro-t-con utilises **multivariate linear regression**, along with **patented algorithms** to develop a Mathematical Model of the process. [Lo 1999]

Only one journal article was found that discusses Pro-t-con in any way. This was a short promotional article by Mapleston 1994. The article claims that Pro-t-con may have a profound significance in process modelling and discussed the basic methodology and expected results from the software. It was a very short article and offered no data or experimental basis for its claims.

All other literature regarding Pro-t-con came directly from the suppliers of the software i.e. either GS Technology in England or more recently Glenvern Associates of Australia. The most useful elements of this work are sections 3 and 6 of the user manual, which discuss how to apply Pro-t-con to an application. It makes suggestions for setting up and

undertaking experiments giving the list previously presented on page 23 of this report to describe the essentials of a Pro-t-con endeavour.

The user manual is based mainly on the experiences of Pro-t-con's suppliers and is anecdotal in its approach. Unfortunately no data, results or methodologies are presented for consideration. Being partially a marketing document it is biased toward the Pro-t-con method but does give some good advice for any such endeavour. The manual does not mention any of the methods used for making its assertions or suggestions. Its aim is to "train the converted" to use Pro-t-con most effectively. The following lists were presented in the frequently asked questions section of the operations manual [Lo 1999].

***What is so unique about Pro-t-con compared to other process improvement techniques?***

- Pro-t-con can handle up to 500 variables
- Pro-t-con Model is set-up from real-life process data
- Pro-t-con does not require the user to understand Statistical Analysis Techniques
- Pro-t-con develops the Mathematical Model and determines the Optimised Process Settings from one keystroke.

***What are the limitations of Pro-t-con?***

- Pro-t-con is based on a statistical analytical approach and
- Needs at least 30 sample sets of data for an accurate model
- Needs one sample set of data more than the number of variables
- Optimisation will only be within the Operating Envelope explored during a study
- Each study is tool/equipment/product specific as the performance and outcome from each set of these are usually different.
- The changes in a process must be continuous, as Pro-t-con cannot model on major step changes, such as an explosion.

The frequently asked questions section presents a table that contrasts Pro-t-con with DoE. Table 2

**Table 2: A Comparison of Pro-t-con with Design of Experiments.**

PRO-T-CON	DoE
Can develop a process model with up to 500 variables	Generally limited to a small number of variables, usual maximum is around eight, incl. Controls and Resultants
Needs minimum 30 sample sets and one sample more than variables	Number of experimental runs (sets) increases exponentially with number of variables
Can include Derivatives (Co-Variates) in Model, valuable for problem solving	Derivatives (noise) are usually not included in model. Experimental runs are randomised to avoid their effect.
Software includes optimisation tool	Most packages require a second optimisation step
Complex optimisation study can be completed in "days"	Large number of experimental runs can take weeks or months to complete
Uses linear regression within operating window	Some systems can apply 2 <sup>nd</sup> or higher order regression in the modelling process
Front end is designed for operator/ technician use	Knowledge of Statistics required, for Engineers to use

Table 2 is presented in such a way as to make Pro-t-con attractive. For example the suggestion is that DoE requires more experiments than Pro-t-con and that these experiments take longer. This leads the reader to believe that a Pro-t-con study will always take fewer experiments than an equivalent DoE experiment. This is not necessarily the case.

Design of experiments can be undertaken with as few as four experiments, the number of experiments necessary increasing exponentially with the number of variables under analysis. Fractionalisation of the design reduces the number of experiments necessary and it is possible using a Plackett Burman screening experiment to analyse for single factor effects with one more experiment than the number of factors under study. This means that with a similar number of experiments a similar amount of information about a processes single factor effects can be discovered with fractional factorial experiments as can be with Pro-t-con.

A fundamental flaw with this is that it is always at the expense of understanding the interactions between these variables on the process. In fact if strong interactions exist between variables, fractional experiments become prone spurious results. [Shainin 1988].

The Pro-t-con method advocates a one factor at a time method of changing factors. If this rule was strictly abided by for all factors in the model it would require that for two levels of each factor twice as many runs as there are factors would be necessary, for three levels, three times as many etc. So the efficiency of experimentation with a method of this type is worse than that of DoE. Also, unlike DoE, Pro-t-con does not encourage randomisation of the experimental runs, this leaves it open for errors due to the order in which experiments were carried out throwing doubt on the conclusions drawn.

However it is widely accepted that DoE methods require a significant statistical background and tutelage in their application. Pro-t-con on the other hand is taught in a three day session at the plant and can be used by skilled operators or technicians. The ability of Pro-t-con to allow operators with a low understanding of statistics to use it effectively is a substantial advantage in industries where statistical knowledge is rare.

The issue of which technique gives the most information about a process from the least number of experiments, the statistical basis for this information and the conclusions drawn from it was not mentioned in their text as this was not its intention. It basically suggested methods the suppliers believed to be necessary for the successful implementation of Pro-t-con. In this respect it was similar to Antony 1999b that presented methods for the successful implementation of DoE.

### ***Multivariate Linear Regression. [5]***

Pro-t-con uses Multivariate Linear Regression for building its “real process model”. Multiple regression is a generalisation of simple regression where variation in the data is explained by more than one variable. Like simple regression, multiple regression utilises the concept of least squares for building a process model. It does however only analyse for single factor effects so cannot discover interactions. Being only linear regression it does not attempt to use higher order polynomials in the model. The general equation of a multiple regression model is

$$T_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_k x_{ik} + e_i$$

Where;  $T_i$  Is the response

$\beta_0, \beta_1, \dots$  Are the model coefficients

$x_{i,1,2 \dots k}$  Are the observed values of the independent variables that the model predicts the response with.

$e_i$  Is the error term, i.e. the variation in the response that is not attributable to the model.

A multivariate regression model can be used to predict the response with any combination of the independent variables ( $x_i$ ) as long as the model explains suitable variation in the response. Multivariate regression is often undertaken in conjunction with DoE in order to enable prediction of the response from a set of given settings.

### ***Pro-t-con Software Details***

The software analyses the data, changing controllers within pull % restrictions to give the machine settings that will run the machine as close as it can get to the desired targets.

New versions of the Pro-t-con software allow the percentage pull restriction i.e. the percentage change in control factors Pro-t-con is allowed to use when seeking an optimal solution, to be altered. This is known as the pull % and can be used to free up or restrict Pro-t-con optimisations. Where curvature or interactions are suspected the recommendation is to use a low pull factor i.e. 10% or less.

It is important to correctly categorise factors into controller (control variable), derivative (co-variate), and resultant (response) as Pro-t-con only changes control variables when attempting to achieve the chosen targets.

One is also asked to prioritise and give tolerances to each target before the model is built to allow Pro-t-con some room to move around in when compromising between settings.

### ***Model Information***

Pro-t-con reports three sets of statistics on its information screen upon development of a model.

“correlation between the target (dependent) variable and the control (independent) variables are determined and expressed as the Total Variability and Pareto values in the information screens” [GS Technology 1999]

Glenvern and GS Technology suggest that a model with total variability above about 80% to 90% will be reasonably accurate. Less than 80% and it is likely that an important variable has been left out of the analysis.

The third statistic reported by Pro-t-con is the ratio value. The variables which have the highest ratio values for each target are those Pro-t-con believes have most influence on that specific target. The calculations used in developing these are unknown to the student. In the new version of the software graphs of the range over which each factor has been varied multiplied by its Ratio value ( $\text{Range} \times \text{Ratio}$ ) are drawn to show the relative effect of each variable on each response. These are very useful for quickly seeing the factors that have most effect on the process.

If Pro-t-con cannot achieve the desired targets then further experiments may be necessary. The  $\text{Range} \times \text{Ratio}$  chart drawn to show which variables have the most effect on specific targets can be used to suggest further experiments to concentrate on these variables.

One can also perform “what if” experiments around the optimised solution by changing control variables within the software to see what effect this has on reaching the targets. These virtual experiments are helpful for designing actual experiments to make the model more comprehensive.

Further information about Pro-t-con from GS Technology and Glenvern Associates suggested that.

1. The mathematics is based on multi-variant linear regression
2. Pro-t-con starts by selecting a complete data set, then changes controllers within given restrictions to try to achieve the target values.
3. It will only predict within the operating envelope seen.
4. Behind Pro-t-con is some fairly complex maths and unique algorithms that have been presented in a very user-friendly way. This is one of the big differences to DoE.

### ***Patent Search***

It was mentioned in the literature provided by the suppliers that Pro-t-con used “Patented” algorithms in its analysis. In order to get a patent it is necessary to document and publish details about the patentable part of the product. A search for this patent was therefore done but was however unsuccessful. Software is not usually protected through patents these days as it is easier to protect the code through other means. This avenue of investigation was therefore abandoned.

#### 2.4.7: SUMMARY

1. There are concerns as to the Pro-t-con software’s ability to “optimise” a process effectively.
2. Pro-t-con uses Multivariate linear regression in its analysis of process data.
2. Pro-t-con is very easy to use and aims to directly develop the settings necessary to achieve the desired targets.
3. Significant improvements in process performance can be achieved through use of the Pro-t-con methodology and software.

The methodologies reported by Brinkley 1993 and Antony et al 1999a are more transparent and statistically verifiable than that suggested by Pro-t-con whilst reaching a similar result in terms of optimised setting conditions. They do however require a deeper understanding of the statistical methods used in their application and this is typical of DoE, RSM and Taguchi methods. This is likely to discourage their use in industry by all but the most able experimenters. Pro-t-con does not suffer from this problem, being easily used by anyone with a basic knowledge of computers. However it is not possible to have as much confidence in the results of a Pro-t-con optimisation model as the results of the other methods as Pro-t-con ignores non-linear factors and the interactions between variables. The methods involved in analysis of Brinkley and Antony et al’s experiments can be relied on as they are well known and accepted techniques. Unfortunately however an analysis of the statistical foundations of Pro-t-con has not been possible as its algorithms are protected by the supplier.

With classical systems of experimentation the goal is to reduce the number of variables

under study down to just the most important ones. Information about a small number of important variables is gained from the analysis but it is up to the experimenter to decide how this knowledge will be applied to optimising the machine. Often further experiments are necessary to achieve an optimum solution.

With Pro-t-con all plausible variables are often included in the model. The result of the optimisation is a list of the settings necessary to run the machine at the requested targets. The experimenter should be able to take these settings set the machine up the way they dictate and expect it to perform to the targets Pro-t-con anticipated.

Pro-t-con seems to occupy the easy to use end of the market and it was the only package found that allowed direct single step optimisation of a process. The literature however suggests its fundamental statistical basis is weak as it ignores interactions and non-linearity and does not encourage the randomisation of experiments.

Nonetheless this review has uncovered a variety of techniques available to industrial experimenters interested in process improvement and optimisation. It has also discussed a variety of well-accepted experimental methodologies that will be of use for comparing with Pro-t-con. Finally it has developed an understanding of the difficulties involved in undertaking classical experimental design methodologies and thus an appreciation of why a process optimisation package such as Pro-t-con is attractive to industry.

The analysis of Pro-t-con in section 5 will be designed to shed light on the algorithms used by Pro-t-con in its analysis and discuss the advantages and disadvantages of the method.

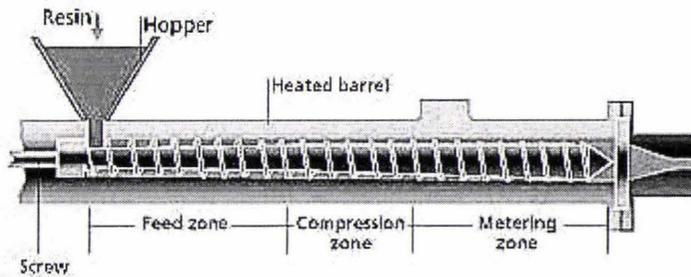
## 2.5 BLOWN FILM EXTRUSION FUNDAMENTALS.

A thorough knowledge of the process to be improved or optimised was recommended by authors in sections one and three as essential to the success of an experimental effort. The assumption is that otherwise it will not be possible to design the experiments necessary to push the boundaries of what is presently known about a process. Consequently significant research into the field of blown film extrusion was deemed necessary.

### 2.5.1: THE EXTRUSION PROCESS AND EQUIPMENT

Polyethylene is fed into a hopper. It drops into the channel of a screw rotating within the hardened liner of an extruder barrel and is forced forward by the rotating screw flights. As it moves it is heated, melted, thoroughly mixed and compressed by complex flow patterns along the screw channel.

**Figure 10: Extrusion hopper, Screw and Barrel [Exxon 1999]**



A well mixed homogenous melt is necessary to ensure an end product with uniform cross section and good mechanical and optical properties. The quality of the melted polymer presented to the die is related to the temperature settings on the barrel, the screw design and a number of other processing parameters. Because the viscosity and flow characteristics of Polymers change considerably with temperature, accurate control of the barrel temperatures is essential to maintain control of the melt temperature and level of mixing as these affect final film properties.

The barrel can be divided into feed, compression and metering zones (fig 10) and there are usually four or five controllable temperature zones along the screw. Although heat may be added in these zones generally more than 70% of the heat generated in the extrusion process is done through the action of the screw. Consequently the major

function of these zones is to control the barrel zone temperatures, this usually means cooling it.

The **hopper throat and feed zone** is where the material first makes contact with the screw. This zone must be temperature controlled to prevent the polymer from melting prematurely and sticking to the hopper throat before reaching the screw. In the feed zone early melting occurs and the polymer is conveyed to the compression zone.

In the **compression zone** the screw root diameter steadily increases to provide slow but uniform compression. By the end of this zone melting should be completed and serious mixing begins. The compression ratio is the ratio of the volume in one screw flight in the feed section to the volume of one screw flight in the metering section. The increase in pressure prevents air, which could cause oxidation gels, from being forwarded with the melt to the final product.

In the **metering zone** a consistent action is provided as the screw rotates for homogenisation and pressure build up. This is highly important for obtaining a uniform melt viscosity and for minimising melt surge. In many modern screws and certainly in those found at AEP Filmpac there is a **mixing section** included between the compression and metering zones. This section homogenises the melt and often helps to break down gels by working and mixing the material before it goes to the metering zone.

The melt, finally passes through a **screen pack** and then through the **adapter** to the **die**. The screen pack serves primarily as a filter for foreign particles that may have got into the hopper, but also builds up pressure in the extruder so that the polymer is worked and mixed well. Finally the melt passes through the die, where it is shaped into its final form. The die design is important as it affects the thickness variation of the film, most modern dies are spiral mandrel dies the spiral helps spread the molten polymer evenly around the die reducing thickness variation. Die size affects the **blow-up ratio** of the final bubble and **die gap** affects the necessary **draw-down**, more about these later. Because the polymer flows from zone to zone being acted upon by the factor settings at each zone there are reported to be significant interactions between the factors in the process.

Figure 11: Spiral mandrel and die. [Exxon 1999]

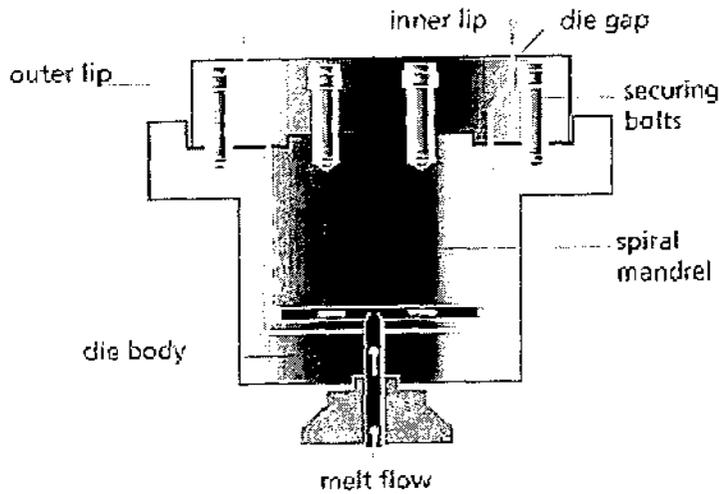
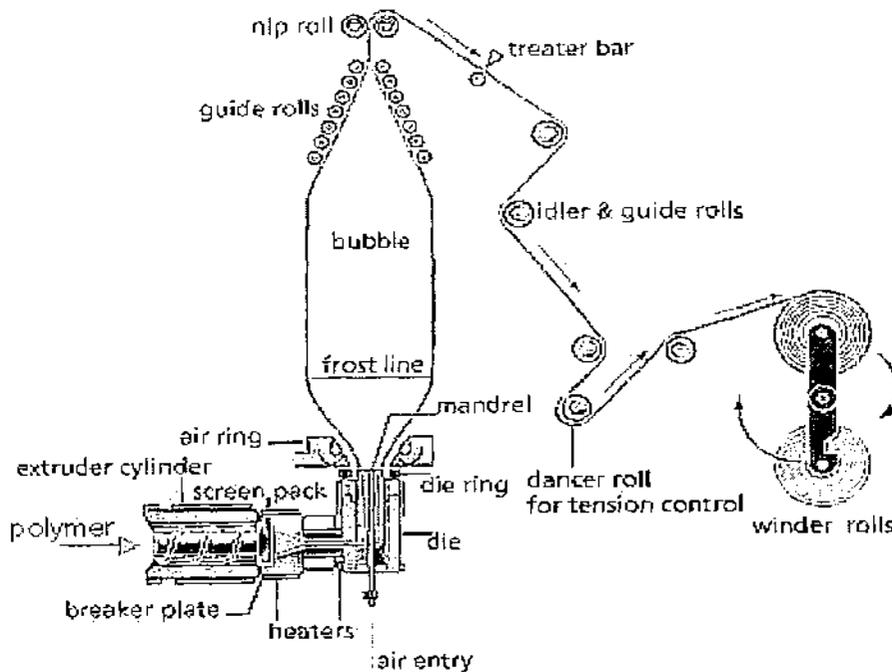


Figure 12: The extruder through the die to the winder. [Exxon 1999]

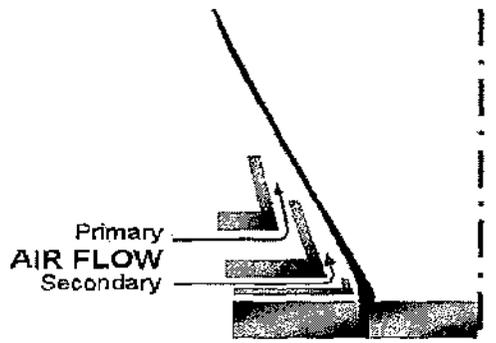


Film thickness depends directly on the extruder output, the bubble width, and the haul-off speed. By changing these variables a range of films with different widths and thicknesses can be produced. A typical range of widths from the same machine might be from 0.4m to 2m wide, with thickness ranging from 10 to 200 microns. A range of

materials can also be processed with the same equipment giving many options for a blown film manufacturer.

Bubble cooling is done through airflow on the outside of the bubble. In modern extruders air-cooling is often also applied on the inside of the bubble with an internal bubble cooling mechanism (IBC). This helps to increase the maximum throughput by stabilising the bubble and elevating what is often the major process constraint, cooling.

Figure 13: Cooling air flow against the bubble. [Exxon 1999]



Once cooled the film tube enters a collapsing frame and is hauled off via rotating nip rolls. The resulting double layer is led to a winding station, where it is wound on to a cylindrical core. Before winding the film can be slit to specific widths, and or corona treated for further printing and converting.

Strong relationships exist between the variables in a blown film extrusion machine. These relationships depend heavily upon the type of extruder used, the properties of the raw materials, available cooling on the extruder/air-ring and the properties of the die and mandrel. It is therefore important to be careful when generalising about machines as experimental evidence is based solely on the machine used for the experiments.

Most of the information available on this topic comes from the manufacturers of the various parts of the process, whether they be machinery manufacturers, screw and die designers or material suppliers. These proprietary texts often quote ideal melt temperatures and blow up ratios for processing specific materials but concurrence with these depends upon the desired film properties and the constraints of the machinery it is made on. Since resins and processing equipment vary greatly, it is not possible to list the exact processing conditions necessary to run a given resin. It is more important for the processor to understand the effects of extrusion variables on particular properties, as

this will enable them to make adjustments to their equipment and processing conditions to obtain a film with the desired optical and mechanical properties.

For this reason all independent texts consulted in this part of the search suggested only general “rules of thumb” for the operation of an extruder to achieve specific product characteristics. Also none of Filmpac’s lines are “stock standard” as they have been modified significantly since their initial purchase. The goal of this part of the research was to become familiar with the extrusion processes within AEP Filmpac so that the problems likely to arise throughout the project could be solved. It seemed most appropriate then to spend time investigating Filmpac’s machines using the operators, senior members of the manufacturing team and other technical staff to assist in this education.

#### 2.5.2: THE EXTRUSION PROCESS

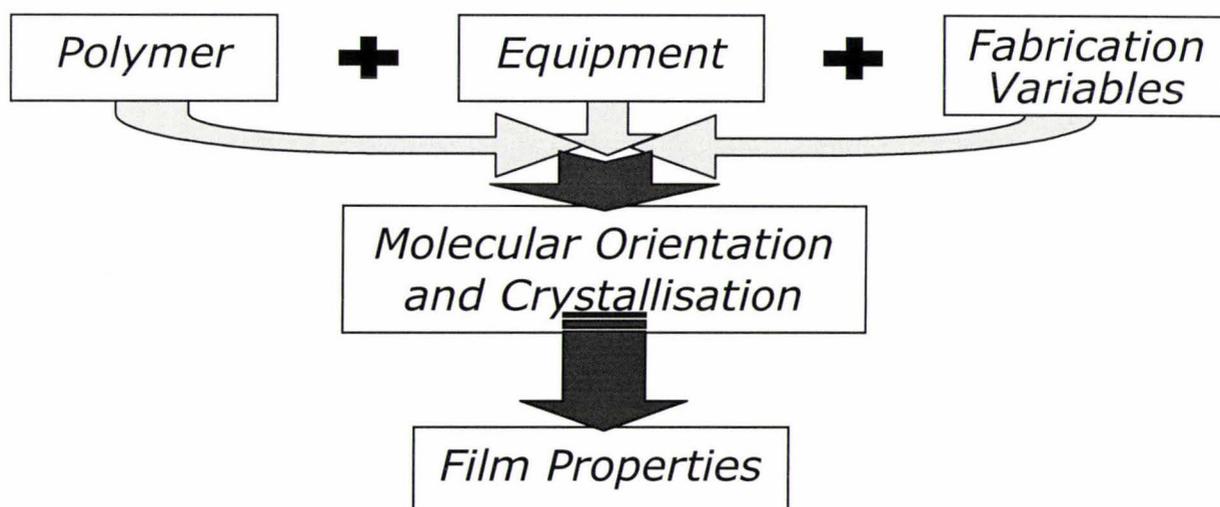
Three major factors influence the final physical properties of a film structure. These are;

**Polymer Structure**, i.e. whether the polymer is Low Density Polyethylene (LDPE), Linear Low Density Polyethylene (LLDPE) or High Density Polyethylene (HDPE). Polymer density, molecular weight distribution (MWD) and length and type of branching all affect the final properties

**Equipment Design**, e.g. die gap, screw and barrel design, die design, air ring type etc.

**Fabrication Variables**, e.g. melt temperature, blow up ratio, frost line height, line speed etc.

Figure 14: Factors effecting blown film properties. [Dow (17)]



A film structure can be described in terms of its degree of orientation and crystallisation. The combination of polymer, equipment and fabrication variables together influence the film's degree of orientation and crystallisation and therefore its physical properties.

The variable factors within the scope of this project are mainly Fabrication Variables as the Polymers and Equipment used are fixed for most products. An understanding of the existing Polymer and Equipment variables for each product under study is however essential in designing suitable experiments for the optimisation of their fabrication variables.

### 2.5.3: FABRICATION VARIABLES INFLUENCE ON THE PHYSICAL PROPERTIES OF BLOWN FILM

Molten polymer is subjected to a shear stress as it exits the die and is oriented in the direction of this shear stress i.e. the machine direction (direction of flow). As the polymer gets free of the die the molecules are able to relax. The rate at which relaxation occurs is dependant upon the type of polymer, its temperature and the stresses it is subject to. As each element of the polymer is drawn off the die and cooled it is under the influence of stress in the direction it is travelling e.g. if the bubble is travelling straight up off the die then the stresses are mainly in the machine direction (MD). If the material is however blown up to be significantly bigger than the die the material must flow outwards as well as upwards and will be stressed in the transverse direction (TD) also. These stresses cause the crystalline lamella to orient themselves in proportion to the stresses they are subjected to in each direction. Once the film is cooled to its freezing point (the frost line) by the cooling air stream, it is solidified and these stresses are frozen into the film.

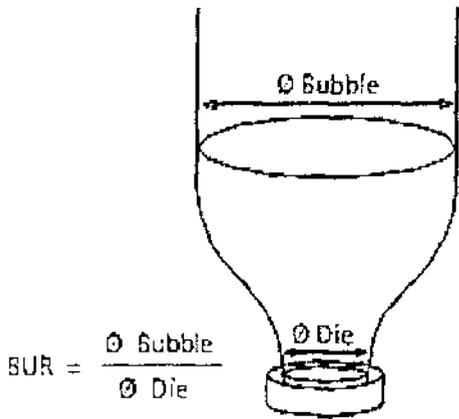
In blown film there is generally a low level of stress applied in the transverse direction relative to the machine direction. Therefore there is less transverse orientation than machine direction orientation. High orientation along the machine direction produces film that has good tensile strength but poor impact resistance and MD tear strength. By increasing blow-up ratio the film becomes more balanced as it is stressed and oriented in both directions. It will thus have better tear resistance in the machine direction and better impact strength.

As the molten polymer cools, some molecules fold upon themselves to form crystalline lamellae. The remaining molecules solidify in an amorphous state. The slower the

quench rate of the polymer the more opportunity molecules have to form crystalline lamellae resulting in more, larger lamellae and increased film density. This crystallisation reduces the optical properties of the film as crystals disrupt the passage of light. Increasing crystallinity generally increases ultimate tensile strength but reduces tensile elongation, impact resistance and tear strength.

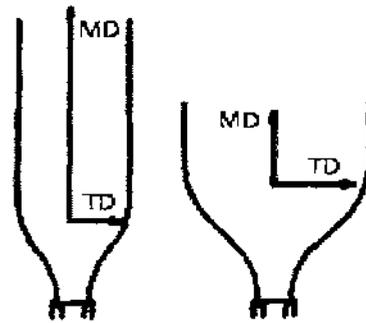
The level of crystallinity and orientation can be controlled to a large degree by modifying the fabrication variables.

**Figure 15: Definition of Blow Up Ratio. [Exxon 1999]**



The blow-up ratio is the main factor having an impact on orientation. It represents the ratio between the bubble diameter and the die diameter.

**Figure 16: Orientation Through Changes in Blow Up Ratio. [Exxon 1999]**



Narrow bubble shape: high MD orientation, low TD orientation  
BUR 1.5

Wide bubble shape: MD nearly equal to TD, tensile properties more balanced in MD and TD directions  
BUR 3.0

**Blow-Up Ratio**

A bubbles blow-up ratio (fig 15) has a significant effect on the final properties of the film. Increasing the blow-up ratio is the only mechanism for increasing the amount of TD orientation in blown film. For LLDPE a blow-up ratio of at least 2.5:1 is recommended for a good balance of MD and TD orientation and film physical properties. Low blow-up ratio's can result in the production of splitty films with poor impact and tear strength. Increasing blow-up ratio increases MD tear strength, elongation, impact strength and optics but decreases TD tear strength, elongation and MD tensile strength. A balanced film with equal extension in MD and TD (fig 16) has a better ability to absorb energy, and is less likely to be weak and split.

### ***Die Gap***

Changes to the die gap have a relatively minor effect on film properties. Increasing the die gap requires that the line speed be increased to maintain a film thickness. As a result the increased die gap acts to increase the level of MD orientation which can have a detrimental effect on film impact, MD tear and puncture resistance. This variable is out of the field of influence of this project as it can only be changed by altering the size of the die or mandrel, both of which require significant capital expenditure.

### ***Frost Line Height***

The Frost Line Height is the point at which the polymer turns from a liquid to a solid. It affects the quench rate of the molten polymer. Basically a high frost line means that the polymer molecules have a long time to relax, de-orientate and crystallise thus they have significantly improved impact, MD tear and puncture resistance. This is however at the expense of optical properties, bubble stability and thickness variation and also makes the film more susceptible to outside influences such as drafts. Vice versa for a low frost line.

### ***Melt Temperature***

An increase in polymer melt temperature can have a significant effect on film properties. An increase in melt temperature increases the rate that molten polymer crystallises to a solid at the frost line (quench rate). The increased quench rate causes polymer chains to produce smaller lamellae as they have less time to form, which in turn reduces film crystallinity. This reduction in crystallinity makes the surface of the film smooth and glossy and also reduces film haze. An increase in melt temperature also reduces the overall level of orientation because it allows molecules to relax more easily before the frost line. This improves the balance of MD and TD orientation and results in significantly better impact, MD tear and puncture properties.

### ***Extrusion Variables Effect on Melt Temperature.***

The job of an extruder is to melt and mix the polymer before transferring it to the die in an homogenous form. When discussing Melt Temperature it is important to be aware that the temperature read by the melt temp probe may not be the average melt

temperature. So when aiming to make changes to the melt temp it is important to also consider temperature variation across the adapter. The aim is to have minimum variation in melt temperature otherwise known as a low delta T as this is believed to improve the properties of the final product. The individual temperature zones on an extruder are the factors that directly affect the melt stream for any given polymer. The way these are adjusted depends on the type of polymer, screw design, screen pack, available cooling and output. Because of this it is impossible to generalise the effect of changing individual zones on the melt temp.

The trend at Filmpac is to use a hump profile that begin with a cold feed zone (zone 1), a hot zone 2 to promote early melting and then cooler zones 3 and 4 for compression and mixing. It is felt that this produces the best melt temp profile with the barrier screws generally used at Filmpac. There is however some debate as to the ability of later zones to cool the resin effectively after a hot zone two. Basically most heat profiles are set arbitrarily by the operators, however occasionally a variable depth thermocouple (VDTC) is put on a machine to help understand the effect of changes in the zone temperatures on the melt flow. This is a useful tool and was a part of the testing equipment used in this project. One way of reducing delta T is to increase the temperature of the adapter to the same temperature as the melt thus heating up the polymer close to the wall. This works very well and the suggestion from both resin and machinery suppliers is that all temperatures down stream of the screw should be set at the average melt temp. This can however mean a hotter bubble and thus a reduction in average melt temperature is often desirable. This can be achieved through adjustments to the zone temperatures discussed previously.

#### 2.5.4: RESIN PROPERTIES

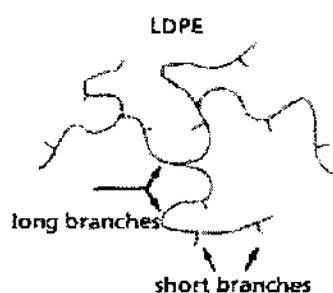
During polymerisation basic building blocks, monomers, are tied together. Polymer chains of different lengths and molecular weight are produced depending upon how and when the reaction started and stopped. The length of the chains and the level of branching determine the rheological and mechanical properties of the resin.

All commercial polyethylene's are branched. The degree of branching, the position,

composition and length of the branches all influence their physical properties

Above their melting point polymer chains flow across each other and are randomly arranged, below their melting point they become frozen into a solid state. When molecules are lined up in an orderly fashion they are said to be crystalline and when randomly arranged, amorphous. A heavily branched molecule is difficult to line up with those next to it to form a crystalline region but in the same way, a linear molecule is easy to pack in close to others of the same type. Therefore the shape of a polymers molecules significantly affects its, density, ability to crystallise and its viscosity. The combination of crystalline and non-crystalline regions gives individual polyethylenes their specific properties. Thus density is a measure of how closely the molecules are packed together in the solid state.

**Figure 17: Low Density Polyethylene (LDPE) [Exxon 1999]**

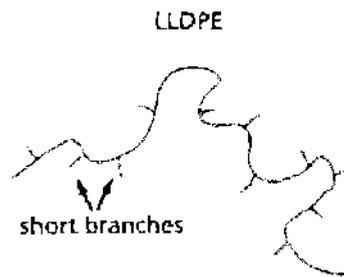


Low-density polyethylene is characterised by a highly branched structure with both long and short branches. It has a broad molecular weight distribution (MWD).

Key film properties include Moisture Barrier, Good sealability, good optics and good mechanical properties.

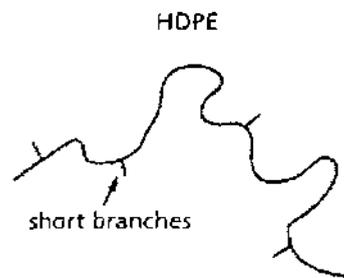
Other types of PE used in the blown film industry are linear. The two types shown below have properties depending upon the amount and length of their short chain branches.

Figure 18: Linear Low Density Polyethylene (LLDPE) [Exxon 1999]



LLDPE is used frequently to give better mechanical properties than LDPE it allows thinner gauge film to be extruded i.e. better draw down. LLDPE produces higher melt temperatures thus more cooling is necessary and poorer bubble stability results.

Figure 19: High Density Polyethylene (HDPE) (lowest number of short chain branches) [Exxon 1999]



HDPE has very few short chain branches and thus molecules can pack very close to each other. As density increases so too does stiffness and tensile strength however impact resistance and toughness at low temperature are often reduced. HDPE has poor optical properties as the large crystals deviate and scatter light. Higher density generally results in better gas barrier properties.

#### 2.5.5: MECHANICAL PROPERTIES AND FILM DEFECTS

Poor Mechanical properties have a wide range of possible causes:

**Polymer:** (Resin not suited to the application.) The choice of material for any particular application is very important as the polymer used is the most significant factor in the

final characteristics of the film. Gels and contamination in the raw material also contribute to problems with the materials performance.

**Processing conditions:** Once the material is chosen issues such as blow-up ratio, die gap, thickness variation, die lines, melt fracture, unmelted gels and port-lines all have effects on the mechanical and optical properties of a piece of film.

### *Gels*

Gels are visual defects in the film and affect strength, printability, film appearance, draw-down ability and lamination quality. They can be of the following types, arrow head, background, cross linked, oxidised and fibre gels (from contamination) They have two Primary causes,

**Extruder/Die gels** are caused by, die build up or oxidised polymer in the die or extruder, poor homogenisation of materials during extrusion or polymer deterioration through overheating.

**Feedstock/Polymer gels** come from, gels inherent in the raw materials, contamination from paper, cardboard, other polymers, dust or metal, recycled material, masterbatches and blend components.

### *Port lines.*

Port lines are hazy lines often visible in the bubble and finished product. They are caused by material entering the die through the ports in its side. In a spiral die this is minimised however if there is an inconsistency in the temperature of the melted polymer presented to the die i.e. a high delta T, the material which is hotter and thus less viscous will flow up the die more easily than the colder material. This will therefore exit the die at a different temperature and crystallise in a different way to the rest of the film. Port lines are undesirable as they look bad and generally produce weak lines in the film.

### *Melt Fracture*

Melt Fracture is surface roughness caused by high shear stresses at the die lips. Above a critical level the melt breaks or loses adhesion at the die surface and this causes the rough, shark skin, surface. A low melt temperature, narrow die gap or absence of processing aid all increase the probability of this.

### ***Bubble Instability***

Bubble instability can be caused by thickness variations, thin film, low melt strength (from a high melt index or high melt temperature), large blow up ratio, high frost line, air drafts in the process hall, unsuitable air ring or high extruder throughput.

### ***Film Homogeneity***

Inconsistencies in a film sample may be caused by melt index variation. A high amount of reclaim/recycled material of unknown composition may cause this; low melt temperature may cause incomplete melting and the wrong screen pack may let through micro gels or lumps of unmelted polymer.

*References consulted in this discussion include; Exxon Chemical Europe Inc. 1999 [18]; ICI Chemicals Ltd [7]; Butler 1993 [12]; Dow Chemical Company Ltd [17]; Glanvill, A.B. 1971 [21]; Dow Chemical (Australia) Ltd. 1997 [15]; Rauwendaal, Chris 1993 [30]; Whelan T, et. al. 1993 [39]*

A Matrix showing the relative effect of changes in specific variables on film properties is presented in appendix C. Butler 1992.

The quality characteristics to be focused on in this project vary with the differing products that will be optimised however output is always an important factor in an optimisation experiment. The matrix referred to above suggests that melt temperature, blow-up ratio, screw cooling, die gap, and air ring cooling capability are the most important issues in any quest for increased output.

#### 2.5.6: PALLETFAST STRETCH CLING FILM (SCF) STRENGTH MEASUREMENT

To optimise Machine 9 it was decided to focus on the performance of Palletfast in the market as well as the machine's output. In order to do this it is important to be able to effectively measure the performance of the product. Initial investigations into the viable testing methods suggested use of the following methods

Tensile Properties Test (Instron)	ASTM D638M-8
Puncture Test (Instron)	Not an ASTM Method
Elmendorf Pendulum Tear Test	ASTM D1922-67
F/50 Impact Resistance Test	ASTM D1709-85

A discussion of these methods can be found in the appropriate ASTM Standard yearbooks.

### ***1997 Pacific Area Commercial Stretch Cling Film Evaluation***

Dow Chemical Company tests samples of Stretch Cling Film from a variety of suppliers around the Asia Pacific region with both on-pallet and laboratory methods to help clients compare their films performance with that of their competitors. The following graphs were developed with data taken from Dow Chemicals 1997 Commercial Stretch Cling Film (SCF) Evaluation test results. The aim of the analysis below was to look for correlation between laboratory testing results and on-pallet performance results to see whether any of the available laboratory test methods were good predictors of on-pallet performance.

Max Pre-stretch percentage was chosen as the on-pallet test used by Dow that most affected SCF performance in the market. Laboratory tests have been plotted against this dimension.

Scatter plots of these graphs are shown below with a line of best fit and their correlation coefficients ( $R^2$ )

**Figure 20: Impact strength vs. maximum pre-stretch %.**

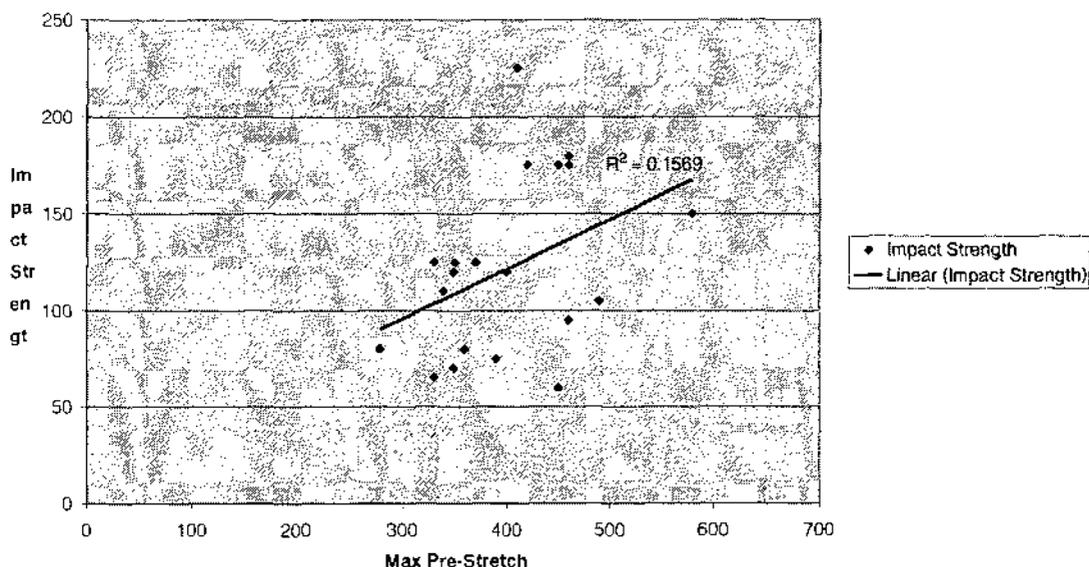


Figure 21: Puncture tests vs. maximum pre-stretch %

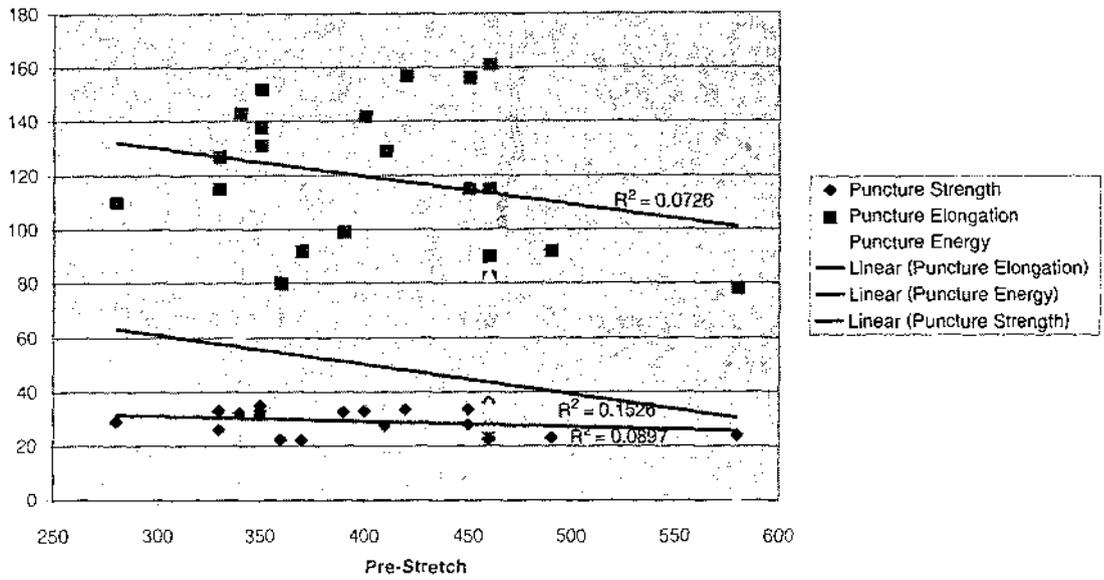


Figure 22: Tear tests v.s maximum pre-stretch %

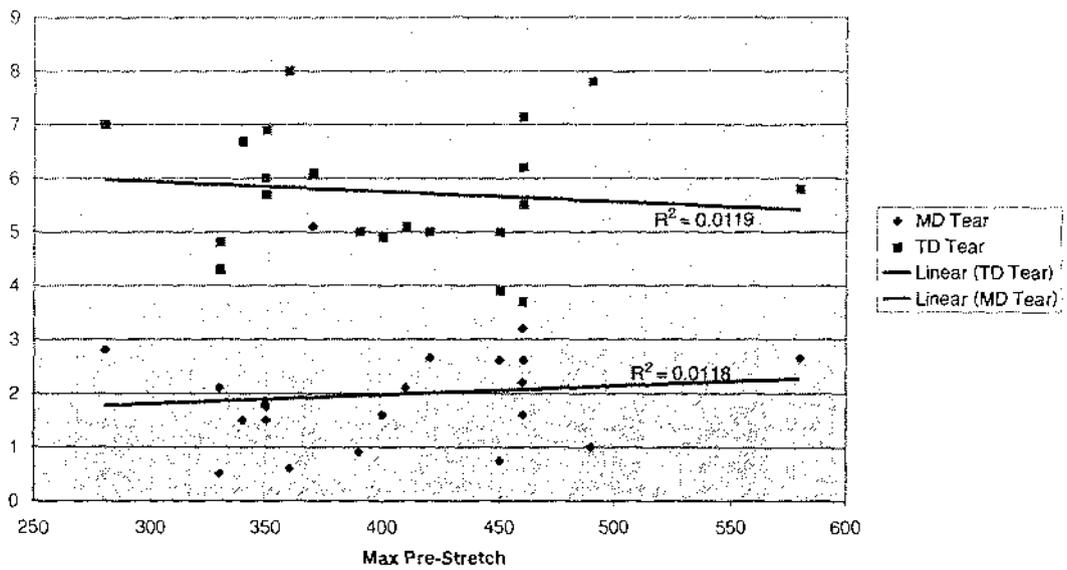
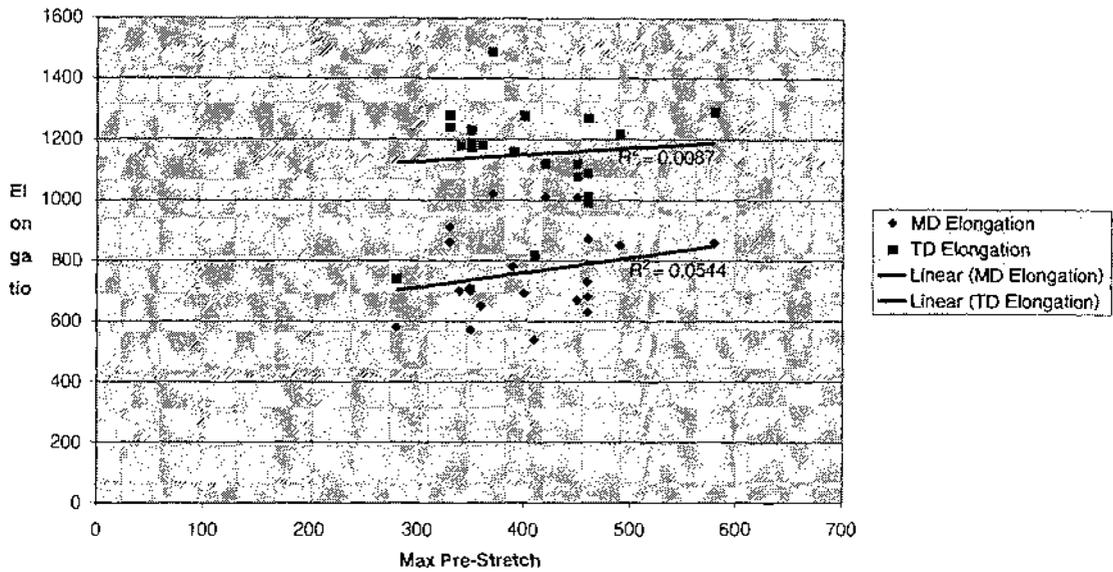


Figure 23: Elongation tests vs. maximum pre-stretch %



The graphs above are a selection of those drawn from the SCF Evaluation data and relate to the options available for laboratory testing at Filmpac. All show very poor correlation between on pallet testing and laboratory testing. It is clear then that it is not possible to accurately predict the on-pallet performance of stretch cling film with the laboratory testing methods detailed above.

There is therefore little confidence that controlled laboratory experiments will yield the results necessary to improve the product's performance in the market as these existing methods do not mimic the strain rates seen in the marketplace. More appropriate methods are therefore necessary for adequately testing the performance of SCF.

## 2.6 CONCLUSIONS

The options available for process improvement in industry are many and varied. The literature review suggests that certain issues be addressed in designing a methodology for applying Pro-t-con at AEP Filmpac. It is clear that manufacturing plants differ dramatically and thus it is not possible to suggest the performance of a methodology at one plant will be the same as at another. Thus the following statements were used as principles by which a sound methodology would be developed. Environmental factors specific to Filmpac such as the operators' knowledge of the machines and the skill of supervisors in administering the system will also play large roles in the final solution.

Issues to address in designing a system for applying Pro-t-con at AEP Filmpac.

- 1) Involve the employees that will be affected by the improvement system in its design and keep them informed of developments by holding regular meetings.
- 2) Gain and maintain support from management through monthly reports and meetings to elicit help where necessary.
- 3) Train those that are involved and affected by the system so that they understand why the change is necessary and where they fit in. This will reduce resistance to the change.
- 4) What gets measured gets done so develop key performance measures for the system, review them and ensure this information is visible to employees.
- 5) Involve operators in recording data and in decisions based on this data, so that they become responsible for the new system and improvement effort.
- 6) Pro-t-con is involved in the exploitation of machines so that they may reach their full potential. Improvements beyond this can be described as constraint elevation exercises and were outside the scope of the project.
- 7) A deep understanding of the process under study is necessary for success in such experimental work. This can however come from experienced operators that are willing to work closely with the experimenter in designing suitable experiments.

Process improvement is an iterative process of learning and thus a methodology to enable process improvement should be based on this. The structure proposed by

Upton 1998 has been used along with those proposed by Barnes 1997b, Hoerl and Snee [Statistical Methods for Quality, 1997], Taguchi [Antony 1999a] and Pro-t-con [Lo 1999] to aid in development of a methodology for the application of Protcon on the Filmpac site. The methodologies reviewed in this research suggest that the following factors are important within a process improvement system.

- 1) Emphasise process improvement as a knowledge creation and development process.
- 2) Process improvement initiatives should include stages that ensure improvements are ongoing, i.e. include maintenance stages that involve process measurement and documentation.
- 3) An iterative approach to process improvement promotes a continuous search for improvement opportunities.
- 4) Begin process improvement initiatives by optimising/exploiting the current process.
- 5) Consider process redesign and constraint breaking exercises only when certain the process is incapable of achieving the necessary performance in its current configuration.

Another side to this review was to analyse the options available to industry for process experimentation and optimisation. This suggests that Pro-t-con belongs in the easy to use section of the market. An analysis of Pro-t-con's fundamental statistics was not possible with the information available however a reasonable idea of the limitations of the software was developed through discussions with the suppliers.

The system is more difficult to analyse as any improvements from it are confounded by other changes occurring simultaneously within the plant. It is thus difficult to prove causality in such a situation. Measurement of the level of improvement gained through other process improvement efforts reviewed in the literature was achieved through comparisons of process capability analysis before and after the projects. However process capability can only be demonstrated in a situation where the process is deemed to be under control, this is not the case with the processes at Filmpac and thus it is not possible to be comfortable with this approach. However the expected result of implementing the process improvement system is a reduction in process variation and a

general improvement in mean output. Historical information is available to plot trends with and improvements along the aforementioned dimensions shall be analysed.

Finally the extrusion variables within the scope of this project have been defined. The large number of variables available has been limited to those fabrication variables that can be altered under current machine configurations. They include frost line height, extrusion temperatures, output, and additive percentages. They do not include material formulations or die size/extruder type as these are fixed for the machine/product mix. The research has established that the relative effect of these variables depends upon machine and material variables and thus cannot be generalised.



## 3.0 - METHODOLOGIES

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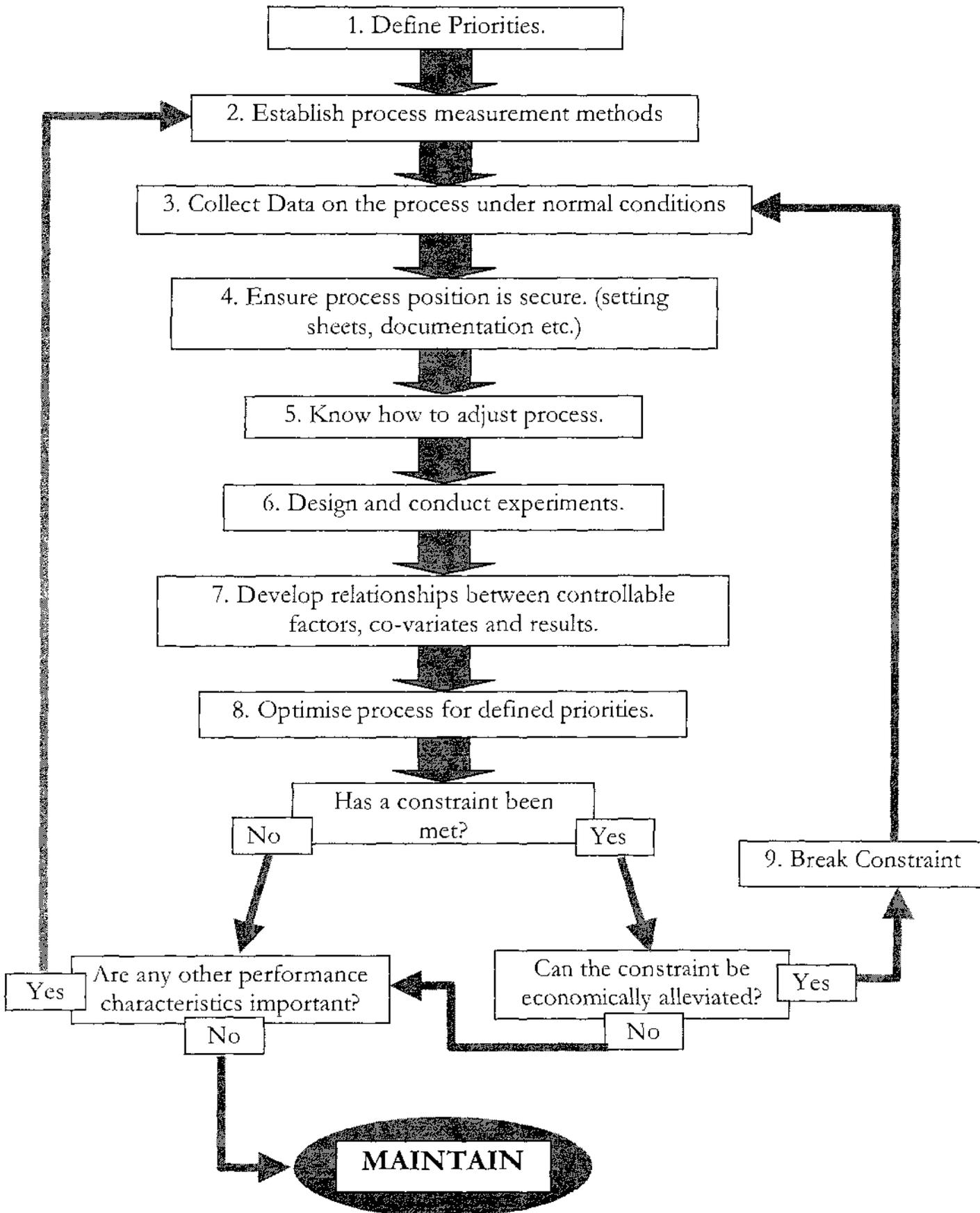
This section describes the methodologies used and developed throughout sections 4,5, and 6 and introduces the three major elements of the project.

### 3.1 RECOMMENDED METHOD FOR PROCESS IMPROVEMENT (10 STEPS)

Many models for process improvement have been proposed and a number of these were discussed in the literature review. These were combined and manipulated with the experience gained in this project to produce the following flow chart (fig 24) which is aimed at individual improvement projects for specific machines. Other process improvement systems vary in their scope from the management of an overall continuous improvement culture to the actual process of experimentation. Figure 24 fills the gap between these levels and combines an iterative constraint breaking system with an experimental problem solving method.

The drive of the following approach is to first “exploit” a machine in its current configuration using experimental tools such as DoE, Pro-t-con and general problem solving techniques. Then using the knowledge gained in exploiting the machine, choose constraints to break so that its performance can be “elevated”. It is basically an iterative, learning method that continuously improves a process by moving through the 8 stages of knowledge detailed by Barnes. It therefore aims to take a plant up to levels 3 and 4 of Upton's framework for process improvement [Upton 1998b] and beyond Barnes's 8 stages of knowledge [Barnes 1997b]

Figure 24: A 10 Step Method for Process Improvement



### 3.1.1: EXPLANATION OF 10 STEP FLOW CHART.

#### ***Step 1: Define Priorities***

Most process improvement methods begin by stressing the importance of clear goals and priorities at the outset of the project. It is essential to set precise goals to measure the performance of the project against and to aid the team by focusing on these goals. Priorities need to be defined in terms of their effect on the products bottom line i.e. company profit and internal/external customer satisfaction. With this in mind it is more likely that the attributes that most affect these dimensions will be chosen for improvement.

#### ***Step 2: Establish Process Measurement Methods***

In order to improve a process it is essential to be able to measure the responses to be improved and the variables that affect them. These must be documented and standardised so that if others attempt to improve the process they can compare results. Measurement methods should use the highest practical scale available, i.e. a ratio or interval scale if possible, normative and ordinal scales are sometimes necessary but can be statistically questionable.

#### ***Step 3: Collect Data on the Process***

The process measurement methods once developed should be used to collect data on the process to gain an understanding of its present state in terms of quality and output variation. If possible establish the process capability  $C_{pk}$  value so that improvements can be quantified against this. Operators and supervisors should be involved in the data collection process to help ensure their co-operation in stage 4.

#### ***Step 4: Ensure Process Position/Settings are Secure***

The work done in 2 and 3 helps to develop an understanding of the processes operating envelope. Setting sheets or recipes should then be developed from the best settings so that they can be used again and workplace systems/disciplines implemented to ensure the continued creation and use of these setting sheets. This step enables the improvements gained by optimising the process in the following stages to be available for future runs of the product and in itself can produce a significant improvement in process stability and performance. (Upton's level 1). It could be argued that this stops the development of new, better settings for the process as operators get used to using setting sheets. However if operators are given the opportunity to improve their settings and

have them become the new setting sheet more stable machines and continuously improving settings should be produced. This is discussed further in section 5.

***Step 5: Know How to Adjust the Process***

A prior knowledge of the effect of changes in machine variables helps to design effective experiments. It is important in this stage to be able to alter specific variables independently of the others under examination. Skilled operators are generally very helpful in achieving this as they have the tacit knowledge of the process necessary to tune it to the desired settings. As the goal is to develop the best possible settings for future use it is sensible to use the best operators as they are likely to be able to develop the best settings.

***Step 6: Design and Conduct Experiments***

With an idea of which variables are most important, an estimate of how they affect the process and an ability to set these variables independently it is possible to design experiments to verify and extend the present level of knowledge. A variety of methods exist for undertaking these experiments and include Pro-t-con, DoE, RSM, Taguchi and Shainin, all have their benefits and limitations which were discussed in section 2. Considerations must include desired accuracy and resolution, the number of variables under study, the number of experiments possible, the cost of these experiments and whether curvature or interactions exist within any variable/response relationships.

***Step 7: Develop Relationships Between Variables, Results and Co-Variates.***

Using any one or a combination of the above techniques it is possible to develop the strength and direction of the relationships between the factors and responses. Regression and ANOVA techniques may aid in the analysis and model building. This leads directly to stage 8.

***Step 8: Optimise the Process for Defined Priorities.***

With the process knowledge developed through experimentation and analysis the process may be optimised for the desired results. A Taguchi method would suggest first reducing variation in the response and then adjusting the mean to its nominal value. Pro-t-con would, given the correct information, attempt to do this automatically and create the settings necessary for it. However the optimal solution is achieved it should result in a list of settings for the process variables to be used as a setting sheet in step 4.

### ***Has a Constraint Been Met?***

Is a physical or psychological constraint holding the process back from the desired output or quality characteristic?

### ***Can the Constraint be Economically Alleviated?***

Do the financial or practical benefits of elevating the constraint outweigh the cost of doing so?

### ***Step 9: Break Constraint***

This may involve allocating more labour to the machine, changing a gear ratio, automating a part of the process, buying a new machine, or simply improving work practices. Goldratt 1992 suggests a three step process for breaking constraints which involves deciding what to change, what to change it to and how to change it.

### ***Are Any Other Performance Characteristics Important?***

E.g. can the process achieve better quality at the same time as high output? If so, can it also achieve less process variation? If so, can it also be run by only one person? If so, etc, etc...

### ***Step 10: Maintain***

Maintenance of a process is essential if the benefits of the improvement are to continue for the life of the product. Stage 4 is the beginning of a maintenance program and aims to minimise changes to the process set-up, which can produce a significant special cause of process variation. An excellent tool for longitudinal maintenance of product quality is Statistical Process Control (SPC). SPC centres on understanding process variation and reacting to specified changes in the process rather than its natural variation.

A natural extension of the Pro-t-con project is to introduce SPC to the AEP Filmpac plant to strengthen the work done in stage 4.

## 3.1.2 TESTING THE 10 STEP METHODOLOGY

It is clear in the situation that exists at Filmpac that approaching a machine in a planned manner and applying rigorous statistical methods is likely to be more successful than the haphazard methods of trial and error employed in the past. This could be expected to have a benefit in itself whether or not Pro-t-con did the analysis, for the simple reason

that there would be more information available to base decisions on. The 10-step process improvement methodology proposed above was, at one level, designed to help guide the process of improvement on specific machines or processes. Its quality is therefore measurable in terms of its ability to help guide such improvement projects. The method could have theoretically been tested against some of the other methods presented in the literature review by comparing the level of improvement gained by using each of them. However as well as being a very laborious task this would be also be difficult to control for outside influences and was thus outside the scope of this project. The 10-step method was however used to help guide a number of improvement projects within the course of work. A series of these case studies are described in section 4, of interest are

1. The improvements made to the machine settings in terms of output and quality
2. The ease with which this was achieved
3. The actual improvement in machine performance
4. The reasons for any problems that were encountered.

This will enable a discussion of the various stages of the process and an analysis of its performance. Subsequently improvements to the method shall be recommended.

### 3.2 SETTING SHEET SYSTEM DEVELOPMENT (STAGE 4)

One of the most important elements of the 10 step process improvement method described above is the inclusion of step four to encourage early development of a system for documenting and controlling the process. It is essential that this step be successfully completed, as without it the likelihood of success is remote.

The International Quality Study of Management Practices found the use of process improvement practices to be one of only three management practices to have universal benefit across all the industries studied [Mahlen 1993]. Continuous process improvement is an essential element of total quality management (TQM). Although there has been no mention of commitment from the management of Filmpac to an overall TQM philosophy the focus of present work in the plant is on the development and acceptance of standard operating procedures. The system described below is a key part of this and aims to go a step further by adding to the standard machine settings a method for continuously improving them. [Ward 1994] suggests that continuous process improvement involves documenting, analysing and measuring all activities performed by the organisation and that processes should be standardised and simplified to limit variability. The system described below aims to measure, document and analyse the processes at Filmpac, then standardise them to reduce variability.

There are a number of things to consider when designing and implementing a system for continuous process improvement within a company. A common issue throughout the reviewed literature was that support had to be gained from the people who were to be most affected by the change. Methods for gaining this support often included employee involvement and reward schemes, also training in the new system and employee influence in its design were seen as critical to successful change implementation. They mentioned that upper management had to be seen to be actively supporting the change, "quality begins in the boardroom" [Terry Morgan; M.D. Marconi, Australasia], and the existence of a strong project champion to defend the project was seen as extremely important. This advice was taken into account in the design of the setting system at Filmpac.

### 3.2.1 THE CONTINUOUSLY IMPROVING SETTING SHEET SYSTEM

In a competitive environment it is necessary to be as efficient as possible in manufacturing ones products. Although it is possible to achieve superior performance through purchasing new machines or increasing the labour force, the drive of management is often to fully utilise the resources they have before considering other options. The work at Filmpac was designed to enable better utilisation of their machines through continuous improvement of their machine settings.

The work of Upton 1998b and Barnes 1997b was used to help develop the previously discussed 10-step method for process improvement at Filmpac. Initially Filmpac was pre stage 0 of Upton's framework and at step 2 of the 10 steps i.e. suitable measurement methods for data collection did not exist. These methods were thus developed and all operators involved routinely collected process data from the machines. From this data the present operating envelopes for many products were defined. The best settings were chosen from this process data based on those which gave the best output/quality compromise, and setting sheets were developed for each product. Setting sheets were therefore being produced for many products on most machines but the system to ensure that they were used effectively was not available. Thus any improvements made to machine settings were not there next time the machine was run and were consequently not ongoing. So the process was being documented effectively but the documented information was not readily available. It was therefore necessary to concentrate more effort on the development of a system for step 4 of the 10 steps to ensure that process settings were more secure. The development and testing of this system is the topic of section 5.

### 3.2.2 MEASURING THE EFFECT OF THE SETTING SHEET SYSTEM

In a learning environment it is often difficult to demonstrate an improvement due to a single cause as so much else is going on that also affects the response. It can therefore be difficult to distinguish between improvements that are due to the actual change and those that are due to factors such as the Hawthorne Effect. The 1924 Hawthorne studies demonstrated that people work harder when change is introduced into their environment and it was found that when attention was paid to employees, they responded positively

[Neimark 1988]. In fact Neimark suggests that simply by introducing continuous change to a company an improvement in worker performance can be produced. This is likely to be because the excitement of getting involved and making an impact encourages workers to try harder. This has obvious connotations for measuring an improvement in factory performance due to a change in the everyday practices of operators. One must therefore make sure the process of generally doing something new is not the reason that the measured characteristic changed from its baseline measurements. To minimise or quantify the Hawthorne effect a control group should be established so that the effect of the different situations can be compared. This was necessary in section 5 when analysing for an improvement in overall machine performance.

The expected result of the setting sheet system is an improvement in average machine production and a reduction in production variation from run to run of the same product. This shall be measured through an analysis of historical data from the companies accounting database. A comparison will be made between machine 9, that was subject to this standardisation and machine 6 that was not, in order to analyse the effect of this initiative on the average machine output and its variation.

### 3.3 PRO-T-CON TESTING METHODOLOGY

A major element of 10-step process improvement method was the use of experimental problem solving techniques to aid process improvement initiatives. The Pro-t-con process optimisation software was purchased for this purpose. Weaknesses in the Pro-t-con software were suspected and thus an analysis of its functional pros and cons was deemed necessary to decide whether further use was warrantable.

*"Pro-t-con is applicable to any continuous process, as every process is only a combination of process variables influencing a combination of product variables. Providing you can measure variables, it is possible to establish the relationship between them and optimise the process with the Pro-t-con technique".*

*[Harry Lo; Pro-t-con Marketing Presentation 1999]*

There are a number of dimensions along which a package such as Pro-t-con performs, These are

- 1) Its ability to do optimisations.
- 2) How much information it gives about the process.
- 3) Number of experiments necessary.
- 4) Ease of use.

The relative importance of these factors depends heavily upon the company's present level of knowledge about their processes. If, for example, the company were at a very crude stage of process knowledge, then a manager would be most suitable for undertaking the project as systems and leadership would be necessary to lift the company to a position where their processes were stable. In this early stage the ability of the software would be relatively unimportant as the major gains should be achieved through organising the process in such a way as to facilitate an experimental procedure rather than through the experimental procedure itself.

If on the other hand the company were at stage 4 or 5 of the 8 stages of knowledge detailed by Barnes [Barnes 1997b] then the usability of the software and the number of experiments necessary would be very important because these issues could hinder the experimentation process. Management should still be involved in order to facilitate the development of recipe or setting sheet systems. However able line operators or supervisors could undertake the development of setting sheets and documentation to

enable this stage and if the package were easy to use, also undertake experiments and analyse data.

Thirdly if the company were at stages 6 or 7, trying to get to stage 8 i.e. attempting to develop a more complete, predicative process knowledge, then the amount of information the method gave and its ability to optimise would be the most important factors in its application. In this situation verifiable statistical information is essential for quantifying variable effects and interactions. Generally technical staff with the skills required to perform experiments and use a variety of software packages would undertake this stage, thus usability and number of experiments would be less important.

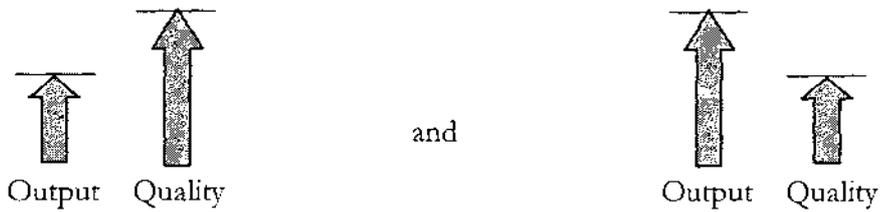
Filmpac has a variety of processes at different levels of knowledge. However from the point of view of an operator their knowledge of how to run a product when handed a work order is between stages 2 and 4 depending upon individual ability. So most have an idea of the factors that affect the process, these factors are generally measured and the skilled operators know how to suitably adjust the mean with these variables.

### 3.3.1 ABILITY TO DO OPTIMISATIONS

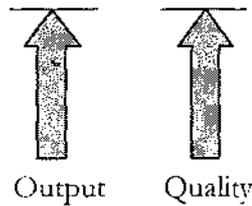
Some time after the software was purchased, it was made clear by Pro-t-con's suppliers that it could not optimise a process outside of the range of data it had seen. This means that if a machine had seen a range of speeds from 140 to 200 kg/hr then an attempt to get Pro-t-con to optimise the process for 210 kg/hr would be unsuccessful. So in order to allow Pro-t-con to give settings for 210 kg/hr it must have first been achieved. This was a disappointment to the project team as it has significant implications for the way in which optimisations trials are undertaken.

Therefore the power of Pro-t-con must be such that it can develop settings which help to compromise between targets. For example when given the process settings which produce the following combinations of output and quality. (fig 24)

Figure 25: Supposed benefit of using Pro-t-con for optimisations



Then it should be able to give the process settings that will produce



Or any combination in between, providing enough experiments have been done to adequately explore the two responses and that the two responses are not mutually exclusive, i.e. it is in some way possible to have both high output and high quality at the same time.

If the only target desired is the highest output then Pro-t-con can do nothing but reproduce the settings that are closest to that target. For example if 200 kg/hr were asked for in the above example the settings from Pro-t-con would be simply the settings that were used to achieve 200 kg/hr in the first place.

Consequently it is important to have two or more targets to aim for in an optimisation experiment

Initial questions that need to be answered in order to discuss Pro-t-con's ability are

- 1) How accurate is its analysis of the process?
- 2) How accurate are the optimal settings it develops?
- 3) Are optimisations repeatable?

In order to test Pro-t-con's ability to "optimise", a variety of experiments were necessary. This work is detailed in section 6 and all experiments to test Pro-t-con in section 6 require it to compromise between two or more targets.

### 3.3.2: PRO-T-CON TESTING METHODS

To analyse Pro-t-con for the elements described above and thus gain an understanding of its utility in an industrial setting it was tested with two simulated “dummy” processes and a variety of field studies on real machines.

Simulated “dummy” processes were used so that known factor/response relationships could be compared to Pro-t-con’s analysis of them. A dummy process allows the experimental design and number of runs to be varied much more easily than in a real process and also enables the process to be changed to see what effect this has on the results.

Field studies on real processes were also used in order to compare results with the dummy processes, as a true test of its utility and to aid the company in improving their processes.

With both types of process, comparisons were made between the factor effects predicted by Pro-t-con and those developed by methods such as Design of Experiments and Multiple Regression. Optimal settings developed by Pro-t-con were also checked back in the process to see if they produced the results predicted by Pro-t-con. The results of a series of Pro-t-con optimisations were then compared with a series of trial and error experiments to see which was the better method.

The result of section 6 will be a better understanding of the algorithms behind Pro-t-con and thus an analysis of its statistical advantages and disadvantages will be possible. From this its position on the scale of process improvement in an industrial setting, described above, will be discussed.

A discussion of the functions and jargon surrounding a Pro-t-con analysis was presented as part of the literature review in Section 2

### 3.4 PROCESS MEASUREMENT METHODS

Step 2 of the 10-steps for Process Improvement detailed in section 3 acknowledges the importance of suitable measurement methods for process improvement. There were a number of levels at which measurements needed to be made in this project. Initially it was necessary to measure the inputs and outputs of each machine, also in order to demonstrate improvements to the plant as a whole it was necessary to measure certain elements of its performance. This sub section discusses the development of these measurement methods.

#### *Measuring Machine Variables.*

Machines at Filmpac vary greatly in their age, set-up and the methods used for measuring and setting variables. The suggested Pro-t-con approach to optimisations used at the outset of this project was to measure all the variables on a machine regardless of how minor they were. Although most of the important variables had gauges or potentiometers (pots) on them some were just knobs or slides with no position indication or scaling at all. This required that methods be developed for measuring these slides and knobs. The aim was to get as high a level of scale as possible i.e. a ratio or interval scale, in some situations however nominal scales were necessary.

Occasionally an important variable could not be measured directly. In these situations the unmeasured variable could often be derived from the combination of two other measurable variables e.g. air ring insert height is proportional to air ring speed and air ring pressure. Insert height can't be measured directly but the other two can be, thus an operator can set the insert height by first setting the air ring speed and then adjusting the insert until he achieves the correct pressure.

Under certain conditions various heat settings within the extruder were unachievable. For example some barrel zone and die temperatures consistently override their set points. This is common in the older machines and those with water cooling elements. In this situation the set temperature was established as usual and the actual temperature was assumed to be related to the combination of the other set machine variables. So the settable values were still used for setting the process even if they were overridden.

Six of the nine extrusion machines at Filmpac have dosing systems that are computer controlled; five by a system known as "Weighbarch" and one (MC 1) by a system

provided by TSM. An investigation into the data logging capabilities of these systems was seen as an opportunity to reduce the amount of data collection done by operators and improve the quality of this data. None of these systems, however, logged data in the required form, thus their suppliers were consulted and software updates were provided to allow this functionality.

### ***Measuring Product Performance***

A major frustration of the optimisation studies carried out in this project was that physical and personnel constraints were often met before Pro-t-con was able to help with the optimisation. This was fine for the company as they got improved output from the machine regardless. However it caused problems when aiming to determine the effectiveness of Pro-t-con, as to achieve this it is necessary to demonstrate the softwares ability to compromise and find the best settings.

In some situations this problem was to do with the availability of adequate measurement techniques for secondary targets. Initially it was thought that the 1 to 5 nominal scales proposed by Pro-t-con's suppliers would be adequate however these quickly proved to be inaccurate and inconsistent. Standard quality checks on the product at Filmpac were adequate for some of the optimisation experiments. Most of these methods can be found in ASTM standard reference books and they are generally good enough for ensuring the product is within specification. However when the goal was to improve a factor outside the normal Quality Control regime such as a specific dimension of product strength it was necessary to look for other methods. So to test Pro-t-con effectively on the processes at Filmpac, methods for measuring important quality aspects had to be developed specifically for each process. An example of one of these (the development of a method for testing Palletfast stretch cling film) is presented in appendix D.

### ***Measuring Machine Performance***

When aiming to improve a process it is essential to have a suitable metric to measure performance with. For example when measuring the output of a machine, uptime and stability are important factors to consider in conjunction with cycles per minute (CPM) or kilograms per hour (kg/hr). It is conceivable that a machine running "flat out" is less stable than a machine running at a slower speed and vice versa depending upon the

process. Thus the machine's running speed, along with external factors such as the ability of the operator may affect its uptime. The initial focus was to be just on CPM and kg/hr i.e. to ignore uptime. However because

$$\textit{Total Production} = (\textit{CPM or kg/hr} * \textit{Uptime}) - \textit{Scrap}$$

It would be inadequate to omit one of these measures from the analysis, as the final expected result is an improvement in total production. At Filmpac this required operators to collect accurate information about their own performance. Significant training was necessary to ensure this was undertaken correctly.

# 4.0 - ANALYSIS OF THE 10 STEP METHOD

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## 4.1: CASE STUDIES FOR ANALYSIS OF THE 10 STEP PROCESS IMPROVEMENT METHOD

This section presents a number of short case studies in order to illustrate the 10-step process improvement methodology and discuss its strengths and weaknesses. Suggestions for its improvement shall be made from this.

### 4.1.1: CASE STUDY EXPERIMENTS

The measure of performance provided in the following cases is the machine running speed in kg/hr or CPM as these were the elements focused on in the experimentation. A truer measure of improved machine performance is the average output and standard deviation over time. In order for improvements to be made to these elements the system required for ensuring machines are run to consistent settings, i.e. step 4 of the 10 steps, are likely to be necessary. The development of this system is the topic of the next section.

Data recording sheets that included measures for all variables on a machine, as well as for measuring its performance, were developed for each extrusion machine. So steps 2 and 3 of the 10 steps were reached before the optimisation work in extrusion began. The development of these recording sheets is discussed in section 5, as it was necessary for the development of setting sheets.

#### ***Machine 9, Palletfast***

Initial experiments with Pro-t-con in an attempt to use it to optimise Machine 9 for a variety of products proved relatively unsuccessful. Steve Tilly of GS Technology had suggested that it was possible to combine data on products from the same machine and materials but with different thicknesses in order to build up the data necessary to undertake optimisations more quickly. These experiments showed that it was

possible to run Machine 9 at over 200 kg/hr. on many products. However important customers were having problems with 20-micron film on their stretch wrapping machines. Priority then moved to improving the strength of the product in terms of its performance in the market place whilst maintaining a high output (step 1 of the 10 steps).

A review of the Dow Chemicals 1997 Stretch Cling Film Evaluation literature (see section 2.6) suggested that laboratory testing methods would not be sufficient for testing film strength. The development of a suitable methodology for measuring the strength of Palletfast SCF can be found in appendix D (step 2 of the 10 steps). Failed rolls of film from customers and a number of virgin rolls from normal production were tested to get an understanding of the film's present situation (step 3). Using the best two operators to help adjust the process (step 5) a set of 14 Plackett Burman designed experiments were conducted (step 6). The rolls of film from these experiments were tested with the SCF testing methods and the data analysed for its factor effects. This analysis and experimental design are presented in section 6.2 of this report.

Possible result: An improvement in corner strength from 5.9 to 6.26 and in flat strength from 3 to 15 cycles, output maintained at 190 kg/hr.

However due to the lack of a suitable setting sheet system for maintaining the improved machine settings significant variation in the products performance persisted.

#### ***Machine 4, Shrink Film***

Shrink Film was initially approached with the intention of using Pro-t-con to optimise it for output and shrink properties. Machine 4 was iteratively sped up to a maximum of 192 kg/hr by tuning the extruder speed, line speed, air ring, die/extruder temperatures and winder variables. Shrink tests were done to ensure the product stayed within specification. Thus work was done up to step 6 of the 10 steps i.e. the process was being adjusted and experiments were being done. Help from the machine's operators was necessary to enable efficient experimentation. However when the machine's extruder reached 80 RPM it went out of control. It was discovered that this was because the signal from the extruder "prox" was not

suitable for the Weighbatch control software at this speed. A constraint had been identified.

At the higher output the film's shrink properties were also better than seen previously due to greater MD orientation (a desirable property for collation shrink film). As no other measurable targets were seen as important for optimisation of the product it was pointless to continue with the experimentation until the constraint was broken. Thus a maintenance request (MR) was filed to have the plant electricians remedy the problem. This should have been a relatively quick and easy job however as it was not a high priority it remained, despite considerable pressure from the student, unresolved for over 8 months. If the systems necessary for ensuring the process position settings were secure (step 4) were in place after the first experiments then the output could have been fixed at around 185 kg/hr. However this was not the case and thus the higher output was not maintained.

Observed result. 0% improvement in output.

Possible result. A 28% improvement in output from 150 to 192 kg/hr.

Pro-t-con was however used to attempt to optimise this process for output, thickness and shrink properties, the results of this work are reported in section 6 on the analysis of Pro-t-con. This took the work on shrink film through 9 of the 10 steps i.e. relationships between factors and responses were developed, the process was optimised for its present ability and a constraint was discovered and broken. However because of the plants weakness in maintaining the process at its optimal settings the improvements were not realised. Upon breaking this constraint the opportunity exists to further improve the output of this product and thus go through steps 3 to 8 again.

#### ***Machine 4, Bread Film***

Bread Film was also approached with the intention of using Pro-t-con to optimise it. Again the machine was iteratively sped up with the help of a skilled operator from the normal 160 to 220 kg/hr using the variables previously mentioned in shrink film. However at around 200 kg/hr the corona treatment unit became unreliable and thus the machine could go no faster and reliably make good product. The training officer estimated that the machine was capable of 240 kg/hr with a better treater unit.

Work done to improve the corona treater was unfortunately unsuccessful. Consequently the treater constraint stopped the Pro-t-con optimisation in its tracks. The machine could go significantly faster than before at 200 kg/hr, however the system for ensuring this was maintained was not in place. In this case then the process stopped at step 6 of the 10 steps for process improvement, however step 4 was again inadequate and the machine subsequently fell back to its old ways.

Observed result. 0% improvement in output.

Possible result. A 25% improvement in output from 160 to 200 kg/hr.

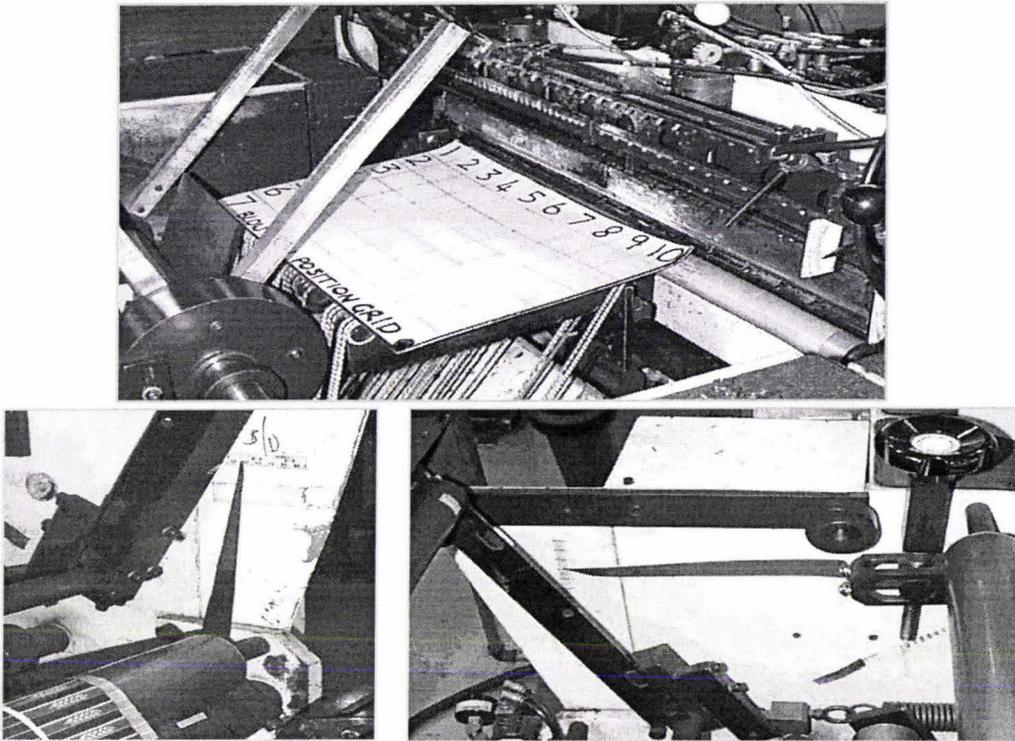
With a better corona treater. A 50% improvement in output from 160 to 240 kg/hr.

The possible improvements were again not realised due to the weakness of the system for maintaining machine settings at their optimal level and the ability to elevate constraints.

### ***Machine 51 Amplas Wicketer***

Work on the high-speed bag making Amplas wicketer began with the development of a recording sheet that included all the variables used by operators to set the machine. Some of the important variables did not have scales on them and thus work was done to develop measurement methods for these variables. (Fig 26) Step 2 of the 10 steps for process improvement. Operators were trained to collect data off the machines and this data was used to gain an understanding of the present situation i.e. step 3.

Figure 26: Measurement methods used on Machine 51



The aim of the project was to improve total production off the machine whilst not compromising quality. Thus a methodology for measuring the actual performance of the machine along the output dimension was necessary. As the quality of a roll was seen as a major factor in machine performance the number of bags made throughout a roll, and the time it took to make those bags were used as the overall measure of performance.

In conjunction with a skilled operator an increase in the number of cycles per minute (CPM) from a previously believed maximum of 280cpm to 345cpm was achieved, a 23% improvement in output. It was clear that although the machine could run at this speed it was impossible for the operator to keep up with it especially if it didn't stack the bags accurately. Discussion with the operators and the production manager produced a standard of 300 bags per minute for the operators to run their machine to on a day to day basis. The operators began to run the machine at this increased speed and production went up, the machine was being exploited. The goal was to slowly increase CPM as the operators learnt to run the machine at the higher speed.

Work was done to increase the number of bags stacked on an index so that operators would have more time for packaging and thus be able to run the machine faster.

This resulted in a slightly higher variable cost due to the requirement for more wires, grommets and backing boards per thousand bags and was not justified in terms of the increased output. In the mean time work was also done to improve the static removal bars so that the bags would be able to stack more accurately. However as this work was being completed the machine developed a worn cam on the sealer bar that caused it to be run at a speed of no more than 260 cpm. Although the machine was subsequently fixed the operators had become used to the 260 cpm speed again. Also changes to the management structure of the conversion team meant that the responsibility for managing the shift was passed on to the skilled operators who had originally run machine 51. This meant that less skilled operators would run the machine while the new team leaders administered the shift. Thus the machine never made it back to the 300 CPM that was achieved before. The constraints in this case were the worn cam, the work practices and supporting processes involved in running the machine.

In this case it was proved using simple problem solving techniques that the machine could be run significantly faster. However the situation in the department did not allow enforcement of the improved settings and thus things returned to their normal state. Again improvements made to the machine were not ongoing because of a poor maintenance program for machine settings.

Observed result. 0% improvement in output

Possible result. A 23% improvement in output from 280 to 345 bags per minute.

### *Liquipac*

The aim at Liquipac was to optimise the GN 1 machine to make wine cask bladders as fast as possible without deterioration in product quality.

Working with the operators from one of the two shifts the first step was to establish methods for measuring the process (step 2). In the first cycle of improvement the machine speed was increased from 17 bags per minute (BPM) to 21 BPM. A setting sheet was developed for this product and thus the speed of 21 BPM was maintained, despite some resistance from night shift.

Previously if a seal was faulty the sealer dwell time would be increased, effectively slowing the machine down. However there are in fact three factors that affect seal strength (pressure, temperature and time). As the spout placement system was seen as the constraint in the process, work was done to increase the heat of the elements and thus allow a reduction in the dwell time. This reduced overall cycle time and therefore increased output. Basically the constraint was exploited.

At 21 bags per minute the minimum dwell time had been reached, regardless of any increase in heat, thus the elements on the spout placement mechanism had to be upgraded to improve their heat transfer properties. Upon successful completion of this constraint elevation exercise the machine will be re-experimented with and the speed increased further. It is expected that the machine will be capable of 28 bags per minute with the new spout placement elements. However a human constraint will also be met at a speed of around 22 bags per minute as the spout placement operators will be unable to keep up with the faster moving bags. The approach in this case will again be to first exploit the constraint by improving the methods used by the operators or by putting two operators on the job instead of one. It is likely that this will be sufficient, however, if not, automatic spout placement may be necessary.

In the course of working with the machine step 7 understanding of the factors that most affected BPM was achieved, the best settings were developed (step 8) and a constraint was acknowledged.

Observed result. A 23% improvement in output from 17 to 21 bpm.

Possible result. A 64% improvement in output from 17 to 28 bpm.

Though the initial plan was to use Pro-t-con for the analysis there was in fact no need for it in this improvement project. Pro-t-con may have been able to suggest “optimal” settings however in solving the problems of speeding the machine up, no quality characteristics were jeopardised. Thus Pro-t-con would have had nothing to do in suggesting settings that gave a speed of 21 bpm as the settings to achieve this were already known. The improvement in this case was therefore due mainly to the process of improvement and the fact that the machine was approached in a structured manner. This improvement was also ongoing because of the existence of

operators who were willing to work to setting sheets and the commitment of management to break constraints with small amounts of capital expenditure.

### *C22, Filmpac Sydney*

Machine C22 was approached at Filmpac Sydney in order to demonstrate the 10-step process improvement method and to train one of their staff in the use of DoE methods for analysing the process. As usual early work was done on defining priorities (step 1) and establishing methods for measuring the process and the priority elements of product quality (step 2). Preliminary experiments were undertaken to get an understanding of the machines capabilities and to see where opportunities may lie for improvement. Filmpac Sydney already had a setting sheet system in existence thus any improvements made could be recorded and reused later (step 4). The technical staff member knew how to suitably adjust the process (step 5) and helped in the design of experiments (step 6). This experimental design and its analysis are discussed in section 6.3 of this report. The machines air ring was acknowledged as a constraint and plans were made to upgrade it when funding became available. No other performance characteristics were of interest as these had all been decided upon in the definition of priorities step.

Actual result: A 50% improvement in output from 8 to 12 m/min

The improvements were made through following the 10-step process improvement method and maintained through the use of a good setting sheet system (step 4).

#### 4.1.2: SUGGESTED IMPROVEMENTS TO THE 10-STEP METHOD

The results of the above work from a plant management viewpoint were not great, as its effect on the Filmpac plants actual output was negligible. The Ten-Step method for process improvement can be seen to have worked well in terms of increasing the run speed of Filmpac and Liquipac machines. However without the provision of methods for securing process settings these improvements were seen to be transient. It is clear that the method described above helps to increase the output of a machine in terms of its CPM or kg/hr and tools such as Pro-t-con can be helpful in this respect. However the useful effect of improvements in machine output to the

company must be measured in terms of the average output of the machine over time as this has been shown to vary considerably from run to run. In order to improve the average speed of a machine it is necessary to ensure that optimal settings are used for all future runs of the product. So it is one thing to optimise a machine for output but quite another to ensure the work improves the average output of the machine over time. The development of methods for ensuring improvements in the average output from a machine (step 4) shall be the focus of the next section (section 4) of this report.

The skilled staff necessary to aid with experiments (step 5 of the 10 steps) were often unavailable. Filmpac's labour force was heavily utilised and thus the staff, which would have been used for helping to adjust the machine, were often utilised elsewhere. An attempt was made to get skilled operators in "off shift" to do experiments and a variety of options for this were considered unfortunately however nothing eventuated. This element requires further focus and a commitment of operator resources as successful experimentation depends upon skilled staff for machine stability.

Another weakness was in the decision-making process used for constraint elevation exercises. The lack of commitment by AEP to invest small amounts of capital to improve their processes was frustrating and may have been due to a weakness in the accounting methods used for measuring the effect of process improvements on profitability. Goldratt 1992 suggests the use of Throughput Dollars for quantifying the increase in company profits due to an improvement in throughput.

Delta profit = Delta T - delta OE

Where: T = Throughput \* margin = throughput dollars

OE = Operating expenses.

This would have allowed cost benefit analyses to be undertaken to decide whether constraints should be broken or not. It would therefore have been relatively easy to justify minor capital expenditure for breaking constraints this could have been expected to improve the probability of these elevation projects being undertaken. The absence of this element in the ten-step system may have been partly to blame for the blockages experienced with constraint elevation exercises throughout the project.







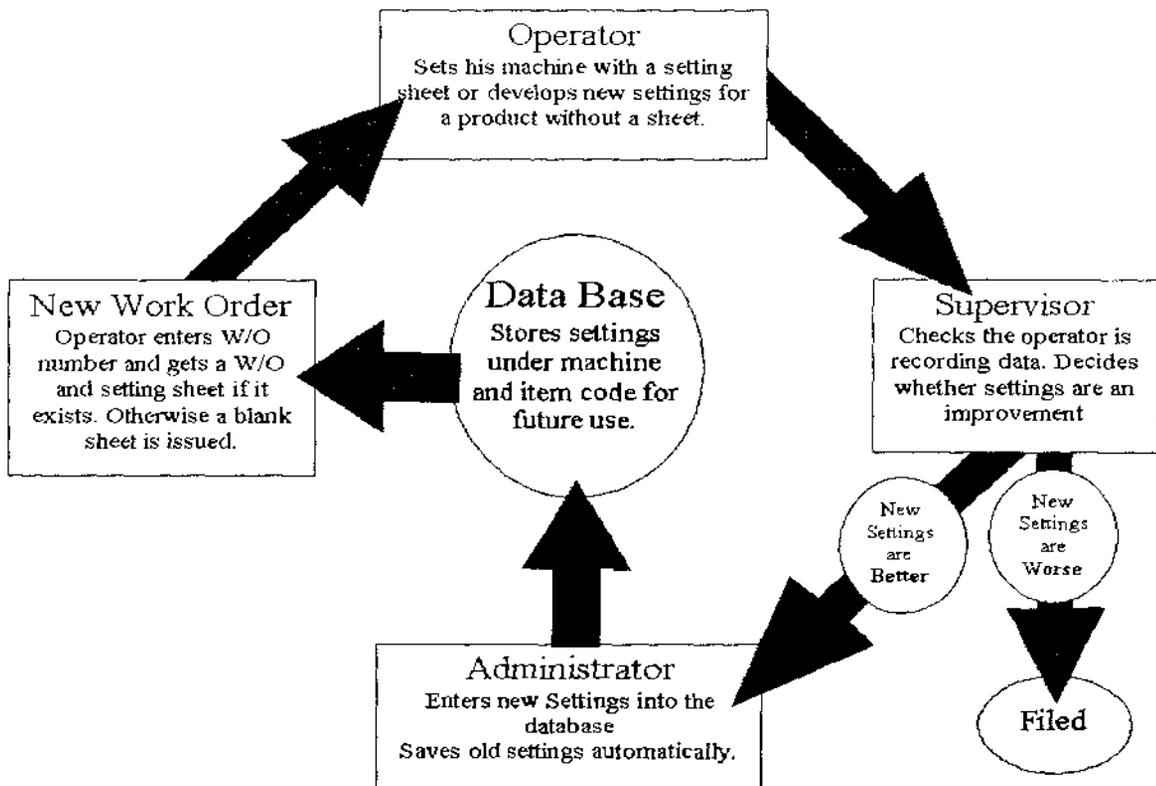
# 5.0-SETTING SHEET SYSTEM AT FILMPAC

This section describes the system used for helping Filmpac to ensure the settings used on their machines were secure i.e. step 4 of the 10 steps for process improvement proposed in section 3. Step 4 relates to level 1 of Upton's process improvement framework [Upton 1998b] and stages 4 and 5 of the stages of knowledge detailed by Barnes.

## 5.1 SETTING SHEET SYSTEM

Filmpac makes over 1000 products. A system was therefore necessary to ensure setting sheets were produced, distributed, used and updated for all products. In order to store setting sheets for all these products a database was deemed necessary. The overall system and supporting database are shown below in figure 27.

Figure 27: Setting Sheet System



The starting point for the development of setting sheets is with the operators, so this is where the process shown above began. The major focus of the early part of the system's development was therefore on the ability of operators to collect data.

#### 5.1.1: ENVIRONMENTAL CONSIDERATIONS.

At the outset of the project the salesman for Pro-t-con made it clear that there were two paths that could be taken in the application of Pro-t-con. The first was to target specific products and attempt to optimise them one by one. The second was to concentrate on the development of a system for collecting Pro-t-con data so that enough data would be available to optimise all products at some point. At the time Filmpac had no system for collecting data or producing setting sheets so this was seen as an opportunity to combine the two into a comprehensive setting sheet and optimisation system. Without a setting sheet system, optimised settings would be impossible to save, so basically knowledge would be created but not kept for future use. It would therefore be very difficult to build the company's knowledge base, as prior knowledge would not be explicitly recorded.

A setting sheet system existed before Filmpac changed its accounting system from BPICS to MFG Pro. When MFG Pro went "live" all product item codes were changed and the link between the old BPICS item numbers and the new MFG Pro item numbers became too hard to follow. Filmpac's training officer had developed setting sheets in Quattro Pro, that applied to the old BPICS item numbers, however there was no organised system for updating them. Often setting sheets were not revised for a number of years, in which time the machine and materials had normally changed enough to render the old settings inaccurate. There was also no way to know whether a setting sheet existed for a specific product except by searching for it. The operators were not compelled to use the setting sheets stored in the computer and these settings were often irretrievable by the mostly computer illiterate operators. Thus in most cases a supervisor had to retrieve the setting sheet, if it existed. In the past operators had been encouraged to collect data on their machine settings to get them to take more notice of the machines running conditions. The data produced through this was generally however unused except for occasional problem solving. Both of these efforts were to a large extent optional as far as operators were concerned and as there are always many other "important" things to deal with in the plant their use was rare.

It quickly became clear that many products simply didn't run for long enough to produce the data necessary to do a Pro-t-con optimisation. Also in order to get suitable variation in the process to quickly explore the operating envelope the machine needed to be adjusted by the operator to different settings during a normal run. This was against their instincts, as an operator's main responsibility is to keep the machine running smoothly in order to avoid scrap and down time. Playing with the settings of their machine was seen as likely to cause problems and thus make their job more difficult. Also with the low skill level of many operators they seldom knew which variables to adjust in order to make an improvement. An attempt was made to get supervisors to do the trials as they did their rounds during the day and this was also unsuccessful for similar reasons.

#### 5.1.2: PRO-T-CON RECORDING SHEETS

In order to produce setting sheets it is important to be able to measure and record the factors that operators use to set their machines and the effect these have on the process. Methods for this were discussed in Section 3. The methods developed were compiled into recording sheets for each machine and used to record data on the key parameters affecting the machine. These recording sheets were developed with the help of previous setting sheets, supervisor and training officer input and through an investigation of each machines settable variables. They were essential for saving the knowledge produced by each shift and,

- 1) Include a section that records inputs to the process such as machine factors and raw materials.
- 2) Include a section that records outputs of the process such as quality characteristics of the product produced and machine performance.
- 3) Cater for three sets of readings per 12-hour shift and have a column for suggested machine settings.
- 4) Are easy to follow around the machine to allow the operator a natural progression from recording point to recording point.
- 5) Are pink in colour so that they are easily recognised among the other papers on an operator's desk.

See appendix E for examples.

### 5.1.3: THE OPERATORS ROLE

Operators were required to collect data on the settings and running condition of their machine using the Pro-t-con recording sheets developed for each machine. In order to achieve this each operator had to know their way around the machine i.e. know what settings need to be recorded and where to find them. Initially it was assumed that operators were familiar with their machines and that they could record the necessary data with a small amount of group instruction. Poor performance in data collection early on suggested otherwise. Thus a training program was developed so that each operator could be individually shown through the recording sheet for the machine they spent most time on and given a score to relate to their ability to do each part of the job. This was very successful and a significant improvement in the quality and quantity of collected data was noticed.

The operators responsibility to the overall system requires that they

- 1) Set up their machine as detailed by the setting sheet.
- 2) Record the actual running conditions of the machine on the setting sheet and be able to justify differences between the settings they used and those on the setting sheet.
- 3) Aim to improve the performance of the machine in terms of output/quality and record improvements on their setting sheet.
- 4) Hand the completed setting sheet to their supervisor at the end of each shift.

### 5.1.4: THE SUPERVISORS ROLE

The supervisors role in the plant is to make sure machines are running smoothly i.e. help with start ups, trouble shoot, support operators in their day to day activities and ensure quality standards and specifications are met. They also report on the daily performance of their department to the production manager through a shift report that is discussed at a daily production meeting. In terms of the process improvement system they should,

- 1) Check that operators set up their machines to run at the specified settings
- 2) Discover why, if it is not possible to run the machine at these settings

- 3) Take measures to remedy this with the operator.
- 4) Address maintenance and manning issues that become apparent with the operating conditions, e.g. if settings are not achievable because of a machine fault the machine should be fixed.
- 5) Aim to continually increase the output of each machine and the quality of every product.
- 6) Update sheets with new settings should improvements be made or conditions change.
- 7) Ensure all operators fill in their sheets for the day and record this on the Shift Report for presentation at the daily production meeting.
- 8) Pass the filled in sheets to the administrator.

#### 5.1.5: THE ADMINISTRATOR

The system administrator is a person skilled in the process and is in charge of making the system operate smoothly. He must be competent on a computer and able to perform optimisation experiments when necessary. It is his responsibility to

- 1) Ensure new and improved settings are entered into the database for future use.
- 2) Check the validity of the new settings.
- 3) Conduct Pro-t-con optimisation trials on important products.
- 4) Defend the project, encourage continued use of the system and develop it as necessary.
- 5) Report to management on issues concerning the success of the system and specific improvement projects.

#### 5.1.6: WORK ORDER SYSTEM

The concept of a work-order was discussed in Section 1. The machine setting sheet is a new development to the work-order system and comes out automatically, on a separate setting sheet, with the work-order. So the operator knows what materials to use, the

product specification and the machine settings to achieve it. He should therefore have all the information he needs to run the machine successfully.

#### 5.1.7: THE DATA BASE

The database was developed in Progress (MFG Pro is written in Progress) and was designed to hold setting sheet data against item codes and machine numbers. Work-order and setting sheet data from Progress is downloaded daily to a Sequel database, which is accessed by the company's work-order print software. It is simply a storage space for setting sheet data but being in MFG Pro is accessible to anyone in AEPNZ who is given access to the necessary fields.

#### 5.1.8: IMPROVING/UPDATING SETTING SHEETS

It could be argued that the enforcement of setting sheets might reduce the operators' opportunity to develop settings for themselves and thus reduce innovation in the plant. Likewise it could also be argued that without suitable control over the settings used by operators it is likely that variation in settings and thus product will continue unchecked. Also in the rapidly changing manufacturing environment at Filmpac using DoE or Pro-t-con to improve machine settings may take too long to react for all but the longest running products. It is therefore necessary to achieve a balance between control, skilled/experimental innovation and reaction time in improving machine settings. It must be accepted that it is neither practical nor worthwhile to engage in significant experimentation with all of Filmpac's products as there are simply too many. Also because of the variation in run length, product specification, machine constraints etc. it is impossible to set hard and fast rules for the decision as to whether a product gets special treatment such as DoE/Pro-t-con for its optimisation.

The depth of involvement in setting sheet improvement is dependent upon the skill of the person undertaking the work. Generally operators will be involved with iterative improvements to output, roll quality, creasing and other easily measurable responses. They will therefore be most interested in process factors such as line speed, extruder rpm, air ring speed and the winder i.e. factors that directly affect the stability of the

process. More radical improvements such as the reduction of port lines, improvements in film strength or product performance will need the involvement of the system administrator or training officer as this is likely to involve changes to temperature profiles the effects of which are not as easily measured or understood. The everyday improvement of settings will therefore be operator driven, with strong involvement from supervisors to ensure that product remains in specification. The system administrator with the intention of using DoE or Pro-t-con for their optimisation will approach products that are seen to have significant opportunity for improvement.

Because of the variation in skill level apparent at Filmpac it is likely that the more skilled operators will endeavour to improve the settings they get more than the less skilled operators. Attitude will also be a factor as some operators are more likely to use setting sheets than others, various skilled operators are known to be very poor at following instructions preferring instead to work it out for themselves, often to their detriment. These innovators are, by experimenting, more likely to produce good settings, however they are also prone to having very bad days as well. The discipline of starting their machine to known settings will help them by reducing the overall variation they produce in the machine.

#### 5.1.9: THE ROLE OF PRO-T-CON

Pro-t-con fits into the setting sheet system as a tool to be used for speeding up the improvement process by encouraging work up to stage 8 of the 10 steps for process improvement. It will be used on products that are seen to be most important to the company's business strategy. Examples of such key products are Butterwrap, Bread Film, Palletfast and Shrink Film. These shall be optimised in order to ensure exploitation of the potential of the machines they are run on. Settings developed by Pro-t-con will be tested on the machine and if successful subsequently entered into the setting sheet system to be used on future runs of the product.

The inclusion of Pro-t-con in the above system will enable Filmpac to move from level 1 to level 2 [Upton 1998b] and develop up to stage 6 knowledge of their processes [Barnes 1997b].

#### 5.1.10: EXPECTED BENEFITS OF THE SYSTEM

The combination of these steps to form the system described above will conspire to remove a significant special cause of process variation (machine settings) across the machines and serve to improve the ability of operators to set their machines up correctly. This will position Filmpac at stage 4 of the 10 steps for process of improvement, level 1 of Upton's levels of involvement and at stage 5 of Barnes's stages of knowledge.

The expected results of this are,

- 1) A reduction in the variation in process performance from run to run of the same product.
- 2) An improvement in average machine output for each product
- 3) Better utilisation of the company's resources through exploitation of machine constraints.
- 4) Happier operators as setting up their machines becomes easier.
- 5) Lower scrap and down time due to poor set-ups.
- 6) Easier planning as variation in output reduces and standards are more easily developed.
- 7) Continual improvements in all of the above factors as settings get better over time.
- 8) Constraint elevation possibilities will be more easily recognised.

The combination of these will enable Filmpac to be more competitive and profitable in the flexible packaging market.

## 5.2 IMPLEMENTATION OF THE SYSTEM

When presenting a new system to a group of people heavy resistance can be expected from those that will need to change but can't see the benefit of that change and nothing but "luke warm" support from those who can see the benefits. Because of this it is essential to convince everyone involved of the benefits the change will offer them and then get them involved in its implementation. This was achieved through training the operators in the system and by encouraging peoples' issues to be brought to the student's attention before they became problems. Authors suggest that without the support of supervisors, improvement initiatives that involve their staff can be severely hindered. Production supervisors were therefore the first to be involved and trained in the system so that their support was gained and they could spread their knowledge and correct problems early.

### 5.2.1: SYSTEM MEASUREMENT

The system described above is only as good as its weakest link. If any part of the process fails to perform then its integrity will suffer. For this reason it is essential to have the support of management and co-operation from each of the individuals involved in the system i.e. the operators, supervisors and system administrator. Brooks 1995, suggests that "What gets measured gets done" as operators are unlikely to undertake extra tasks if no one is going to check if they have done so or not. Methods for measuring the performance of the system therefore need to be developed so that management can see how well the system is working and know when to intervene.

#### ***Shift Report***

The shift report was developed from the previously existing "shift scrap report". The new shift report is filled in by the supervisor and contains a column for recording whether operators have handed in their Pro-t-con sheets. Shift reports are discussed at the daily production meeting usually to discover the causes of excess scrap, poor production or poor quality. The number of completed setting sheets is now also discussed at this meeting and the operators who have not completed sheets without good

reason are reprimanded by their supervisor. Herein lay an opportunity to also measure other key performance indicators (KPI's) such as

- 1) The proportion of work orders that come out with setting sheets.
- 2) The percentage of operators that set their machine to the setting sheets.
- 3) The number of improvements made to the setting sheets.

The system administrator will be responsible for ensuring that these KPI's are available to management and if a drop in performance is noticed then appropriate action can be taken by the production manager to remedy the problem.

### ***Reward System***

A reward system was proposed for operators who consistently improve their machine settings. Each time an operator makes an improvement to their process a thank you note will be put forward for the "employee of the month prize". This will encourage further participation with the system. The system administrator will be responsible for its organisation.

### ***Management Commitment.***

An initial milestone of the project was to finish implementation of the setting sheet database by August of 1999. This was however not possible as the consultants necessary to develop the two parts of the system were not available to work full time on the project and had other commitments that took precedence over the project. Had the database been ready in 1999, then there would have been ample time to test the effect of the system across a variety of Filmpac's products. However for various reasons the database only became fully operational at the end of the project in June 2000.

### 5.3 TESTING THE SYSTEM

#### 5.3.1: MEASURING THE IMPROVEMENT IN PERFORMANCE DUE TO THE SYSTEM

A true measure of improvement in factory performance might be an improvement in the profit made by the company. However many other initiatives and competitive factors that affect company profits are active at any one time. The effect of this project would therefore be difficult to distinguish from the effect of other factors. Thus a search for less obvious measures that everyone agrees will help the company do business more effectively is necessary.

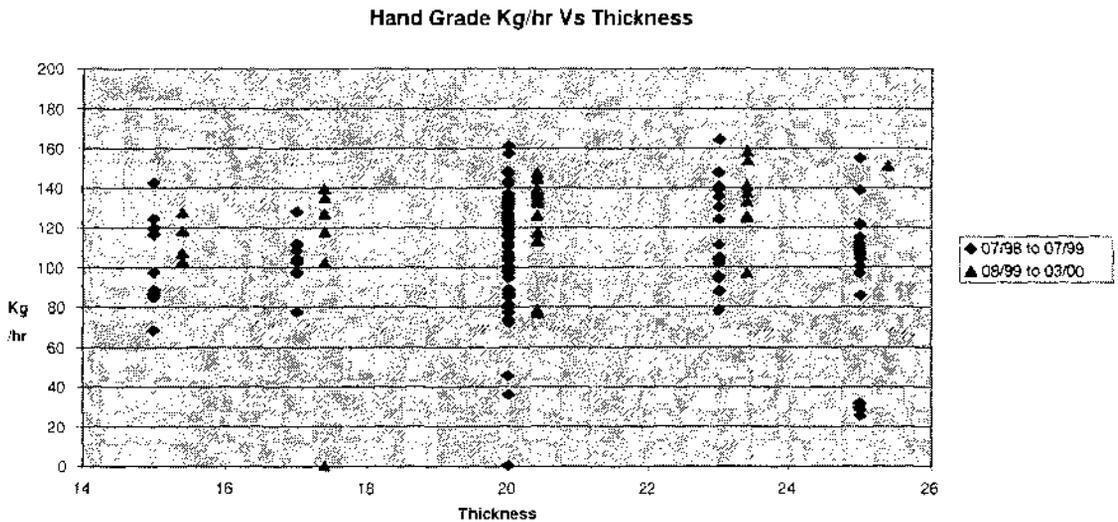
Many authors use process capability ( $C_{pk}$ ) to measure the effect of specific process improvement endeavours. This is a good metric as it measures the ability of a process to maintain specification in terms of its average and variation. In the situation at Filmpac this would work on some of the quality dimensions where a target specification is set such as film thickness or impact strength. To be comfortable with a  $C_{pk}$  calculation it is necessary to be able to demonstrate that the process is in statistical control [Statistical Methods for Quality 1997]. Unfortunately the processes at Filmpac were not in control in terms of the dimension this project aimed to improve i.e. machine output. Also in order to establish a  $C_{pk}$  value a specification is needed, in terms of machine output this was not available. It may have been possible to arbitrarily set a target as well as lower and upper spec limits for machine speed as this would allow  $C_{pk}$  values to be calculated. However it would not be fair to compare one set of data with another in terms of their ability to meet a specification that neither were aiming for in the first place. Consequently process capability is not a suitable measure of process performance for the situation at Filmpac.

The measure chosen for this project was the recorded actual machine output and its variation, for each product. It was assumed that an improvement in the average speed at which a machine made product and a reduction in the variation in this speed would allow the company to make product faster and more predictably. Historical information on machine outputs and scrap levels and other KPI's was available for analysis and frequently updated so that emerging trends were visible. An IT consultant was commissioned to establish a report from MFG Pro, Filmpacs accounting database, so that this would be possible.

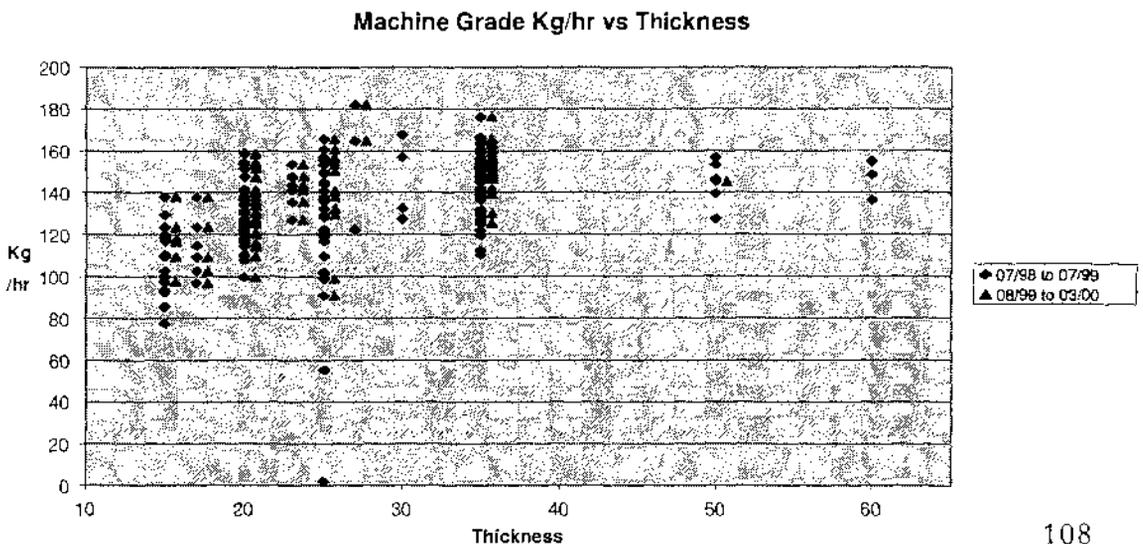
## 5.4 RESULTS

Work was done on machine 9 to increase and stabilise actual output from the machine by setting a standard machine speed (kg/hr) to run it too. Actual machine outputs were calculated with data taken from the companies accounting data base, MFG Pro, and relate to the total quantity of product made divided by the time taken to do so. The effect of having the machine run at a standard speed was expected to have a similar effect on actual output as the use of setting sheets would have on the whole product. The graphs below (Fig 28 and 29) show the difference between finished product output out of Machine 9 from July 98 to July 99 and the six months from August 99 to March 2000.

**Figure 28: Machine 9 output for Hand grade products before and after standard run speed was set.**

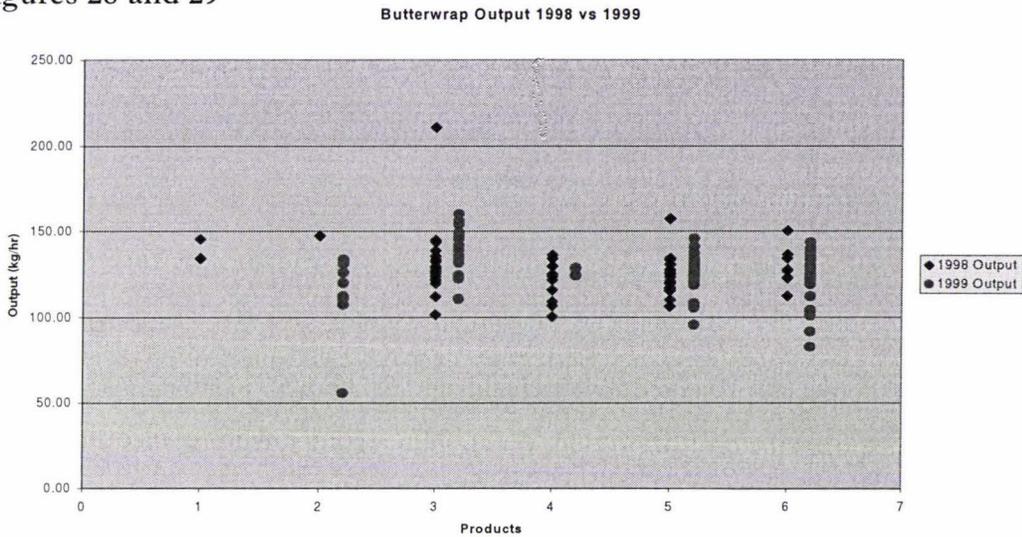


**Figure 29: Machine 9 output for Machine grade products before and after standard run speed was set**



Because of the possibility of the Hawthorne effect, Machine 6, another machine that runs a single type of product (Butterwrap) long term was also analysed for its output over the same period.

**Figure 30: Machine 6 output for products over the same time periods as figures 28 and 29**



**Table 3 A comparison of the output from Machine 9 against Machine 6**

	Machine 9				Machine 6	
	Hand Grade		Machine Grade		Butterwrap	
	7/98 to 7/99	8/99 to 3/00	7/98 to 7/99	8/99 to 3/00	7/98 to 7/99	8/99 to 3/00
Average Output	109.48	127.09	133.04	141.04	127.71	125.4
Standard Deviation	33.01	19.31	20.89	17.2	16.08	15.64

Machine 6 shows a similar issue to machine 9 with output variation from run to run of the same product (fig 30). In this case however it is not possible to suggest that there has been a significant improvement in average output over this time nor is it possible to see a significant reduction in process variation.

It can therefore be concluded that the improvements seen in Machine 9 are due to the factors unique to it over this time. It can thus be postulated that this was due in large part to the fact that a standard output was set for the operators to achieve during the period from July 1999 to March 2000. From this, it can be suggested that the implementation of the proposed setting sheet system will have a similar effect on all the processes at Filmpac.

#### 5.4.1: FINANCIAL EFFECT OF THE RESULTS

Filmpac does not have methods that enable them to calculate the effect of such improvements on the company's bottom line. However two methods do exist for this the first is to do with the improvement in earnings due to increased output. This was presented by Goldratt and assumes that the extra product can be sold.

$$\text{Delta profit} = \text{Delta T} - \text{delta OE}$$

$$\text{Where T} = \text{Throughput} * \text{margin} = \text{throughput dollars}$$

$$\text{OE} = \text{Operating expenses.}$$

Operating expenses at Filmpac have not increased due to the project therefore the increase in profit = increase in throughput \* (selling price - direct costs).

The second method was presented by Taguchi and is known as the Taguchi loss function. This quantifies the cost of product variation to a company in terms of its effect on business profitability. In this case the "higher is better" loss function was used to calculate the effect of the reduced standard deviation. Unfortunately the loss function formula was not suitable for application to this situation because calculation of the term  $k$  requires the existence of a specification and a cost due to being outside that specification. This is not the case with machine output as there is no output specification and the cost, which would be in upsetting the customer by being late, could not be quantified.

However there is an obvious increase in average output across the two machine 9 product ranges, so using Goldratt's throughput equation these produce the following.

$$\text{Hand Grade:} \quad 127.09 - 109.48 = 17.61 \text{ kg/hr} * \text{margin} * \text{hrs/yr.} = \$46285/\text{yr}$$

$$\text{Machine Grade:} \quad 141.40 - 133.40 = 8.0 \text{ kg/hr} * \text{margin} * \text{hrs/yr.} = \$49076/\text{yr}$$

Where margin = Selling price – raw material cost

This equals an increase in earnings of \$95361 over a year for the two product lines providing this additional product can be sold, a likely scenario in the case of Palletfast as it is a commodity product.

## 5.5 DISCUSSION

Although not all of the results from Machine 9 were statistically significant at the 95% level of significance in many cases an improvement in the average speed and a reduction in the spread of the machines output can be clearly seen. This is likely to be due to the fact that on Machine 9 standard machine speeds were set for both hand and machine grade films. These machine speeds were agreed to by the operators and policed by the supervisor's daily. At the same time dedicated operators were assigned to the machine on a 12 hour rotating shift pattern and made responsible for the machine's production.

Significant variation in skill level between the four operators however still existed and this is likely to explain part of the residual variation in actual machine output. Also peripheral machinery such as the trim recycling "Exact" unit consistently caused problems and thus scrap and down time resulted. Again better operators were less affected by this. The remaining variation is likely to be due to run length, product mix and reporting errors.

These results are encouraging and Filmpac can expect the setting sheet system to have a similar effect throughout the other products in the plant when fully implemented. The setting sheet system should achieve this by making operators run their machines the best way previously seen every time. This will solidify high average machine outputs so the speed at which product is made and the quality of this product will improve. Consequently a major cause of variation in output and quality will have been removed.

If similar results to those off machine 9 were realised across all the machines in extrusion then the increase in profit could be in the order of a million dollars a year, provided all additional product could be sold. This would significantly improve Filmpac's competitive advantage and long term viability.

Unfortunately the setting sheet system was not fully implemented in time for direct analysis within this thesis. It would have added significant rigor to the project to have demonstrated an improvement in machine output and a reduction in variation across the company's product range however this was not possible within the time available. Had the analysis of the improvements possible due to standardised settings been available earlier it may have encouraged the support necessary to complete development of the setting sheet system in a more timely fashion.



# 6.0 - ANALYSIS OF PRO-t-CON

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## 6.1 TESTING PRO-t-CON USING KNOWN DUMMY PROCESSES

### 6.1.1: NON LINEAR PROCESS

In order to test Pro-t-con's ability to analyse the relationships between variables in a process, a dummy process was developed in Microsoft Excel. In this way known relationships between each factor and the results could be tested. A dummy process allows the experimental design and number of runs to be varied much more easily than in a real process. Also the process can be changed to see what effect this has on the results.

The dummy process developed here included ten factors with formulas used to calculate the relationship between each factor and the result. A variety of relationships were used including an exponential, a square law, a two-way interaction and a number of linear factors of different strengths. The formula was,

$$e^A + B^2 + C + D*5 + E*0.01 + (F*G + F^2) + (F*G + G) + H + I*2 + J*3 = \text{Result}$$

An element of error was introduced to each of the input variables to imitate the errors inherent in a real life process. This was designed to affect the results in a way dependant upon the levels of each factor e.g.  $e^A$  became  $e^{(A+\text{error})}$  and  $B^2$  became  $(B + \text{error})^2$ . So the effect of the error term on non-linear factors increased with the gradient of their graphs whereas the linear factors were unaffected by it as they had constant gradients.

Treatment combinations were generated to give a variety of different combinations of each factor. Usually in a Pro-t-con type of experiment the process would be adjusted to try and get as close as possible to the targets. In this case the aim was to test whether Pro-t-con could independently achieve a series of targets from the raw data. The experiments were thus done without a prior knowledge of the targets as this may have produced data closer to these targets, making it easier for Pro-t-con to achieve them. Therefore the runs were developed to suitably explore a variety of the possible combinations of the ten factors without concern for the actual result.

Three original data sets were developed by

- 1) Creating a range of possible settings for each of the 10 factors
- 2) Spreading these ranges across 70 experimental runs
- 3) Randomising the order of each factor's settings to create 70 random treatment combinations (runs) of the ten factors.
- 4) Step 3 was done three times to produce the three sets of treatment combinations (data sets) containing the same numbers but in three different random combinations labelled 4.1.1, 4.2.1 and 4.3.1 respectively.

Experiments were done with these data sets by putting each through the dummy process in Excel. This was done ten times for each data set to produce ten replicates for each run. The average and standard deviation were then calculated for each lot of 10 replicates.

The treatment combinations and resulting average and average/standard deviation for each run were then put into the form necessary for importing into Pro-t-con. At this point the order of the runs in each data set was randomised to create 4.1.2 from 4.1.1, 4.2.2 from 4.2.1 and 4.3.2 from 4.3.1. The pairs of data sets were therefore exactly the same except for the order the data was presented to Pro-t-con i.e. they contained exactly the same treatment combinations and the results of the runs were the same, the only difference was the order the runs were presented.

Two sets of experiments were therefore done on each of three data sets to produce six sets of data, (4.1.1, 4.1.2), (4.2.1, 4.2.2), (4.3.1, and 4.3.2)

The settings and results from each data set were then imported into Pro-t-con and a variety of average and average/standard deviation results were targeted in the Pro-t-con analysis. The settings produced by Pro-t-con and the predicted results were recorded from the optimised settings/results screen in Pro-t-con and the settings for each set of targets were put back through the dummy process as a new set of runs. These runs are shown in table 4. The "Targets" row shows what Pro-t-con was asked to achieve. The "Prediction" row shows what Pro-t-con said the settings it had developed should achieve. The "Actual" row shows what those settings actually achieved when put back into the dummy process formula.

### Model Information

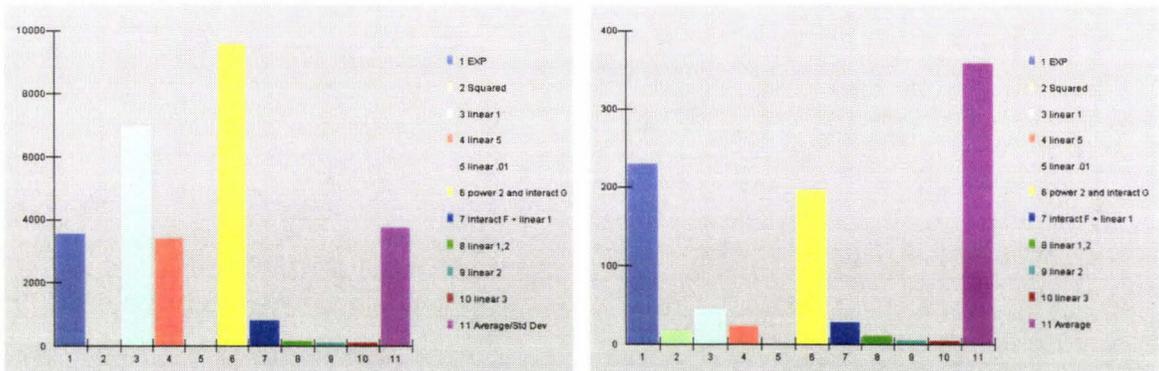
- No tolerances were given to the targets and both were set as priority 1.
- A 10% pull factor was used in the model.
- The calculated Model Variability is recorded in table 4 (see appendix F) under “Model” and next to each target for each set of experimental results.

### Results

Pro-t-con was used to analyse each data set for the effects of each factor on the two responses. (Figures 31 to 36)

These three sets of graphs show Pro-t-con’s analysis of the relative effects of each factor in the process for each data set. Minor differences between the results of an analysis where the experiments undertaken were different might be expected and this can be seen in the different effects between the six pairs of graphs above i.e. the 4.1, 4.2 and 4.3 series’. However not only is there variation between the different data sets there is also some variation within each pair i.e. between the graphs when the only change was in the order that experiments were done. This causes concern as to the reliability of this analysis as the same data, whatever its order, should be expected to produce the same results.

**Figure 31: Factor effects for Average and Average/ Standard Deviation (4.1.1)**



**Figure 32: Factor effects for Average and Average/ Standard Deviation (4.1.2)**

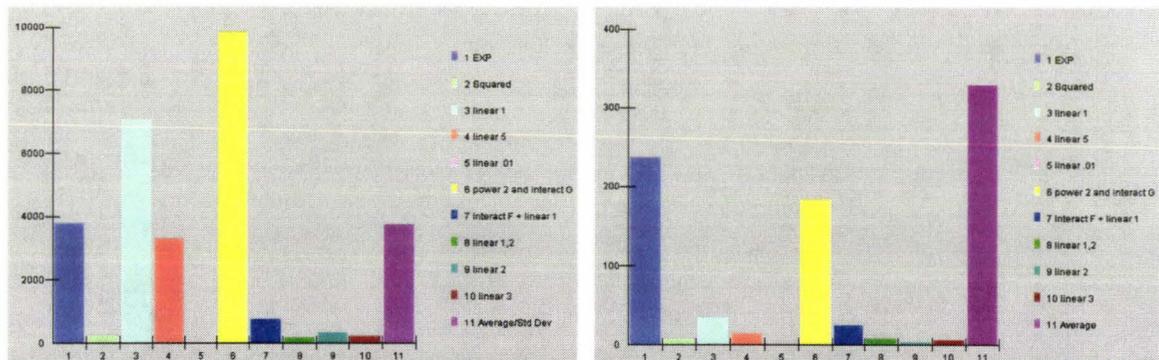


Figure 33: Factor effects for Average and Average/ Standard Deviation (4.2.1)

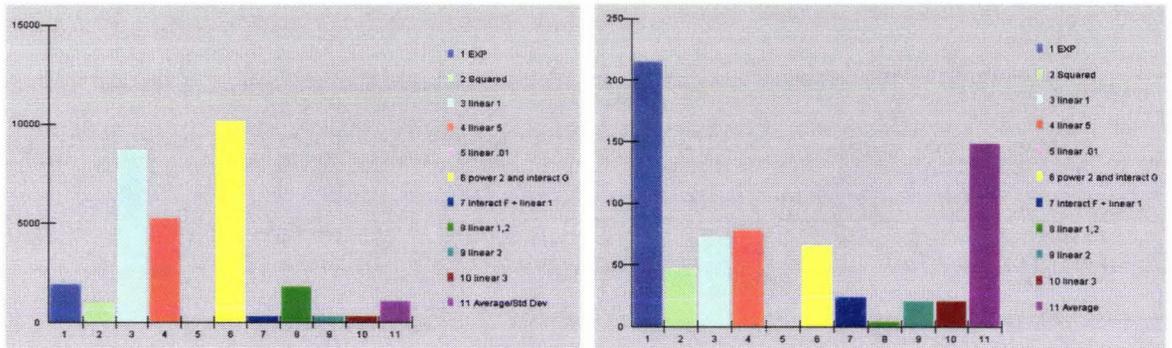


Figure 34: Factor effects for Average and Average/ Standard Deviation (4.2.2)

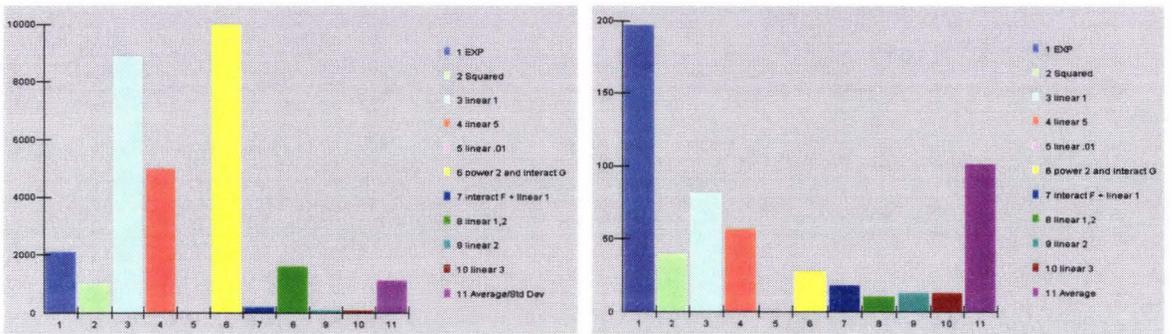


Figure 35: Factor effects for Average and Average/ Standard Deviation (4.3.1)

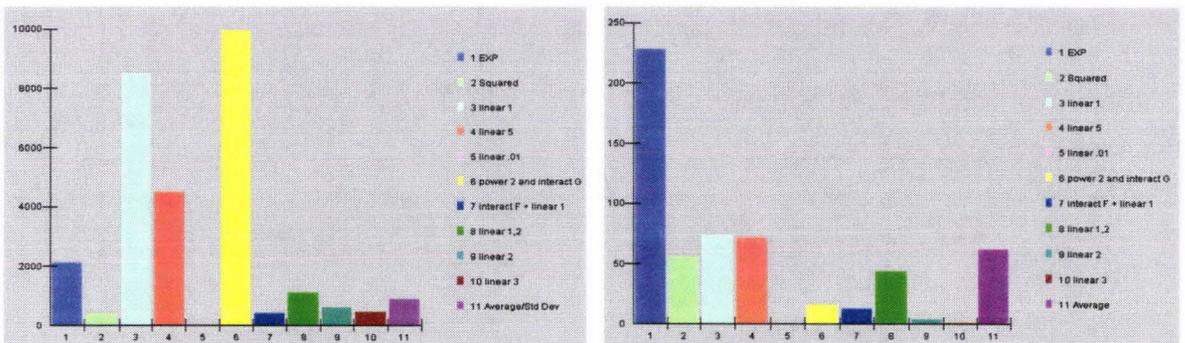
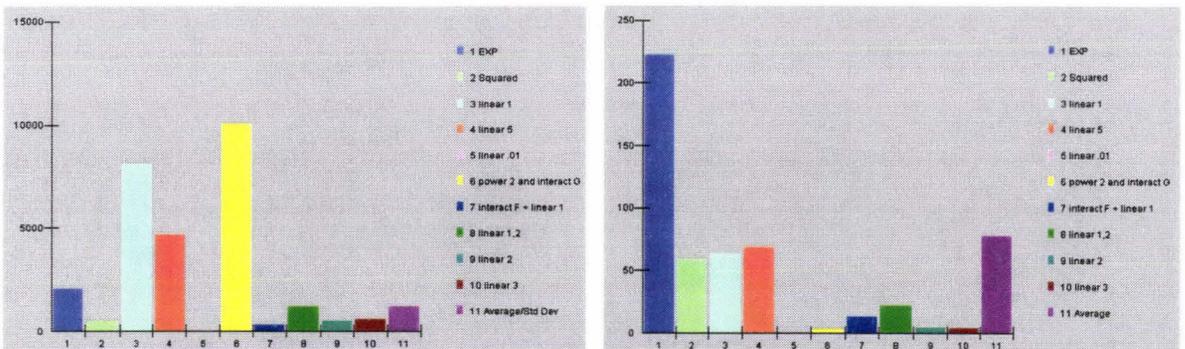


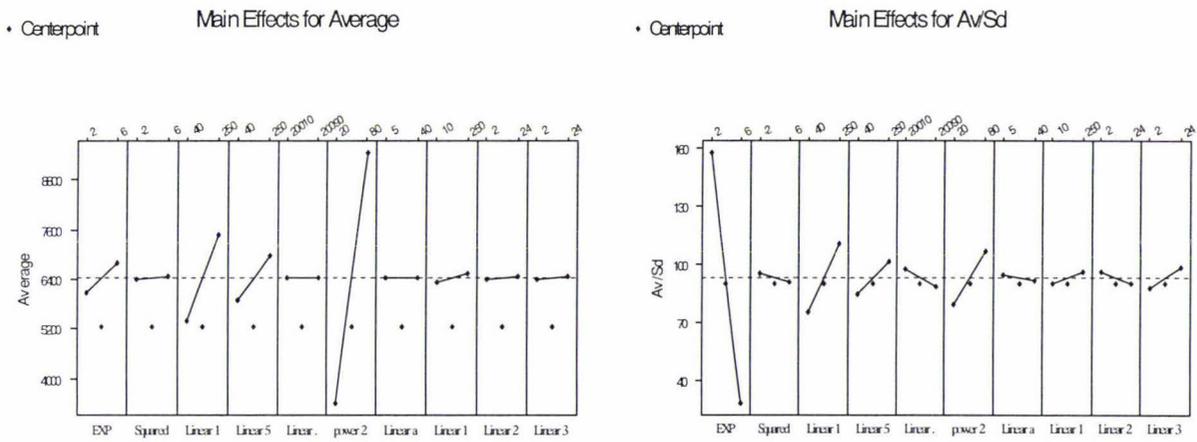
Figure 36: Factor effects for Average and Average/Standard Deviation (4.3.2)



### Plackett Burman

In order to check the above factor effects a 12 run Plackett Burman experiment with 2 centre points was done to analyse the process for its factor effects again. Minitab was used for the design and analysis and the same dummy process was used for generation of the responses. The Plackett Burman is usually used only as a screening experiment and its rigor is thus questionable when interactions exist. However it does produce results at the same level of resolution (i.e. single factor effects only) as Pro-t-con and is thus useful for comparison.

**Figure 37: Plackett Burman factor effects for Average and Average/Standard Deviation**



Figures 31 to 36 compare well with the results of the experiment shown above in figure 37. This suggests that Pro-t-con has produced a reasonable though varying prediction of the effect of each of the variables on the Process.

It is possible to see from the graphs above that the variables, which heavily affect average, do not heavily affect average/std deviation and this is what was expected from the formula. Pro-t-con should therefore be able to adjust the variables that affect each target almost independently. It should then be relatively easy to optimise the process for average and average/standard deviation at once.

A table of the results of each of the 6 data sets is presented in appendix F, table 4.

It can be seen from table 4 that not only has Pro-t-con analysed each pair of data sets for different factor effects (i.e. 4.1.1 differs from 4.1.2 etc.) it has also proposed different optimal solutions to the process for each of them.

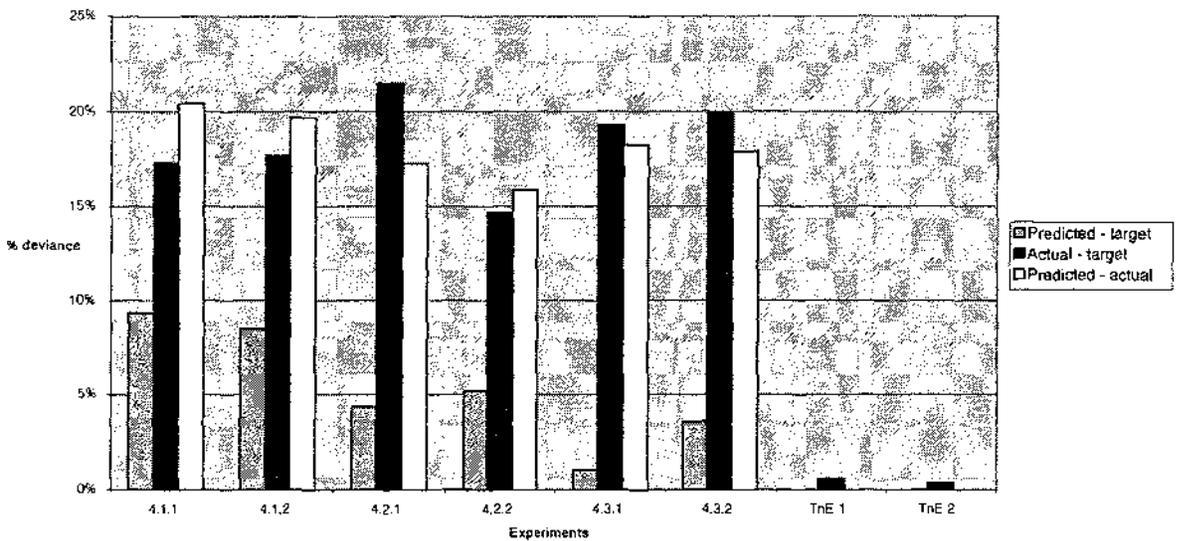
The optimal settings developed by Pro-t-con when put back into the dummy process as a check (Actual values) also differ significantly from Pro-t-con's prediction of the results these settings should produce.

***Trial and Error Results***

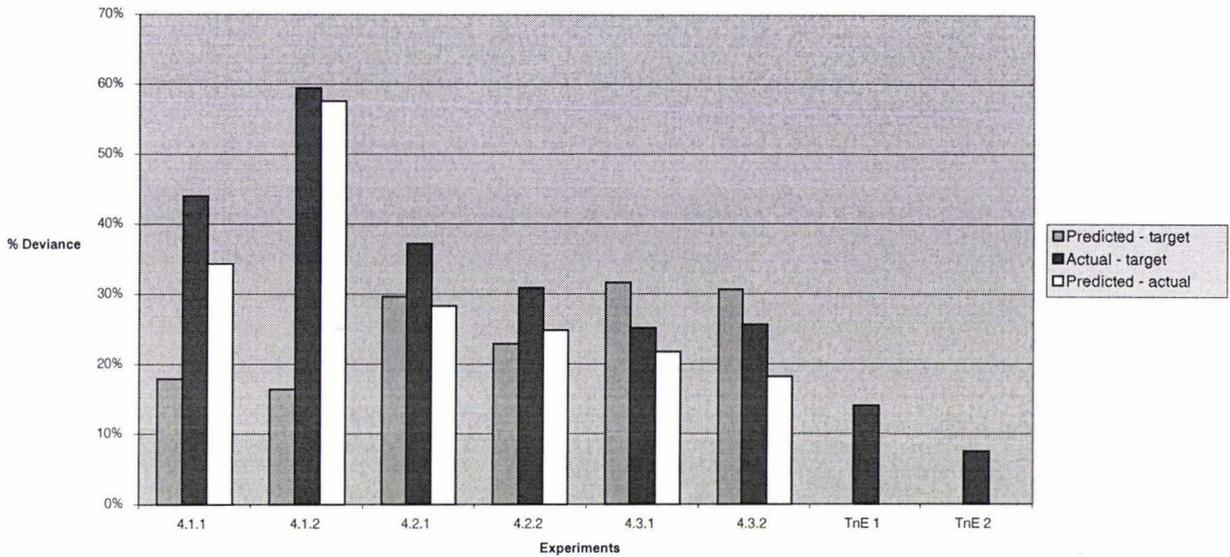
A series of trial and error runs were done, using the knowledge gained through the above effect plots to tune the process, so as to prove that it was capable of achieving the set targets. See appendix F, table 5 for the data. The two trial and error runs (A and B) for each set of targets bracket those target values, except for 2000(average) and 300(average/std deviation) which were just not achievable in the process.

The results of the Pro-t-con optimisations and the trial and error work were summarised into figures 38 and 39.

**Figure 38: Deviation between Pro-t-con's prediction, targets and actual results (Average)**



**Figure 39: Deviation between Pro-t-con’s prediction, targets and actual results (Average/Standard Deviation)**

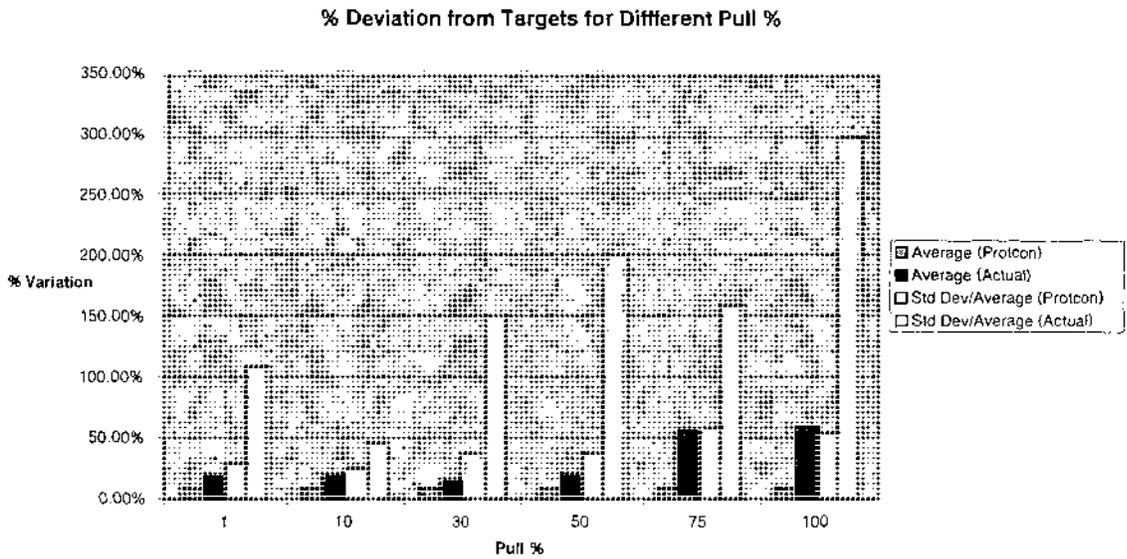


(Predicted – Actual) bars suggest the ability of the Pro-t-con model to correctly predict the process.

Figures 38 and 39 again illustrate the variation between data sets, however they also show that Pro-t-con was inaccurate when developing suitable settings to achieve the target results. In fact the average performance of Pro-t-con was significantly poorer than that of the trial and error method (labelled TnE in figs 38 and 39) for developing settings that would approximate the chosen targets.

This could have been because with Pro-t-con using only linear regression, 10% pull adjustments of the non-linear factors could have caused it to deviate too much from the actual response for the Pro-t-con model to be accurate. Consequently further Pro-t-con tests were done with the same data and a changed Pro-t-con pull % to see what effect this would have on the results. Results of these experiments are shown in figure 40.

**Figure 40: Deviation between Pro-t-con's prediction, target and actual results for different Pull % (Average, Average/Standard Deviation)**



The first and third bars show how far Pro-t-con's predictions were from the targets (see appendix F. The second and fourth bars in each group show how far the actual results were from the target results. So the pull % seems to have a large influence on the accuracy of the settings produced by Pro-t-con, the results it predicts and the accuracy of those results. This suggests that when dealing with a non-linear process it is inappropriate to use a high pull %. In figure 40 the pull % that enabled Pro-t-con to best predict the process was 10% i.e. the pull % used in the earlier analysis.

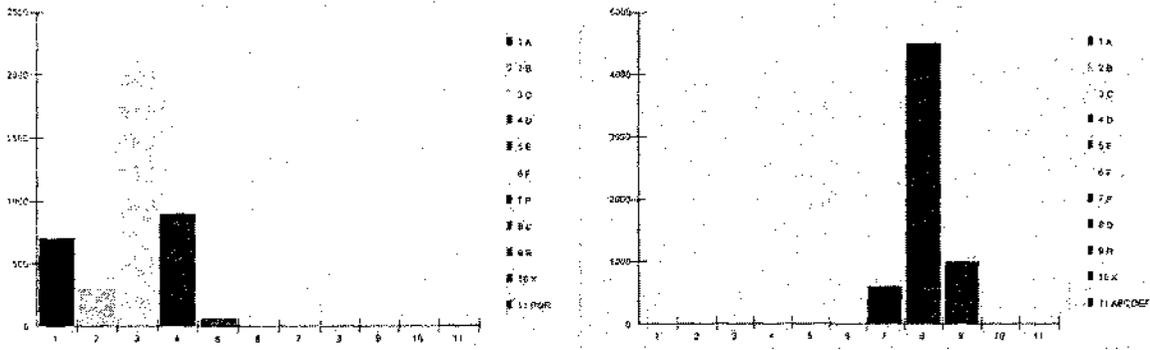
This suggests that Pro-t-con does not develop settings that are able to accurately produce the target results that were asked for in the above analysis even though it was possible in four out of the five cases to do so with the trial and error technique.

6.1.2: ALL LINEAR DUMMY PROCESS

Although the process analysed above was a reasonable imitation of a real process Pro-t-con does only use linear regression for its analysis. It was therefore decided that perhaps non-linear factors were outside of Pro-t-con’s capabilities. A new process was thus developed using only linear factors to see if Pro-t-con could discover the main effects and achieve the desired targets better than it had previously.

In this case the error generator was removed and the two responses were made completely independent of each other. I.e. response ABCDEF was affected by factors A,B,C,D,E and F only and PQR by factors P,Q and R only, factor X had no effect on either response. Pro-t-con should therefore be able to alter them independently to achieve the target results.

**Figure 41: Factor Effects for ABCDEF      Figure 42: Factor Effects for PQR**



Pro-t-con was again able to accurately analyse the process and correctly discover the factors that affected each of the responses. (Figures 41 and 42)

Similar experiments were done with this process across the same range of data as with the non-linear experiments. A variety of targets were sought with Pro-t-con and the settings fed back into the dummy process. Initial experiments were done to see which pull % gave the best results, graphs of these are presented in figures 43 and 44

Figure 43: Deviation between Pro-t-con's prediction, target and actual results for different Pull % (ABCDEF)

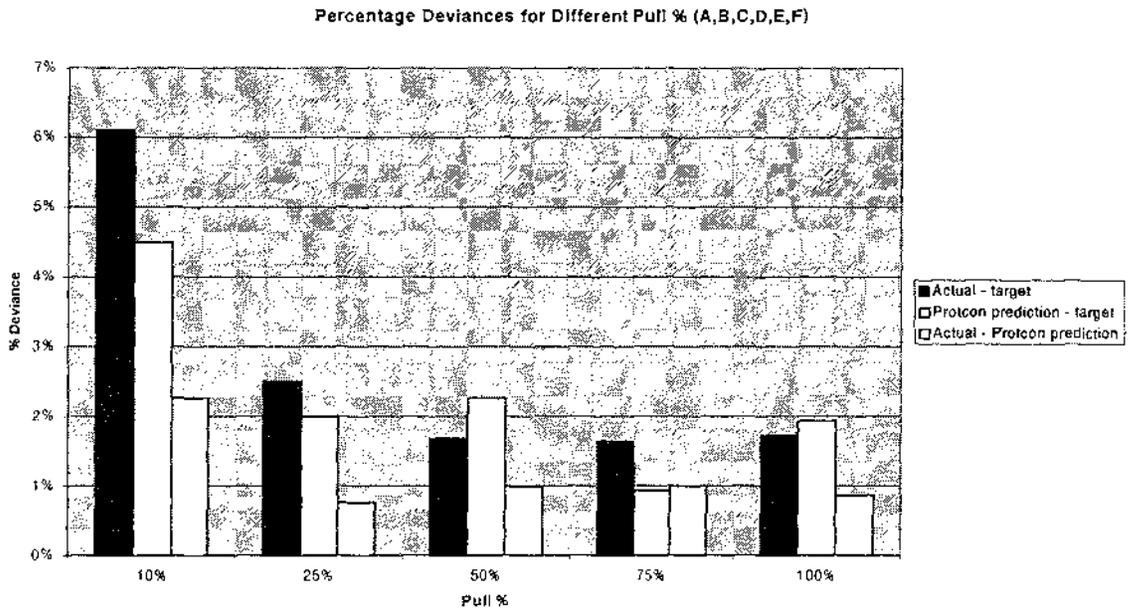
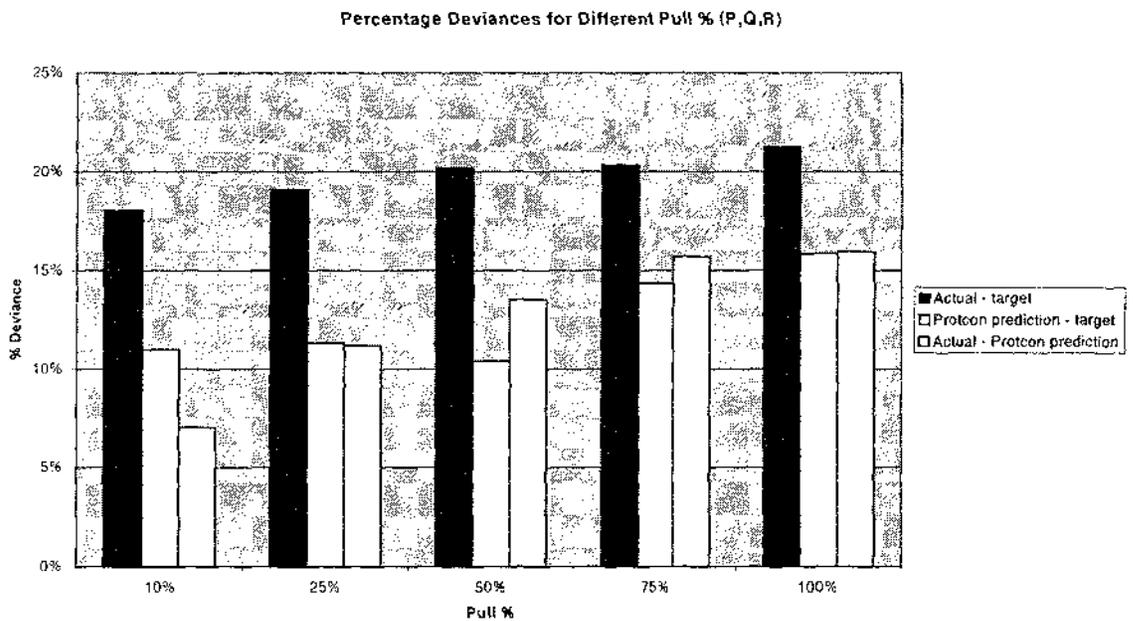


Figure 44: Deviation between Pro-t-con's prediction, Target and Actual results for different Pull % allowance (PQR)



Again the model developed with 10% pull seems to have predicted the process most accurately (Actual-Pro-t-con prediction) when both responses are looked at, so further experiments were done with a 10 % pull model.

**Model information**

No tolerances were given to the targets and both were set as priority 1.

10% pull factor was used in the model. Variability = 100% on both ABCDEF and PQR.

The results of this experiment are summarised in Table 6 for each of five different targets

**Table 6:**

**Linear Model Settings, Targets, Actuals and Predictions**

A	1	7	2.268	3.768	1.602
B	20010	20080	20010	20016.9	20090
C	87.96	80	27.372	10	92.16
D	863.717	170	82.263	10	900
E	1	14	1	22	21.998
F	1	14	1	22	18.198
P	13.748	4	-0.344	14	14
Q	130.805	120	181.097	150	130
R	0	35	74.56	40	0
X	900	90	791.785	150	900
Actual (ABCDEF)	3203.937	3000.8	1216.347	1016.969	3487.21
Protcon Prediction	3145.764	3001.112	1138.918	1024.691	3457.437
Target	3000	3000	1000	1000	3500
Actual (PQR)	379.065	170	166.765	70	370
Protcon Prediction	397.956	170	197.921	74.887	339.823
Target	400	200	200	100	300

The average deviance of the actual results from the targets and predictions was plotted next to trial and error results to show that the process was capable of reaching the targets. (Figure 45)

**Figure 45: Deviation between Predicted, Actual and Target results vs. Trial and Error**

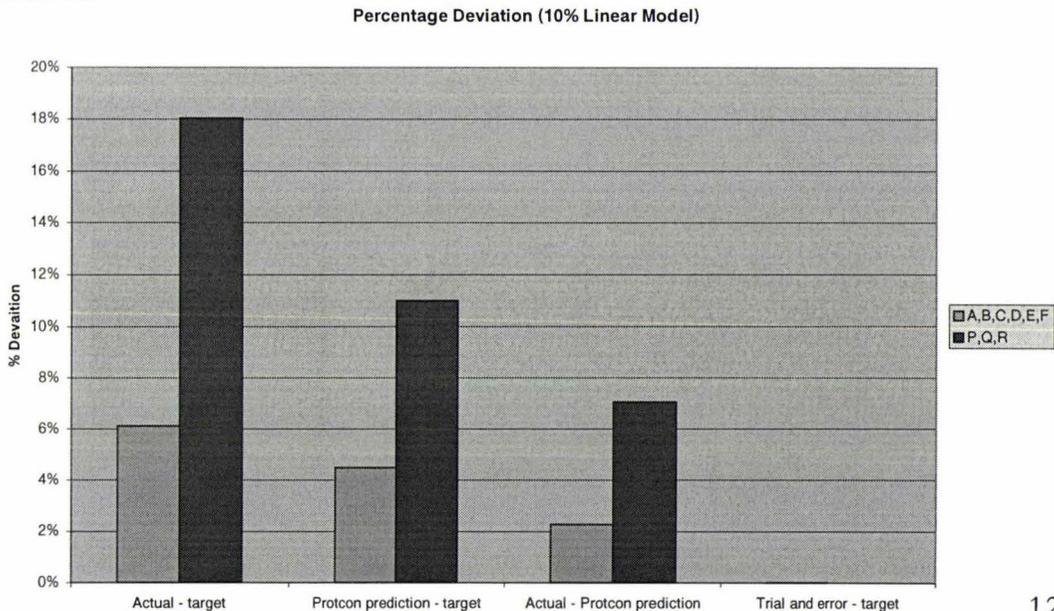


Figure 45 shows that the Pro-t-con optimal solutions and the results that were produced with the Pro-t-con settings again differ from the targets but not as badly as they did in the non-linear process. However the trial and error results show that the process was in fact capable of meeting the desired targets.

So it is clear in this case that Pro-t-con was successful in correctly modelling the process, however it failed to adequately adjust the process settings to achieve the desired targets. It might have been expected that, as the process was linear and targets were independently achievable by the process, they should have been independently achievable with Pro-t-con, however this was not the case, even with the freedom to change control factors over a large pull %.

Possible reasons for this poor performance shall be discussed in section 6.5.

## 6.2 PALLETFAST STRETCH CLING FILM OPTIMISATION (CASE STUDY)

Stages 1 to 5 of the 10-step process improvement method used to guide this case study were described in section 4 of this report.

### 6.2.1: EXPERIMENTAL DESIGN

A 12 run Plackett Burman screening experiment with 2 centre points was developed in Minitab so that the variables thought to have the most effect on SCF could be analysed for their individual effects.

**Table 7: Plackett Burman experimental runs (machine 9)**

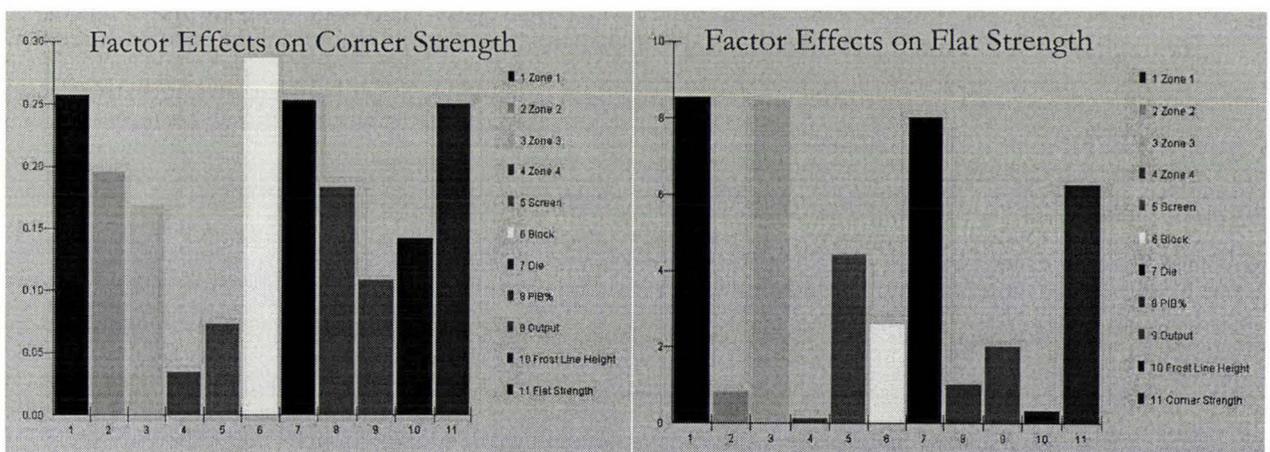
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Zone 1	180	180	180	180	170	160	160	160	180	160	160	170	180	160
Zone 2	220	180	180	220	200	220	180	220	220	180	220	200	180	180
Zone 3	180	200	180	180	190	200	200	200	200	180	180	190	200	180
Zone 4	200	180	180	200	190	180	200	200	180	200	180	190	200	180
Screen	190	190	210	210	200	210	210	190	210	210	190	200	190	190
Block	200	200	230	200	215	200	200	230	230	230	230	215	230	200
Die	210	240	240	240	225	210	240	240	210	210	240	225	210	210
PIB%	4.5	4.5	4	4	4.25	4	4.5	4	4.5	4.5	4.5	4.25	4	4
Output	210	210	210	190	200	210	190	210	190	210	190	200	190	190
Frost Li	700	500	700	500	600	700	700	500	500	500	700	600	700	500

The experiments in table 7 were run and Pro-t-con recording sheets filled in for the machine conditions present after each set. Sample rolls were saved and tested on the test rig. The results of the tests were recorded in excel and then transferred to Pro-t-con and Minitab for analysis. Results are shown below.

### *Pro-t-con*

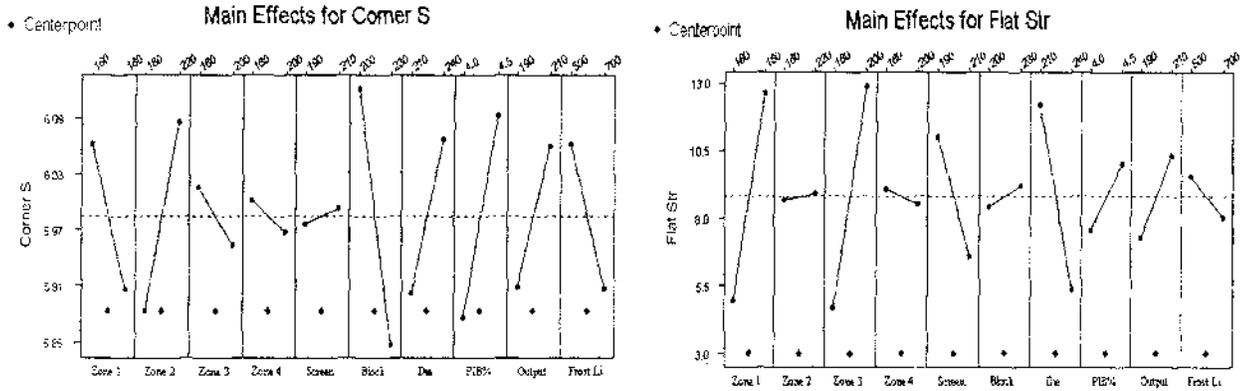
In order to get the 30 experimental runs necessary for a Pro-t-con optimisation, the data set was replicated. The following graphs are the results of analysis with Pro-t-con, DoE and Multiple Regression.

**Figure 46: Pro-t-con Analysis of the factor effects on Corner and Flat Strength**



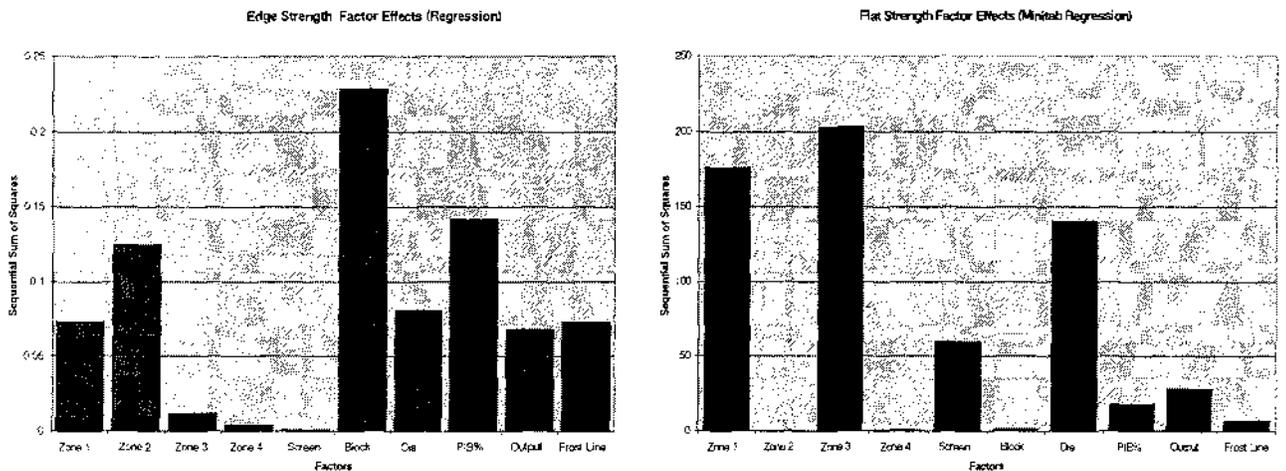
*Minitab*

**Figure 47: Plackett Burman Analysis of the factor effects on Corner and Flat Strength**



*Minitab Regression*

**Figure 48: Multiple Regression Analysis of the factor effects on Corner and Flat Strength**



A comparison of figures 46 to 48 shows that Pro-t-con’s analysis and Minitab’s Plackett Burman analysis using the same data have produced very similar relative effects to each other. The general linear models in figure 48 have also done a similar job in ranking the variables in terms of their effects. However relatively speaking the general linear model has suggested a much stronger relationship between “block” and corner strength than the other methods.

This compares well with the results of the dummy process work above and again

suggests that Pro-t-con is capable of correctly analysing processes for their factor effects.

## 6.2.2: CONFIRMATORY EXPERIMENTS

Pro-t-con suggested the following optimal settings and predicted results from its analysis above. Further work was therefore done with 20 micron Palletfast in order to confirm that the settings below achieve the expected results. The old settings previously used on machine 9 are presented next to two sets of Pro-t-con optimal settings (1 and 2), one at 190 kg/hr the other at 200 kg/hr. 1\* and 2\* are two of the 14 raw data sets used in the Pro-t-con analysis.

**Table 8: Settings and results from Pro-t-con compared to the old settings and actual columns from the raw data**

	Old	1	1*	2	2*
ZONE 1	170	161.99	160	160	160
ZONE 2	200	219.45	220	200	220
ZONE 3	190	180	180	180	180
ZONE 4	190	180.24	180	180	180
SCREEN BLOCK	200	210.01	210	210	210
SCREEN CHANGER	24	24	24	24	24
SCREEN ADAPTOR	200	209.988	210	210	210
BLOCK ZONE	215	200.16	200	230	230
INNER DIE	225	240	240	240	240
LOWER DIE	225	240	240	240	240
UPPER DIE	225	240	240	240	240
SCREW RPM	94.4	82	82	96.9	96.9
HAUL OFF m/min	48	47.1	47.1	49	49
FAN AIR Hz	37.4	40.99	41	39.8	39.8
OUTPUT Kg/hr	195	190	190	199.828	200
P.I.B. %	4.25	4.5	4.5	4.5	4.5
SET GAUGE	21.5	22.5	22.5	22.5	22.5
WEIGHBATCH WIDTH	1650	1650	1650	1650	1650
ACTUAL WEB WIDTH	1646	1650	1650	1650	1650
TRIM WIDTH (mm)	145	150	150	150	150
FROST LINE HEIGHT	600	500	500	500	500
TRIM	1	2	2	2	2
<b>Targets</b>					
Corner Strength		6.25		6.25	
Flat Strength		35		35	
Output		NA		200	
<b>Predictions</b>					
Corner Strength		6.216		6.018	
Flat Strength		35.31		28.969	
<b>Actuals</b>					
Corner Strength	5.9	6.26	6.18	6.14	6.1
Flat Strength	3	15.0625	35	13.125	35

It is possible to see from table 8 that the actual results differ from the results predicted by Pro-t-con, especially in terms of flat strength. This is likely to be because of small edge tears in the rolls of film that cause it to fail prematurely. It is also clear from a comparison of 1 vs. 1\* and 2 vs. 2\* that Pro-t-con has not deviated significantly from the settings seen in the raw data thus it hasn't done much more than reproduce the settings seen during experimentation.

A comparison of the results of the old settings and the two new data sets suggests that this experimental work has however significantly improved the Palletfast product and as this was the goal it can be assumed that the experiments were successful.

The recommendation to Filmpac will therefore be to use the settings in column 1 for all Palletfast products from now on as these produce the best product. Also the issues apparent with edge tears need to be remedied as they cause unnecessary problems in the market.

Further work to analyse the process for non-linearity and interactions between variables would be worthwhile to help improve the settings above and a central composite designed experiment would be most appropriate for this.

### 6.3 MACHINE C22, CHESTER HILL PLANT, SYDNEY (CASE STUDY)

In consultation with the technical department at AEP Filmpac, Chester Hill, Machine C22 was approached with a view to improving the output, gauge spread and optical properties of the Air Pack product. This was seen as worthwhile as the machine was likely to be heavily loaded with this product in the future, therefore any increased output achieved could directly increase sales of the product. The customer was interested in improving the optical properties of their product and a reduction in gauge spread would improve sealing and overall bag strength.

#### 6.3.1: APPROACH

The initial approach was to use a Plackett Burman screening experiment to analyse the machines settable variables for their relative effects on the responses (gauge spread, haze, gloss and output). In order to get an understanding of the machines capabilities initial trials were conducted to see what the maximum output was and where opportunities may lie for improvements.

The settable machine variables were then reviewed (a scale was developed for measuring Air Ring speed) and experiments designed using a Plackett Burman DoE methodology for eight factors. This methodology requires that 12 actual and 2 centre point experiments be undertaken to produce a total of 14 experiments. High and low values for each factor were chosen and entered into Minitab. The experimental runs are shown in table 9 below.

**Table 9: Plackett Burman screening experimental design for Machine C22.**

#### Machine 22 Experiments 27.7.00

RunOrder	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Cylinder 1	190	190	170	170	170	190	180	190	170	170	190	190	170	180
Cylinder 2	210	210	210	210	190	190	200	190	190	190	210	190	210	200
Cylinder 3	190	210	210	190	190	210	200	210	190	210	190	190	210	200
Cross Head	220	190	190	190	220	190	205	220	190	220	220	190	220	205
Die	200	240	240	200	240	200	220	200	200	240	240	240	200	220
Frost Line	200	350	200	350	350	200	275	350	200	200	200	350	350	275
Line Speed	8.5	8.5	8.5	12	8.5	12	10.25	8.5	8.5	12	12	12	12	10.25
Linear %	30	30	20	30	30	30	25	20	20	30	20	20	20	25

The Machine was set up to each of the above treatment combinations and given 30 minutes or so to stabilise. Co-variates such as Screw RPM, Air Ring Speed, Extruder

Amps and Average Gauge were collected. Samples were taken and Haze, Gloss and Gauge Spread measurements were taken and recorded.

Once collected the data was entered into Minitab and the factors analysed for their effect on each response. The results of this analysis are presented in appendix G.

### ***Gloss***

The main effects seen in the effect plot and the P values suggest that a high Frost line improves gloss, and that high Output and high Linear percentage reduce gloss. Extruder Rpm, Extruder Amps and Air Ring Speed also have strong effects on film gloss. This may be because a high frost line gives surface defects from the die, that would reduce gloss, time to relax and even out. High Output and Linear percentage increase friction at the die lips thus increasing the amount of surface defects.

### ***Haze***

The main effects and the P values suggest that a hot Cross Head increases haze, and that a hot die, high Output and high frost line reduce haze. Extruder Rpm and Extruder Amps also have strong effects on haze. Two types of Haze exist, internal and surface haze it is likely that increased output and a hot die reduce the internal haze because of a hotter melt temperature. A high frost line would normally be expected to increase internal haze as the molecules have longer to crystallise and form light deflecting lamellae, however it is likely that the higher frost line reduces surface defects that increase the surface haze more than the opposing internal haze.

### ***Gauge Spread***

The P values suggest that no factors are significant at the 95% level though air ring is at 90%. However one can see small effects in the effects plot and these were used in the design of optimal settings for the machine. Issues encountered with the air ring during experimentation are a likely cause of the problems with this analysis.

## 6.3.2: REGRESSION ANALYSIS

A regression analysis can be used to help predict the results of a set of proposed settings on each of the responses. The analysis of this is presented in appendix G

The regression analysis suggests very good models for Haze and Gloss but not such a

good one for Gauge Spread. Some problems were encountered with the air ring on the machine during the experimentation and this is likely to be the cause of the poor results for Gauge Spread. These regression models can be used for predicting the level of each of the responses based on the settings used on the machine. However it is unlikely that they will be particularly accurate as the above analysis shows large a standard deviation for the constant term and for many of the factors.

New settings were developed for the machine through an analysis of the effects plots drawn in the Plackett Burman analysis. All variables with a positive effect on the targets were set high, all with a negative effect were set low. Some factors affected one factor positively and another negatively, in these cases it was either set to the middle or a compromise was made to maximise the most desirable target. This approach developed the settings in the column headed "New".

Protcon was also used to analyse the data and develop optimal settings these results are headed "Protcon" in table 10.

### 6.3.3: RESULTS

**Table 10: Comparison of the Old, New, Pro-t-con and Run 13 settings and results**

	OLD	NEW	Protcon	13
Product	TD210	TD210	TD210	TD210
Gauge	70	70	70	70
Colour	NAT	NAT	NAT	NAT
Film Width	200	200	200	200
Die Size	50	50	50	50
Bubble size	200	200	200	200
Output	13.9	18.5	18.5	18.5
Cylinder #1	180	170	170	170
Cylinder #2	200	190	209.94	210
Cylinder #3	200	210	210	210
Cross Head	180	190	220	220
Rotator	180	190	180	180
Die	190	240	200.18	200
Extruder RPM	32	40	39.4	39.4
Extruder Amps	29-31	35-36	34	34
<b>Line Speed</b>	<b>9</b>	<b>12</b>	<b>12.001</b>	<b>12</b>
Frost Line Height	250	350	350	350
Linear %	25.0	25.0	20.0	20.0
Air Ring	60.00	75.00	76.00	76.00
<b>PREDICTIONS</b>	<b>Regress</b>	<b>Regress</b>	<b>Protcon</b>	<b>Regress</b>
<b>Gloss</b>	<b>83.8</b>	<b>86.6</b>	<b>95.5</b>	<b>93.8</b>
<b>Haze</b>	<b>9.79</b>	<b>9.00</b>	<b>10.33</b>	<b>11.71</b>
<b>Gauge Spread</b>	<b>12</b>	<b>6</b>	<b>7</b>	<b>8</b>
<b>ACTUAL</b>				
<b>Gloss</b>	<b>93.1</b>	<b>92.8</b>		<b>95.4</b>
<b>Haze</b>	<b>10.36</b>	<b>11.30</b>		<b>10.34</b>
<b>Gauge Spread</b>	<b>10</b>	<b>8</b>		<b>7</b>

Table 10 shows that a 40% improvement in output was achieved through this work. Also using the regression analysis performed previously, predictions of the Gloss, Haze and Gauge Spread results were calculated for each set of running conditions. The results of this work are also included in table 10 and predict improvements in each of these product characteristics. However checks on the above results were not possible before leaving Sydney and consequently the technical department was left to do these when the opportunity arose.

Unfortunately when this opportunity did arise it was only possible for them to test the new settings, thus the results shown under New, Actual are the results of their test trial. Also because of recently occurring cooling limitations with the machine it was only possible to run the extruder at 38 RPM rather than the desired 40 RPM. These actual results are not as encouraging as might have been hoped and do not agree very well with the regression predictions, especially in terms of Haze. This is likely to be because of interactions in the process that were not analysed for in the Plackett Burman experiment (Plackett Burman's are generally for screening for single factors only) and because of the large standard deviation on most of the regression coefficients.

Pro-t-con's settings were not tested on the process, however again there is a situation where a run from the raw data (run 13) shows almost exactly the same settings as Pro-t-con, it can thus be assumed that the results will be very similar. Again the regression results don't predict the responses very well. However these settings seem to have produced good film, so the recommendation would be to test these settings on the process again and attempt to iteratively improve them with the knowledge gained about the process. The work could be extended to a full factorial designed experiment in order to analyse the most important machine variables for the interactions between them. This would help to improve the quality of the optimal solution further.

## 6.4 OTHER EXPERIMENTAL DATA SETS

### 6.4.1: SHRINK FILM OPTIMISATION

Experiments were done with shrink film on machine 4 at Filmpac Auckland to optimise it for output, thickness and shrink properties.

**Table 11: Targets, Pro-t-con's predictions, data set 6 and data set 20**

	Targets	Pro-t-con Prediction	Dataset 6	Dataset 20
Output	190	177.814	177.6	192.6
Port lines	1	1.995	2	2
Shrink MD	74	69.9	70	68
Shrink TD	0	0.081	0	4
Thickness	45	51.344	50.85	44.73
Std Deviation	2	2.308	2.27	1.52

Pro-t-con's prediction is not close to the desired targets however it is very similar to the results of dataset 6. Also the settings developed by Pro-t-con were almost exactly the same as those of data set 6 except for small changes to 2 minor variables, the winding and calendar tensions. Another data set (20) exists that is closer to the desired targets than either 6 or Pro-t-con's prediction and this differs significantly from Pro-t-con's settings.

In this case it seems that Pro-t-con would have misled the user into believing that their targets could not be met whereas in fact they could have been approximated with a single data set. Pro-t-con has failed in its analysis again, however by adjusting tolerances and priorities in Pro-t-con it is likely that the targets would have been more closely met as data set 20 may have been chosen instead of 6 as the starting point.

It might have been worthwhile to try the settings Pro-t-con developed back on the machine again, however they differ so slightly from the settings used in data set 6 that it

can be assumed that they will produce the same results.

#### 6.4.2: DATA SETS FROM GLENVERN ASSOCIATES

Glenvern Associates (experts at using Pro-t-con) were asked to provide data sets that showed Pro-t-con making trade-offs between more than one target result. An analysis of these is presented below.

##### *Co-ex Blow Moulding:*

**Table 12: Comparison of Targets and Pro-t-con's predicted results.**

	Target	Pro-t-con prediction
Cycle time act	15	15.859
Moulding wt	240	240.984
Neck height	18.1	17.709
Major bore D	33.9	33.62
Neck Ovality	0.1	0.172
Base Distortion	1	0.155
Spout fit	1	0.601

The settings developed by Pro-t-con produce results that are reasonably close to the targets and differ significantly from any of the data sets found in the raw data as none of the data sets came close to achieving all the targets at once. Pro-t-con suggests that the above results will be achieved with, among other settings, a "cycle set" value of 8.2. The following graph of "cycle time act" vs. "cycle set" was developed to see if this was possible.

Figure 49: The relationship between “cycle time act” and “cycle set”

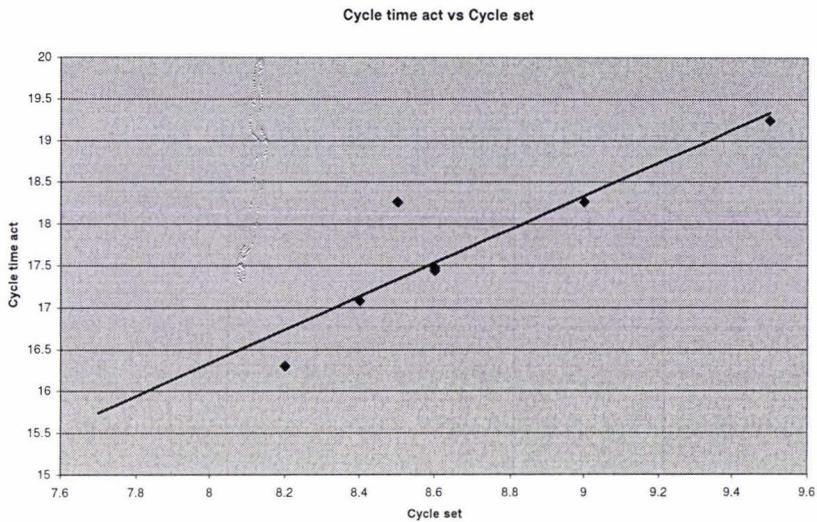


Figure 49 shows that the two variables are strongly related. In fact for each of the six times that a “cycle set” value of 8.2 was used the “cycle time act” was 16.3. Also for a “cycle set” of 9 a “cycle time act” of 18.26 can be expected and for a “cycle set” of 8.6 a “cycle time act” of 17.44 for the same reasons. In each of the cases where variables other than “cycle set” were changed there was no change in cycle time act. The Pro-t-con analysis suggests that with a “cycle set” of 8.2 and its combination of settings that “cycle time act” would be 15.859. Figure 49 suggests that in order to achieve a “cycle time act” of 15.859 one would need to set “cycle set” to around 7.8 and not 8.2. It is implausible that Pro-t-con should suggest that changes in other variables would have an effect on “cycle time act” when in the data they clearly have not.

Unfortunately the actual process was not available to test Pro-t-con’s settings on however a “cycle time act” of 16.3 would be expected from a “cycle set” of 8.2, regardless of any other settings i.e. not the 15.589 predicted by Pro-t-con.

### *Injection Moulding Sample*

In the injection moulding sample data set the following targets, Pro-t-con predictions and best guess results were observed.

**Table 13: Targets, Pro-t-con predictions and best run data**

	Target	Pro-t-con Prediction	Best Guess
Cycle Time	29	27.451	27.33
Weight	41.1	41.528	41.1
Width	99.2	99.116	99.09
Thickness	3.3	3.295	3.28
Voids	1	2.128	1

Although Pro-t-con has got reasonably close to the targets the best guess has produced results that compare very closely to those of Pro-t-con and also come close to the targets, in two cases closer than Pro-t-con. The best guess settings from the raw data are basically the same as those predicted by Pro-t-con and differ only by the set value of one factor "Back P1" which in the raw data was 2 but with Pro-t-con was set to 5.833. Range\*Ratio charts of the variable effects suggest that Back P1 has only a very minor effect on any of the targets.

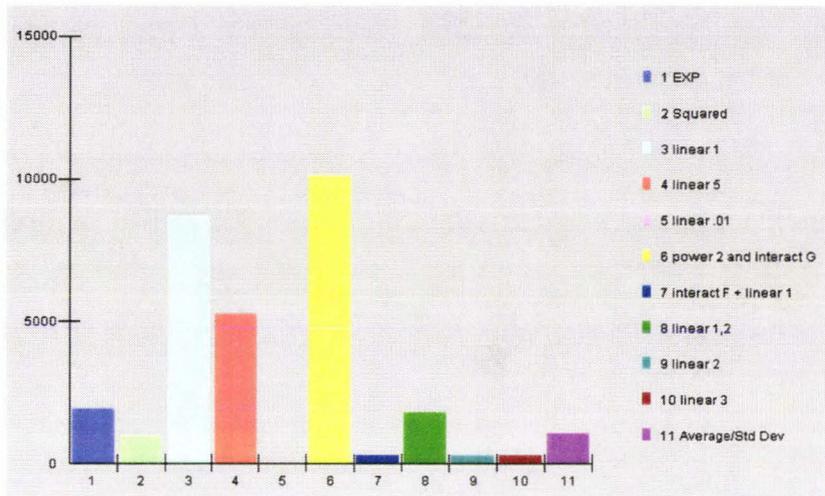
This suggests that in this case Pro-t-con has searched through the data until it found a run which closely predicted the targets and then adjusted only one minor factor to attempt to get closer to the desired targets. One could therefore have achieved very similar results could therefore have been achieved using a best guess approach i.e. without Pro-t-con.

## 6.5 CRITIQUE OF PRO-T-CON

### 6.5.1: CONCERNING OBSERVATIONS

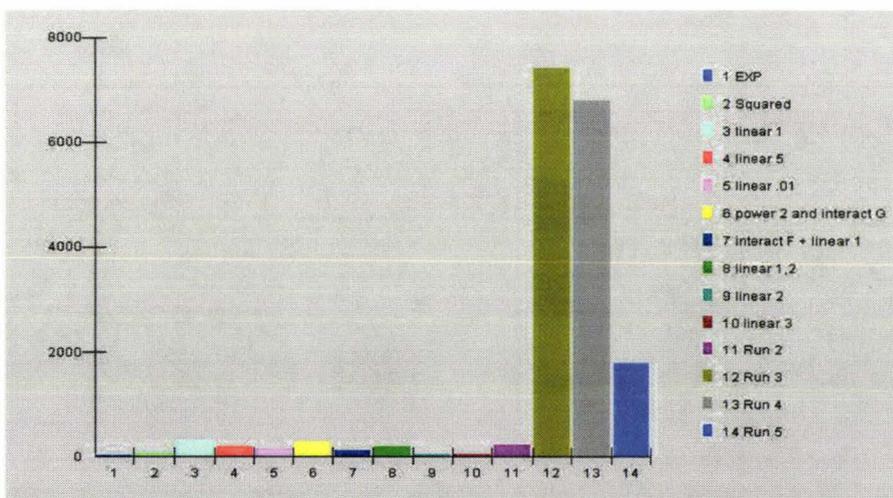
Figure 50 shows a graph of the effect of each factor on the results of the non-linear dummy process experiments and correctly shows the effect of each factor on the target “run 1”.

**Figure 50: Factor effects for the non linear dummy process with one response**



Pro-t-con also developed figure 51 from the same process data in this case however replicated runs 2,3,4, and 5 were included in the model. Again the graph shows the relative effect of each variable on the result “run 1” however in this case Pro-t-con believes the major influences on run 1 are not the variables that created it but the other results i.e. runs 2 to 5.

**Figure 51: Factor effects for the non linear dummy process with replicated responses**



One of the functions of Pro-t-con is that once a model is built it is possible to adjust control variables within the model to see what effect these have on the process. This was done with the two models built by Pro-t-con in the cases above. In the first case adjusting the factors 3,4 and 6 had as expected a significant effect on the result of run 1. However in the second model adjusting these variables had very little effect on the result of run 1. This is because in the second model the factors that Pro-t-con said have the most effect on run 1 are the other results. These results though highly correlated with run 1 are in fact completely independent of each other therefore Pro-t-con should treat them as such.

Often in real life scenarios results can be related to each other in this way. For example output and film strength are regarded as being related, as are film strength and film width. Therefore when attempting to optimise a process where two or more results are highly correlated, even if they are not targets of the optimisation, significant difficulties are likely. This must be considered a major weakness of the Pro-t-con software.

### ***Repeatability***

In the analysis described above experiments were done more than once in order to see what effect this had on the results. An analysis of these runs suggests that the order in which trials were undertaken affects the settings produced by Pro-t-con. One reason for this might be that Pro-t-con's algorithms look for the first column of data that comes within certain tolerances of the targets and uses this for the production of its optimal settings. Therefore the initial settings used by Pro-t-con could be different if the order of the columns was different. This seems a less than optimal way of approaching the optimisation process. The reason for the variation seen in the range\*ratio effect graphs is unknown.

### ***Dummy Variables***

In some situations it is necessary to use a dummy variable to suggest when an element is either for example in or out of a process e.g. if the die rotator is on then a 1 is entered into Pro-t-con if it is off then 0. Half on, half off or any scale in between 0 or 1 are obviously not possible. However when Pro-t-con handles this type of variable it will often suggest that it be set to an unachievable value such as 0.3 rather than 1 or 0.

### 6.5.2: PROBABLE PRO-T-CON OPTIMISATION ALGORITHM

From the prior analysis, discussions with the suppliers and testing Pro-t-con against other methods such as DoE and multiple regression, the following steps are proposed as the method by which Pro-t-con “optimises” a process.

- 1) Analyse the process data for the effects of each Controller, Derivative and Result on each Target using Multivariate Regression.
- 2) Search through the raw data to find a column that closely approximates the desired targets. Either the closest or the first one it finds within certain tolerances.
- 3) Use the factor settings of the data set found in 2 as the starting point for development of the “optimal” settings.
- 4) Adjust the factor settings from step 2 (within set pull % limits) using the information on their individual effects developed in step 1 to bring the process as close as possible to the targets.
- 5) Estimate/predict target results
- 6) Output adjusted factor settings and optimal results for the targets.

Although the six steps above were not verifiable through an explicit knowledge of the algorithms actually used by Pro-t-con (though many attempts were made to view these) the results achieved in the analysis above can be to some extent explained by this methodology.

### 6.5.3: ABILITY TO DO OPTIMISATIONS

From both the dummy and real process results it is clear that Pro-t-con is good at analysing the data to produce graphs of the main factor effects. However its ability to optimise must be questioned as in both the dummy and real processes the software was incapable of effectively achieving more than one target at a time.

The nature of an “optimal” solution suggests that a point where on either side of the solution the situation is slightly worse has been reached. A classic example is that of a parabolic relationship where on either side of the optimum, the value of the response is lower. It seems strange then for an optimisation tool to not be able to rationalise

non-linear factor/response relationships. This suggests that it is not optimising in the same sense of the word.

By choosing a complete data set from the raw data and adjusting the settable factors a unique “optimal” solution is not necessarily achieved. In fact it may be possible to achieve the same result with a different starting point and different settings. Also because the software limits the amount of variation allowed in each control variable the solution produced by Pro-t-con might not have achieved the desired targets. This however does not mean that the process itself could not reach the targets, just that the limitations imposed on the software have stopped it reaching the target. Consequently it cannot always be assumed that the process has been optimised as Pro-t-con may have stopped short of the target results.

Pro-t-con’s inability to analyse for interactions and curvature leaves it on dangerous territory when adjusting factors independently of each other as without a knowledge of these effects it may be inadvertently adjusting the process in a different way than intended. Because interactions and curvature are common in everyday processes this is a significant weakness in the Pro-t-con method. However the software has to some extent got around this issue by encouraging restriction to the amount Pro-t-con is able to move away from the closest data set, i.e. data it can be sure about, with the restricted pull %. In spite of this Pro-t-con was not able to predict results from either of the two dummy processes as well as the trial and error method. Such situations were observed in the analysis presented earlier in this section.

#### 6.5.4: HOW MUCH INFORMATION DOES PRO-t-CON GIVE?

From the previous results it was clear that Pro-t-con is relatively good at analysing the data to produce graphs of the factor/response relationships. This information is in itself very useful for the development of knowledge about the process.

As mentioned earlier Pro-t-con will not divulge information on the interactions between variables nor analyse for curvature in any of the variable/response relationships. It does however go one step further than other methodologies by developing settings that are designed to meet the desired targets. In spite of this functionality, the analysis above suggests that these settings are not reliable especially when curvature is present. In

many cases this is because it assumes linearity in a variables effect on the response between changes in that variable. Unfortunately Pro-t-con does not present statistics that give information on the accuracy of its settings. They do however suggest a confirmatory run to check that the settings work.

Because Pro-t-con experiments are evolutionary in their approach and do not stress randomisation of the runs, it is conceivable that problems such as non-homogeneity of variance and multi co-linearity may accompany the data. Pro-t-con presents no options for checking the raw data for these issues. Percentage variation is presented as a measure of the models quality however the method used for calculating this is not known. As this number often reaches 100%, its relevance must be questioned as it is uncommon to be able to explain all the variation in a process with an empirical model.

Basically Pro-t-con gives information about processes that compares to that of heavily fractionalised (resolution III) DoE experiments but without the statistics to verify its relevance or accuracy. Multiple regression results such as those produced by Minitab are also similar to Pro-t-con however with the presentation of the actual model terms and statistical tests on the importance of each factor the multiple regression technique gives more information.

#### 6.5.5: NUMBER OF EXPERIMENTS NECESSARY

A Pro-t-con experiment, it is said, must contain at least 30 runs or 1 more experiment than the number of variables. Though it is possible to replicate runs to produce the necessary number, the suppliers do not recommend this. There is no such restriction in a DoE experiment though rules do exist that determine how many experiments are necessary to achieve different levels of resolution for different numbers of variables, this was discussed in the literature review. For example a Plackett Burman screening experiment to analyse for single factor effects only (similar to Pro-t-con) takes 8, 12, 16, 20 etc. experiments to find out about 1 less factor than the number of variables (i.e. 7 factors for 8 experiments). Also multivariate regression with a package such as Minitab can be undertaken (including co-variates, AKA derivatives in Pro-t-con) as long as the number of trials done is greater than the number of variables.

In practice however when undertaking DoE experiments it is usual to attempt to reduce the number of variables and experiments so as to minimise the work. Pro-t-con suggests no such objective. In fact their emphasis is on making sure all possible variables are included in the model so as many as 500 trials may be necessary for a large process.

The evolutionary one factor at a time approach that Pro-t-con advocates has a serious weakness in terms of the number of experiments it requires to suitably analyse a process as it requires that each factor in the process be individually adjusted one at a time. This was discussed in the literature review. In practice however this was not the way Pro-t-con was done in the training sessions. The usual method was to focus on what were perceived to be the most important factors, adjusting them through a range of values, paying scant attention to the less important factors and iteratively working towards the targets.

#### 6.5.6: EASE OF USE.

Both the Pro-t-con methodology and software were found to be very easy to use and in comparison to what is required in the application of DoE, Taguchi or RSM methods it was exceptional. Pro-t-con's suppliers suggest that it can and is being used by able line operators in other plants and this to some extent illustrates just how easy it is. On the other hand methods such as DoE are generally only suitable for use by engineers, scientists and technicians as they require significant training in their application. Pro-t-con is usually taught in a 3 day part time session with a company nominee and this is enough time to undertake training in the method, an optimisation trial and results presentation to management. Pro-t-con was the most easily used experimental method used in this project.

DoE experiments tend to be more difficult to run than Pro-t-con experiments as they require significant discipline when setting control variables. If it is not possible to achieve all the settings necessary for one of the designed runs the models orthogonality and thus results will be affected. This in some cases makes DoE runs difficult to complete and often requires the process to be taken out of production for the purposes of the experiments. This can make it hard to plan and undertake such experiments as the loss in production can be seen to produce an element of risk. This issue with DoE was mentioned by authors in the literature review.

The Pro-t-con approach is not so disciplined or rigorous and is thus more easily implemented. A typical approach is to iteratively work towards an optimal solution by adjusting the machines variables along the way. It doesn't matter if the settings aimed for in an experiment can't be achieved as Pro-t-con can deal with this in its analysis. The risk of producing bad product or downtime when undertaking Pro-t-con experiments is therefore minimal and they are thus more easily agreed to and scheduled in to normal production.

#### 6.5.7: SUMMARY OF PRO-t-CONS CAPABILITIES

- 1) The Range\*Ratio plots generated by Pro-t-con compare well with similar effect plots generated using DoE and Multiple regression techniques.
- 2) Pro-t-con does not analyse for curvature or interactions between factors and the response.
- 3) The ability of Pro-t-con to develop the settings necessary to achieve a set of targets depends heavily upon finding a data set that comes close to those targets. Thus often the results produced do not differ significantly from an original data set.
- 4) Pro-t-con does not optimise processes and only operates within the processing window seen during experimentation.
- 5) Pro-t-con does not correctly predict results from processes with strong non-linear factors.
- 6) Pro-t-con predicts results from processes that contain all linear factors more accurately than processes with strong non-linear factors.
- 7) The order in which experiments are done affects the optimal settings produced by Pro-t-con.
- 8) Highly correlated results cause problems for the Pro-t-con analysis as they confound the effect of input factors.
- 9) Pro-t-con is very easy to use, as it doesn't require statistical knowledge for its application.

## 6.6 DISCUSSION

It is clear then that Pro-t-con is not the “better than DoE”, rigorous methodology, it was made out to be by its suppliers. However in terms of its ability to aid a company to improve its processes it is a useful tool for enabling work up to stage 6 of Barnes’ 8 stages of knowledge. Because of its ease of use and ability to develop range\*ratio graphs for the effect of each factor on the response it can help a company move towards an understanding of how important variables affect the response. So, for example, if better impact strength was desired it would be known that blow-up ratio and melt temperature were important but it wouldn’t be known how much to change them for the desired result. This level of knowledge allows much faster problem solving than if the important factors were unknown. Also because of Pro-t-con’s ease of use it is possible for to have a number of less skilled people helping with the experimentation and data analysis. This could enable the amount of data necessary to undertake the analysis on a number of processes to be gathered more quickly.

Design of Experiments methodologies enable more efficient experimentation than Pro-t-con by reducing the number of experiments necessary for a study and also include methods for analysis of single factor effects. As they also enable the informed inclusion or exclusion of factors and interactions. Knowledge of individual factor effects as well as an understanding of how each factor interacts with the others to affect the response can also be developed. A Pro-t-con approach does not allow this.

With heavily fractionalised DoE experiments single factor effects are inherently aliased with interaction effects, thus it is not possible to have confidence that these interaction effects aren’t causing a large part of the variation attributed to the single factors. It is therefore not possible to be sure from the effect plots that a certain change in a single factor will have the expected effect on the response. Likewise for Pro-t-con range\*ratio effect results, as these also ignore interactions. To upgrade this knowledge to include interactions (stage 7) requires significantly more experimentation and thus greater resource and time.

It is arguable that stage 6 knowledge, across most products in a plant such as Filmpac, is more useful than detailed stage 7 knowledge of exactly how much to change the factors by for 20 or 30% of products. Add to this the fact that processes often change over time, and the benefit of in depth studies on specific products may be quickly lost.

Consequently because methods such as Pro-t-con can be undertaken easily by employees with a modicum of ability it is likely that more Pro-t-con experiments will be done in a plant than DoE experiments. Because, to maintain orthogonality, DoE experiments are fixed in their set-up i.e. the exact designed experiments must be done, they are therefore arguably more difficult and more likely to produce bad product than Pro-t-con experiments. Because of this it is more likely that Pro-t-con experiments will actually be done in an industrial environment regardless of the fact that they are less rigorous or statistically sound.

Consequently in the environments of AEP Filmpac and related plants it is unlikely that the skilled persons able to undertake DoE experimentation will exist. Thus Pro-t-con, as it allows similar results to heavily fractionalised DoEs to be achieved, is a valuable tool to enable work towards stage 6 of the 8 stages of knowledge. In order to develop knowledge to stages 7 and 8, DoE, Taguchi, RSM or Shainin methods will be necessary, as will the skilled persons to undertake them. Unfortunately this is unlikely in most situations at Filmpac, however it is possible that DoE will be used for the most important products such as bread, form fill and seal, Butterwrap and other long running items.



## 7.0 - OVERALL DISCUSSION

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The Management of AEP Filmpac identified an urgent need to improve the manufacturing efficiency of their operation. A substantial investment in new equipment was made during 1997 and 1998. However despite restructuring the company to simplify aspects of the manufacturing operation, the potential of these new investments was not realised. A process optimisation software tool called PRO-t-CON was thus purchased with a view to applying it to each product on each manufacturing machine to identify optimal operating conditions.

The drive of this project was therefore to produce a system that enabled Filmpac to realise the potential of their machinery i.e. to exploit their processes.

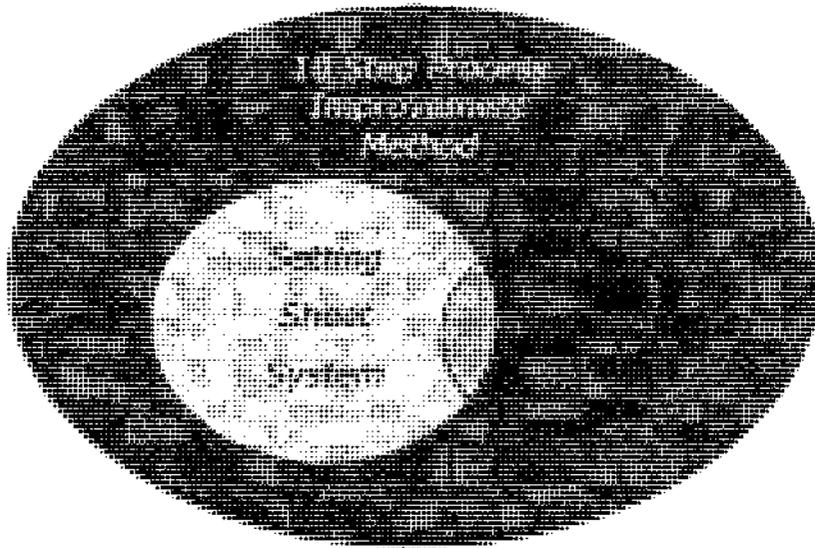
Whenever Pro-t-con's suppliers made contact with Filmpac they were always full of new anecdotes of how Pro-t-con had helped them optimise a number of processes at a variety of other plants. Their arguments were strong and their descriptions compelling. However when asked they were never able to give an objective analysis of the relative roles of the Pro-t-con software and experimentation/problem solving in the process of improvement. Because of the numerous successes both GS Technology and Glenvern Associates have had with the Pro-t-con software it is difficult to discredit the method altogether. However the analysis and results in Section 6 suggest a compelling argument against the ability of the Pro-t-con software to optimise processes as well as was suggested by its suppliers.

It must therefore be asked, how do GS Technology and Glenvern Associates achieve the results that they so proudly boast? The answer to this question lies in two places, the first is the fact that many companies have, for what ever reason, not previously concentrated on "optimising" their processes. Thus there is often significant capacity that could have been acquired through a variety of efforts to improve the process. The second is in their experimental methodology, both GS Technology and Glenvern utilise the most skilled operators in order to understand and make the changes necessary to improve the process. They record all the variables on the machine and iteratively work towards the

desired targets solving problems as they occur. By approaching the machine with an open, inquiring mind and asking the right questions they push the skilled operators outside of their previous comfort zones to achieve better results than previously experienced. It is then very easy to convince the management of such a plant that it was the Pro-t-con software that enabled them to achieve these results. And it is thus a small step to suggest that if the company wants to achieve such results across all their machines, they should purchase the software.

Although Pro-t-con did not perform as well as expected in terms of its ability to optimise processes, many businesses, Filmpac included, have a very real shortage of competent technical staff capable of undertaking other forms of experimental work such as Design of Experiments. Pro-t-con may therefore be a successful product because it removes the need for such strong technical skills. A product which gets most of the results of an involved DoE exercise, without the need for employing extra technical staff, is valuable in a manufacturing environment and is thus attractive to industry.

**Figure 52: Relative position of the sections of this project on the overall system of process improvement**



At Filmpac Sydney they had done very well to get standardised machine settings accepted on the floor, and this is an absolute prerequisite for the type of sustainable process improvement described in this project. The relative ease with which improvements were made to the performance of machine C22 suggests that there is still a reasonable

amount of “slack” left in their machines that could be taken up. There is a high probability that in doing this a significant increase in plant output will result. This was also the case at Filmpac Auckland and at Liquipac.

In terms of Filmpac Auckland’s quest for greater performance from their machines they are close to a full implementation of the setting sheet system. This is expected to produce a significant improvement in the stability of their processes in terms of output and quality variation. Without the success of this element, improvements to Filmpac’s processes are destined to be minor and transient. The work done on Machine 9 indicates that a significant improvement is possible if the setting sheet system is successful. Economically this could be worth in the order of a million dollars a year, providing the extra product that is manufactured can be sold. The gains could however be further reaching than this as with more consistent, faster machines better response times may result whilst product quality should become more stable, two factors that if poorly managed never fail to disappoint customers.

A major aim of this project was to develop a system for implementing Pro-t-con at Filmpac Auckland. So the question of where Pro-t-con fits in the above system must be answered. Pro-t-con, although shown to be poor at process optimisation, shall remain a useful tool for process improvement at Filmpac. This is due to two factors

- 1) Pro-t-con is good at analysing a process to establish its variable/response relationships.
- 2) Unlike other process experimentation methods that are discouragingly difficult to use, Pro-t-con’s simplicity encourages companies to undertake experiments.

Pro-t-con’s user friendliness encourages plants to “get out there” and undertake experiments and this in itself can be expected to encourage favourable results. The major benefits expected from future Pro-t-con optimisation studies are firstly a better understanding of a processes possible operating envelope and from this the development of better process settings. Secondly an understanding of the factors that most heavily affect the process and its target responses. These studies will be done under the guidance of the system administrator.

### 7.1.1: A SIDE NOTE

W. Edwards Demming and Joseph M Juran two of the most highly respected “quality Guru’s in the US, suggest that 85% of quality problems are the responsibility of management, leaving only 15% as the responsibility of line operators. Filmpac is no exception to this rule, though interestingly management would not agree. Unless the focus of future work at Filmpac is focused on improving quality through management’s ability to understand and reduce variation in the plant, thus developing systems to combat it, they will continue to struggle with high scrap and customer dissatisfaction.

Employing a consultant, such as the student involved in this project, is wasted effort unless the knowledge created is effectively transferred to the company. Filmpac understood this and the initial charter of the student was to be a facilitator within the company. He was therefore to hand over system administration soon after its development so that a suitable person from within the company could take over the role. However because of structural changes within the plant and an inability to decide upon a suitable person for the system administrator role, this step did not eventuate before the end of the project.

Throughout the project Filmpac’s inability to follow through on its commitments to the research side of the project produced much frustration and many times, the course of action agreed to by the student and management failed to eventuate. Suffice to say that had this not been an issue the setting sheet system would have been finished with enough time to have analysed its effect within this project. Unfortunately however this was not the case.

## 8.0 - CONCLUSIONS

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Management's excitement to discover that in fact they can run their machines significantly faster than they had previously thought possible seems to cloud their judgement as to what it was that caused this improvement. As the only thing different from normal production during Pro-t-con experimentation was the presence of the Pro-t-con sales man and the use of the Pro-t-con software it was easy for him to suggest that, with the purchase of the software and a bit of training, the company could achieve similar results by themselves. Management saw the increase in revenue possible through faster machines and quickly paid off the \$30000 price tag.

The 10-step method for process improvement described in Section 3 showed that it was useful for helping to undertake process improvement projects and through the use of this method significant improvements were made to a variety of processes. However the situation at Filmpac was weak in its ability to save and reuse information such as improved settings developed through experimentation.

It was shown in Section 4 that it is possible to make a significant improvement to the output of a machine in terms of its average run speed and the variation in this speed, simply by setting and policing a standard for operators to meet. The use of setting sheets is expected to achieve a similar result across all the machines at Filmpac. Although this step in the project was taken to enable cumulative process improvement to take place, it is likely to produce a significant improvement in itself. How much of an improvement will depend upon the work done by the people at Filmpac and the importance placed on it by management.

Pro-t-con was not convincing in its ability to optimise effectively and had significant weaknesses in its approach and analysis that would in the case of most scientific endeavours thrown it abruptly on the scrap heap. Its saving grace if you like is its ease of use and thus because of the equally weak ability of the company to provide the technical resource necessary to undertake more rigorous techniques for process improvement it

shall remain a useful method for process improvement at AEP Filmpac.

Reflection on the aims of this research suggests that definition of the necessary systems and procedures required to achieve a substantial and permanent improvement in the current machine operating conditions has taken place. This has thus allowed the development of a system for applying Pro-t-con process optimisation software to the AEP Filmpac plant. Likewise the demonstrated increase in plant output potential and reduction in the variation of machine output through the use of the above system suggests that it has been successful. The performance of the software and system has also been analysed in sections 4,5 and 6 and as such suggestions for the future development of both have been made. The achievement of these aims will help Filmpac to improve the output and quality consistency of all their products and thus gain a superior position in the very competitive flexible packaging industry.

## **8.1 FURTHER WORK**

### **8.1.1: FILMPAC**

The actions that need to be taken at Filmpac are

- 1) Fully implement and maintain the setting sheet system discussed in Section 4.
- 2) Continue optimising/continuously improving machines using the method detailed in Section 3.
- 3) Implement a statistical process control system for maintenance of machine speed product quality and scrap.

The expectation is that this will begin a new era of much needed quality and consistency at Filmpac

### 8.1.2. PRO-T-CON

It was clear from the analysis of Pro-t-con in Section 6 that both the method and software have some serious weaknesses. Suggestions for their development include

- 1) Involve design of experiment techniques such as Plackett Burman matrices to help reduce the number of experiments required to adequately test all factors in a Pro-t-con model.
- 2) Include the ability to design and analyse experiments for non-linear factors and interactions.
- 3) Include descriptive statistics such as Adjusted  $R^2$  for the model and P values for each factor.
- 4) Investigate the algorithms that develop the multiple regression model and optimal settings to find the reason for the different results seen through changes in the order of the data presented to the software.



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# APPENDICES

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# PRO-CON

for Microsoft Windows9.5/NT

## Revolutionary Application to Gain Control and Improve Quality of Industrial Manufacturing Processes

GS Technology introduces Pro-t-con for Windows95/NT, a new generic software application that accepts measurements from an industrial manufacturing process and builds a mathematical model of that process in order to identify constraints, tolerances, strengths and weaknesses and predict optimal settings to maximise successful production

### ■ A Statistical Wizard

Pro-t-con automatically correlates targets for quality of parts with process parameters and determines how each parameter influences these targets. When the relationship is established between selected targets for specification and quality of parts and the parameters of process performance, the Pro-t-con model shows how to set up the process in order to achieve the best possible target results. The system is a statistical wizard which can produce optimal results with up to 500 process variables.

### ■ Industrial Process Modeling

Until now, most statistical modeling packages for processes produce a hypothetical model of the process. They ignore the real effects of fluctuations in process variables, the resulting variance in product quality and the inherent design characteristics of the process itself. Typically, most packages expect users to have a high-level of knowledge and understanding of statistics in order to create models and interpret results.

Pro-t-con overcomes these limitations. Applying powerful statistical theory in a desktop computer application, Pro-t-con accepts data collected from an industrial process and targets for quality of products to predict optimal settings for process variables. Pro-t-con relies on measurements from your process and targets for the quality of products produced to give you maximal process control.

### ■ Pro-t-con exploits Windows95/NT

Pro-t-con exploits Microsoft Windows95/NT 32-bit operating environment on personal computers to simplify the creation and analysis of a process model. Pro-t-con is easy to learn and easy to use. It has full context-sensitive on-line Help. It

provides simple tables for entry of data and display of results. It lets you print to any printer for which there is a device driver installed. In short, Pro-t-con lets you concentrate on solving the problem of achieving total control of your industrial process. You focus on process variables and problem definitions rather than on statistics of modeling software. And Windows95/NT makes your work straightforward.

### ■ Total Quality Control

Industrial process production will rarely be consistent unless key process variables such as time, pressure, speed, temperature, etc are identified and controlled. The task of determining optimal settings for such variables forms a critical part of any strategy for improving quality. Pro-t-con determines optimal settings and eliminates the causes of variation. It lets you achieve greater consistency and stability of production through continuous monitoring and prediction. It helps you to meet the stringent requirements for high-quality products that your customers demand and reduce losses from production of poor-quality or defective parts and waste.

### ■ Wide Range of Applications

Pro-t-con is a generic application for improving the quality of any industrial manufacturing process, including injection molding, blow molding, extrusion, blown film, rubber chemicals and food. Most industrial processes can be improved significantly by analysis using Pro-t-con because it reveals how to optimise the performance of existing process equipment and maximise throughput and minimise waste.

*Pro-t-con maximises process performance by showing you how to optimise the performance of existing process equipment.*

# Powerful Statistical Analysis

## Define your process ...

### 1. Identify process variables

Identify variables that may have an effect on the process outcome. Pro-t-con can accommodate up to 500 process variables.

### 2. Classify process variable types

- CONtrollers** - adjustable process variables (i.e. screw speed, temperature)
- DERivatives** - dynamic variables present when process runs (i.e. melt temperature, cycle time)
- RESultants** - process outputs (i.e. dimensions, weights)

### 3. Define Target Variables

Targets are variables that you want to control for optimum product quality (ie key dimensions and attributes of a finished product). An unlimited number of target variables can be selected (Screen 1).

### 4. Enter data for each variable

Enter a minimum of 30 samples from an actual production run in order to provide a sufficient statistical measure of variance. Pro-t-con for Windows 95/NT makes data entry easy with comprehensive facilities for viewing, editing, scrolling, printing, etc. Data can be imported readily from automatic data collection systems

### 5. Click the Summation Icon

When you point and click with the mouse on

the summation button/icon, Pro-t-con automatically builds a mathematical model that performs according to the unique desirable and undesirable characteristics of your process. Pro-t-con software then displays a Target Specification, priority and Value Entry screen (Screen 2).

## Prioritise and assign target values

### 6. Assign priorities and desired values to critical target variables

At the Target Specification and Priority Screen, enter optimal values and priorities to the target variables. Multiple variables can have the same priority

### 7. Point and Click on the Summation Icon

Pro-t-con recalculates and applies weights to the model with respect to the information entered in Step 6. It then displays the required control setting information to achieve desired target values (Screen 3).

## Play "What-if" with the Pro-t-con Simulation ...

### 8. Change target variables, types, values and priorities in any combination

Pro-t-con recalculates and then immediately displays a new model prediction to reflect the new target variable information while it continues to perform mathematically like your real process (Screens 4, 5 and 6).

Variable	Ta	Type	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
17 COP	<input type="checkbox"/>	Con	95	95	95	95	95
18 WATEROUT	<input type="checkbox"/>	Der	14.95	15.15	15.05	15.25	14.95
19 OIL	<input type="checkbox"/>	Der	31.05	31.05	31.05	30.85	31.05
20 AMBIENT	<input type="checkbox"/>	Der	19.85	20.05	19.85	20.05	19.55
21 REARTEMP	<input type="checkbox"/>	Con	210	210	210	210	210
22 MIDDTEMP	<input type="checkbox"/>	Con	220	220	220	220	220
23 FRNTTEMP	<input type="checkbox"/>	Con	230	230	230	230	230
24 NOZZTEMP	<input type="checkbox"/>	Con	230	230	230	230	230
25 SCREWTEMP	<input type="checkbox"/>	Der	295	295	295	295	295
26 COOLTIME	<input type="checkbox"/>	Con	8	8	8	8	8
27 SHK	<input checked="" type="checkbox"/>	Res	1.07	1.07	1.04	1.04	1.04
28 DIAMA	<input checked="" type="checkbox"/>	Res	30.28	30.24	30.21	30.25	30.28
29 DIAMB	<input checked="" type="checkbox"/>	Res	31.56	31.5	31.58	31.52	31.56
30 WGHY	<input checked="" type="checkbox"/>	Res	3.71	3.71	3.71	3.71	3.71

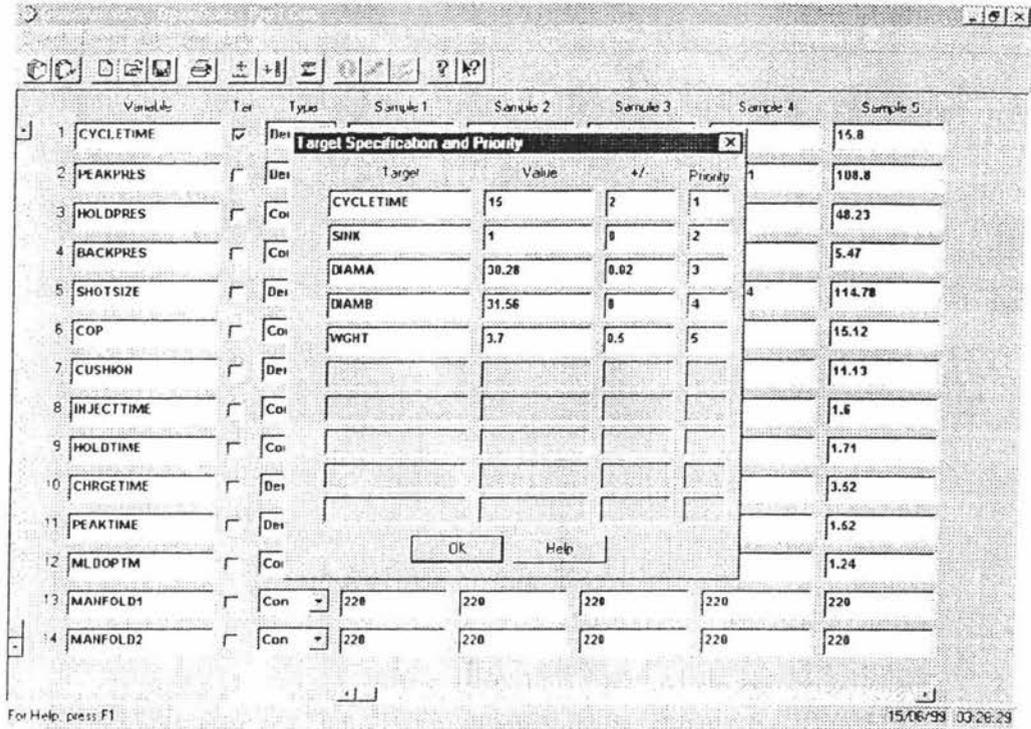
## Process Variable Entry/Classification and Target Selection Screen

Screen 1 records process variable information: variable name, target, designation, variable type and sample data.

# Easy to learn and use in Windows95/NT

## Target Variable Specification and Priority Screen

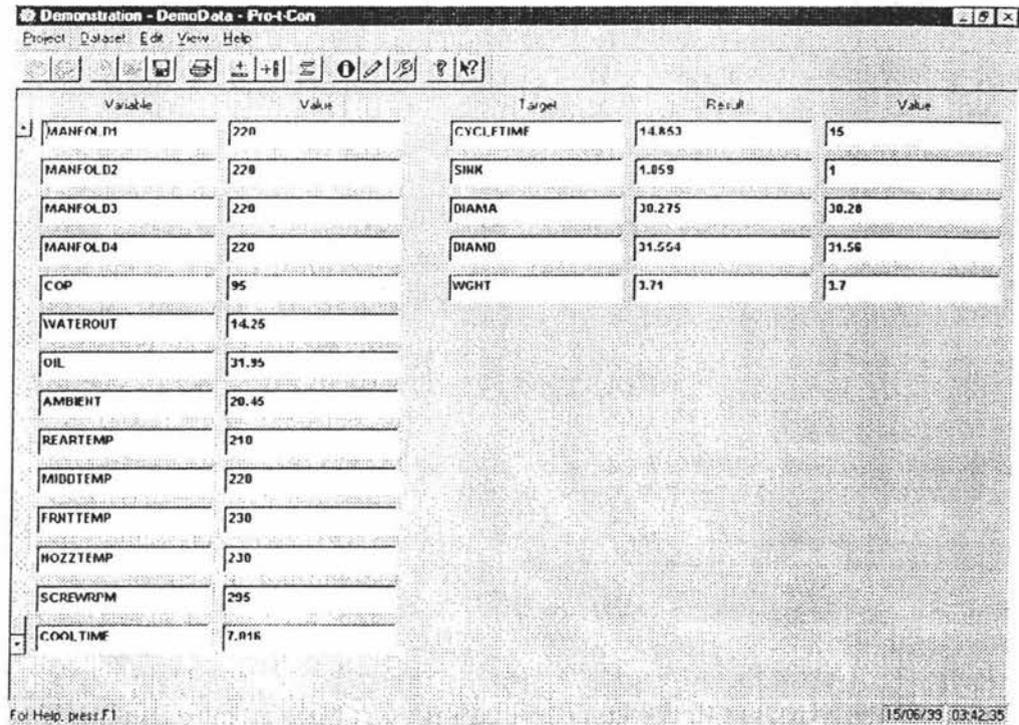
After initial model calculation, Pro-t-con prompts the user to assign optimal values and priorities to target variables. Pro-t-con uses this information to recalculate the model but "weighs" it with respect to this target information.



Screen 2

## Target Variable Result Screen

Screen 3 displays a Pro-t-con model that has been recalculated based on specific target values. The user is able to edit target values, specifications, priorities and recalculate until the model performs according to requirements.



Screen 3

# Solve Your Toughest Processing Problems with Pro-t-con Software

## ■ Easy access to powerful statistical analysis

Pro-t-con applies powerful statistical calculations to your process data. Defining the process problem, classifying the process variable types and entering the data is easy with Pro-t-con in Windows95/NT.

## ■ Meet stringent quality requirements

An analysis in Pro-t-con shows where critical process improvements should be made to meet ever-changing customer requirements. Since precise product specification and quality can be achieved consistently, it is possible to provide customers with the product they want at the price they want.

## ■ Easy to learn and use

Pro-t-con delivers the benefits of complex design of experimental studies with just a fraction of the time and effort required. Detailed knowledge of statistical techniques and analysis is not required.

## ■ Improved process performance

- Reduce process set up and down time with tighter control of your process.
- Reduce scrap by identifying problems earlier in the process.
- Reduce operator error by providing accurate process information.

## ■ Applicable to any continuous manufacturing process

The Pro-t-con analysis is applicable to any reproducible manufacturing procedure. The plastics industry was among the first to benefit from computer modelling. Pro-t-con brings the power of this analysis to any continuous manufacturing process.

## ■ Real-World Data

Because Pro-t-con uses actual data from your process that includes natural variation, there is no need to stop actual production or scrap large amounts of product during data acquisition

## ■ End Result of a Pro-t-con study

Pro-t-con will produce the best settings for continual process success. Hard Copy of this manufacturing setting information is available as a report for machinery operators and technical support staff.

## ■ Pro-t-con gives Total Process Control

Pro-t-con helps you achieve Total Process Control by managing process variation

## ■ Pro-t-con in Windows95/NT

Pro-t-con benefits from using the popular Windows95/NT operating environment and graphical user interface on desktop or laptop computers.

## ■ Enter and edit data in tables

All values are entered into tables in Windows95/NT and can be edited at any time to meet requirements.

## ■ Import and Export Data with ease

Pro-t-con lets you import and export data in tabular formats for use in spreadsheets, databases, reports and other applications.

# Getting Pro-t-con in your plant

## Implementation and training

A site license for Pro-t-con includes installation, training and technical support.

Training involves an introduction to Pro-t-con software, a demonstration and study of results, typically using data from one of your processes.

Your technicians and operators will be shown how to apply Pro-t-con themselves. They will learn how to find the specific settings to enable them to achieve precise product results in the minimum time on a consistent basis.

Once the initial training is completed, G S Technology will provide continuing support and maintenance including software updates and application consultation:

The practical exercise will include the following:

### Statement of the problem

Definition of the objectives (improve product quality, reduce cycle time, reduce scrap, etc.)

Determine variables - product and process parameters

Plan of data collection

### Collection of data

Material data

Process data

Process data (including quality attributes, etc.)

### Application of predicted results

The settings determined from the analysis will be applied to the process

The process will be optimised.

## Consultancy service

GS Technology offers a service on a consultancy basis.

A trained Pro-t-con technician will work with your own team to assist them to improve a particular process, or eliminate a problem.

The team will determine the objectives of the exercise, process improvements, etc., and the data collection and analysis will be undertaken at your site.

The process will then be set up using the information from the analysis and the results predicted by the system will be achieved in practice.

Represented by



GLENVERN ASSOCIATES PTY. LTD.  
A.C.N. 078 946 979

P.O. Box 250  
Kangaroo Ground  
Victoria, 3097

Telephone: (03) 9712 0700  
Mobile: 0418 992 531  
Facsimile: (03) 9712 0433  
Email: [mrpoulton@bigpond.com](mailto:mrpoulton@bigpond.com)

## Minimum System Requirements

Processor	Intel 80486 or better
RAM	16 MB
Monitor	SVGA
Operating System	Microsoft Windows95/NT

**PRO-t-con**  
for Microsoft Windows9.55/NT

# GS Technology

77 Bachelor Lane, Horsforth, Leeds LS18 5NF

Tel: (01279) 436970 Fax: (01279) 422150

Technical enquiries: (01132) 591485

E-mail: [barrie@gstuk.demon.co.uk](mailto:barrie@gstuk.demon.co.uk)



Developed by



Represented by



GLENVERN ASSOCIATES PTY. LTD.

A.C.N. 078 946 978

Email: mrpoulton@bigpond.com, Ph: 61 3 9712 0700

PRO-t-CON is applicable to any continuous process as "every process is only a combination of process variables influencing a combination of product variables". Providing you can measure variables, it is possible to establish the relationship between them and optimise the process with the UNIQUE PRO-t-CON technique.

The optimisation technique develops a real-life model of what is happening in the process

- PRO-t-CON identifies optimal equipment/process settings
- It eliminates conjectures/arguments about the process
  - Removes BLACK ART
- PRO-t-CON allows key resource focus on real issues rather than fire-fighting
- It has business wide application capability
- Enhances standard procedures and disciplines

Business wide application capability:

- Machine Processes
- Whole Process System or Plant
- Troubleshooting
- Material Substitutions
- Product Development
- Special Applications
  - Logistics, Freight/ Transport
  - Working capital
  - P & L performance
  - Strategic business tool!

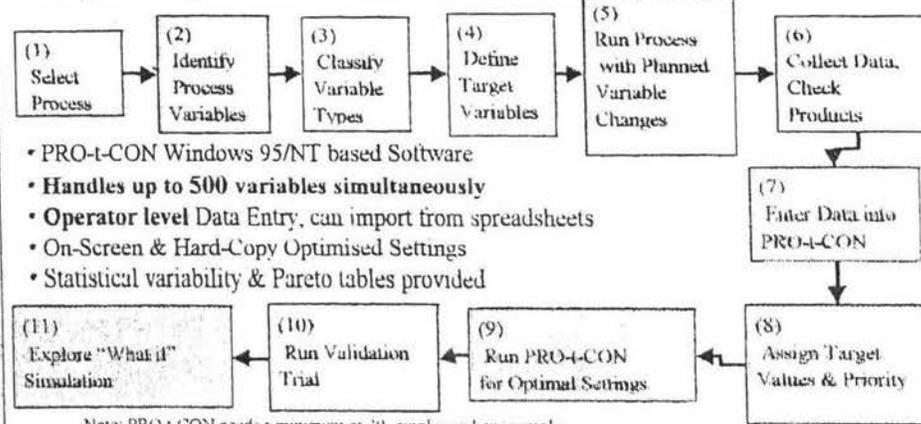
The technique was first developed by GS Technology, UK for industrial applications in 1989.

Has achieved a 100% success rate in process optimisation- applications typically:

Processes	Industries
Injection Moulding	Automotive Components
Thermoforming	Food Packaging
Film Extrusion	Industrial Packaging
Extrusion Laminating	Building Products
Polymer Compounding	Industrial Tools
Rubber Moulding	Polymer Production
Biscuit Manufacturing	Food Processing
Steel Processing	Metal Processing

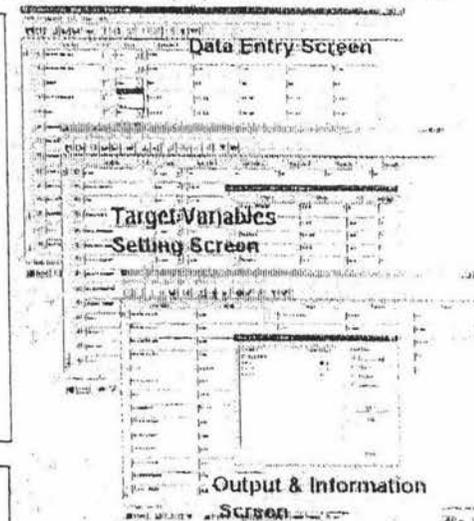
### The PRO-t-CON Technique

•Complex Analyses and Effective Solutions from Simple Steps:



- PRO-t-CON Windows 95/NT based Software
- Handles up to 500 variables simultaneously
- Operator level Data Entry, can import from spreadsheets
- On-Screen & Hard-Copy Optimised Settings
- Statistical variability & Pareto tables provided

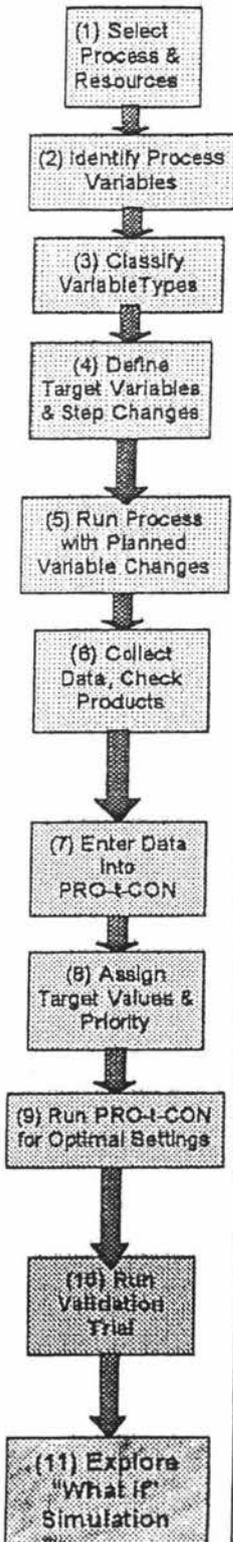
Note: PRO-t-CON needs a minimum of 30 samples and one sample more than the number of variables to operate.



Translates outcomes directly to the "bottom-line"

## Typical PRO-t-CON Study Plan

### • Day 1: Detail Pre-scoping Meeting:



Step	Objectives/Activities	Resource	Notes
1	Confirm Date and Process for Study	Production Manager Production Supervisor	
	Confirm Resource Needs & Names	Process & QC Technicians	
2	Identify Process Variables	Key M/C Operators	Define Initial Study Size
3	Classify Variable Type	Site PRO-t-CON Person	
4	Define Target Variable to develop Variable Step Changes for Study**	Site PRO-t-CON Person	Set targets & determines Sampling Scope
	Develop PRO-t-CON File- Process Specific	Site PRO-t-CON Person	

KEYNOTE: \*\* The design of the step changes is based around the normal operating range of the control settings (variables) that the Production Staff works with to improve output, quality and any of the target variables. The initial aim is to explore/ extend the operating envelope.

### • Day 2: Optimisation Study:

Step	Objectives/Activities	Resource	Notes
5	Run Process with Planned Step Changes- 2 or more steps up and down for Speed Changes, 1 or 2 step changes up and down for other variables. Changes should be made singly for key variables and then in any combination.	Production Supervisor Process Technician Key Operator	Ensure products are measurable. (Typical exercise 3-6 hours)
	6	Collect Process Data and Conditions	Site PRO-t-CON Person
6	Collect Finished Product Samples- 5 sets at standard conditions. (Typ. 3 sets at each change of conditions for Inj. Moulding 10 standard sets and 5 sets at each change for Blow Moulding)	One QC person (Trial period)	Number Samples and Cavity No. for Multiple Cavity Processes
	Measure Finished Products- All quality attributes using normal line gauges. Standard samples for visual assessment should be set-up for scores 1 (v.good), 3 (marginal, OK) and 5 (reject)	QC persons (Use same QC persons- especially for visual and subjective measurement)	Allow time for cooling & shrinkage as per specifications. QC Supervisor to audit measurements & attribute assessments.
7	Data entry into PRO-t-CON	Site PRO-t-CON Person	Determines Optimised Setting
8	Assign targets in PRO-t-CON		
9	Run analysis in PRO-t-CON		

### • Day 3: Validation Trial:

Step	Objectives/Activities	Resource	Notes
10	Run Process at Optimised Settings	Production Team	
	Check & confirm optimal running conditions	PRO-t-CON Person	
	Collect samples & check to confirm Quality Level	QC Persons	Initial Sample checks
	Monitor conditions over next ??no. of shifts	Production Team	Continue normal checks
	Sign-off for new operating Conditions		By Manuf. Manager
	Prepare Report	Site PRO-t-CON Person	

# Appendix D

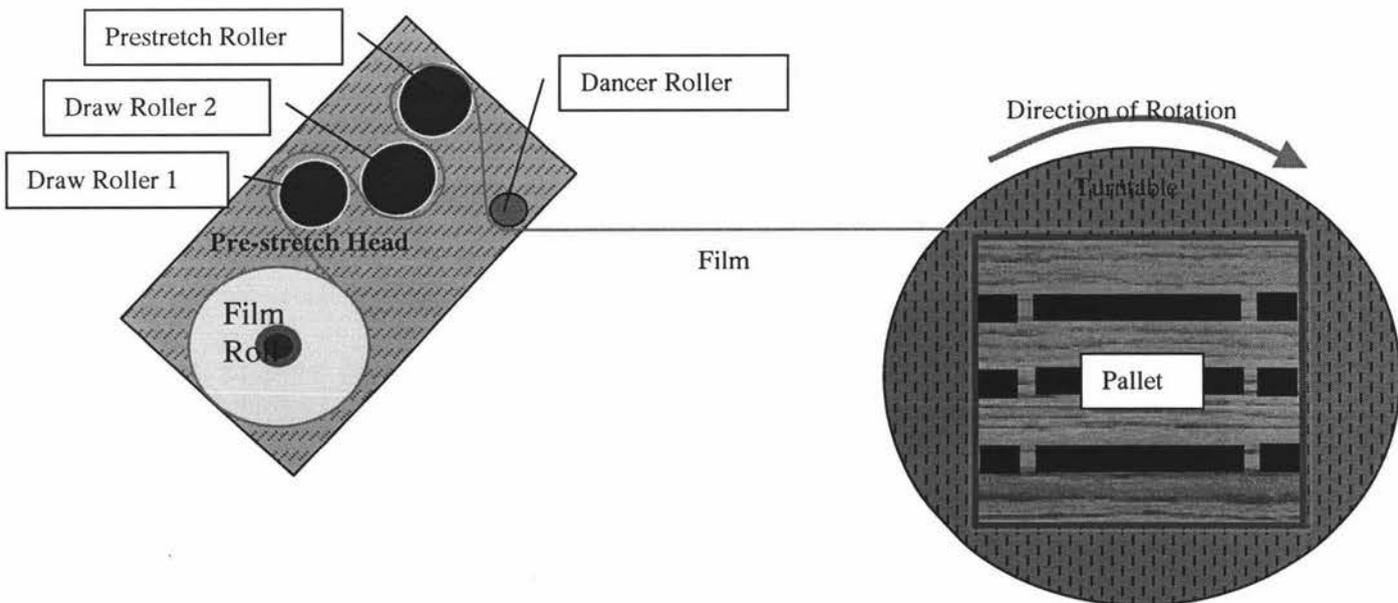
## Palletfast Stretch Cling Film Strength Measurement

### Test Rig Development

The need for the development of this methodology is illustrated in section X of the literature review. In order to design a test rig for Stretch Cling Film (SCF) testing it is necessary have an understanding of the equipment that exists in the market place so that this can be mimicked with the test rig. Consequently a number of visits to various plants that use Palletfast (AEP's brand of SCF.) were undertaken. The aim was to get an appreciation of the settings used by the operators of these machines and to investigate their set-up. This yielded the following results.

- 1) Operators with similar equipment use a wide variety of settings which they believe make the machine work best.
- 2) The pre-stretch ratio is set through fixed centre gear ratios within the machine and cannot be changed by the machine operator.
- 3) Operators can effect changes in “Force to Load” and the “Rotational Speed” of the load in order to tune their machine. A higher force to load gives a tighter pallet.

Figure 25: A Typical Stretch Wrapper



The film generally performs very well when in perfect condition however when SCF fails in the market it is usually between the pre-stretch head and the pallet, this can be due to any of the following reasons.

- Gels (weak points) don't stretch uniformly and cause point stress holes to appear in the film
- Poor film edges may have weak nicks that propagate a tear across the film when under tension.
- Sharp corners or protrusions on the pallet can puncture the film.
- Grit on the pre-stretch rollers can puncture the film.

A JMP pre-stretch head was available on the stretch-wrapping machine in dispatch at Filmpac. JMP pre-stretch heads are the industry standard in New Zealand and were found in many of the plants visited in the preliminary investigation. For the purposes of the present project this was serviced and set-up to "the way most people have it" i.e. a gear ratio of 2.6:1, this should give a pre-stretch of 160%

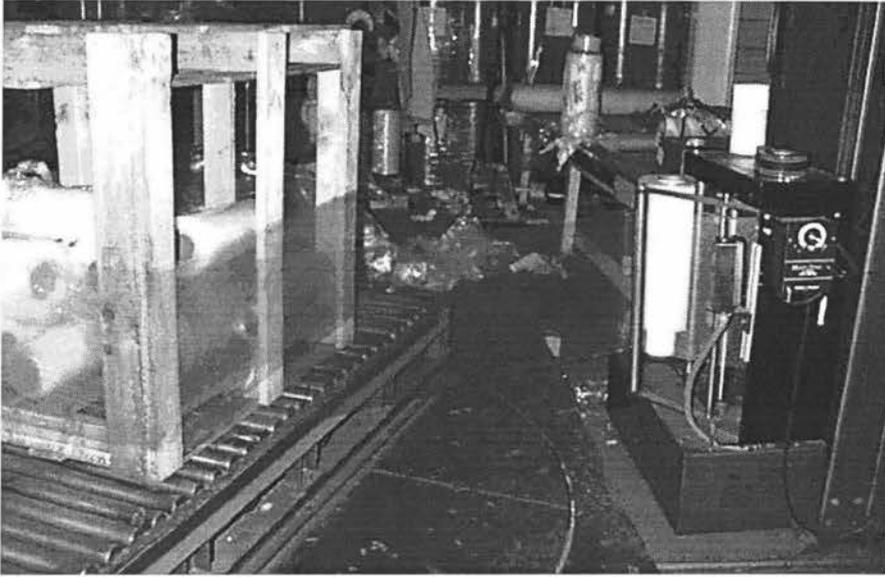
A test pallet was also designed. This was done through an investigation of the pallets used by important Palletfast customers. Dow Chemicals was also consulted as they analyse film in this way. They were of some help though would not provide full details of their testing methodology as this is an element of their competitive advantage.

### **Test Rig Specification**

The Pallet was

- 1 Designed to imitate the pallets found in the market place.
- 2 Made from two new pine pallets nailed together one meter apart to form an open box.
- 3 Square with sides of 1100mm
- 4) 1200mm tall to allow more than 2 widths of film up its height.
- 5) Heavy enough to resist movement from the force of the film.
- 6) Stiff enough to not twist with the force of the film.
- 7) Easily cleaned of old film.

**Figure 26 Flat Test for Film Strength**



Finally methodologies were developed to measure the performance of the film.

### ***Palletfast (SCF) Testing Methodology Development***

#### ***Method 1***

Method 1 utilises the concept behind an ASTM D1709-85, F/50 Impact Resistance Test although modified for the different application find the average failure point of the film.

Film is tested across the top edge of the pallet to discover its resistance to puncture on the pallet's corners.

- 1) Condition samples in the Filmpac warm room for 48 hours to allow migration of PIB to the film surface.
- 2) Position test pallet in the centre of the turntable.
- 3) Put roll on stretch wrapping machine (pre-stretch ratio = 2.6:1) thread film through the pre-stretch head so that film is sticky side in.
- 4) Attach film to a corner of the test rig
- 5) Bring pre-stretch head up to the marks near the top of the pallet so that the film is half on and half off the edge of the pallet.
- 6) Start turntable (10 RPM).
- 7) Find the force to load reading where the film first fails.

- 8) Reduce force to load by one increment (scale = 0.2).
- 9) Test the film for 2 full rotations of the turntable.
- 10) If film fails then reduce by one increment again. If it passes then increase by one increment. Record passes as an O and failures as an X.
- 11) Keep testing, incrementing up and down as the film passes or fails for as many tests as it takes to get 5 passes and 5 failures over the last 10 tests. I.e. 50% pass and fail.
- 12) Use the testing matrix to calculate  $A = \sum(n_i \times l)$  where  $n_i$  = the number of failures at each level and  $l$  = the level these failures occur at.
- 13) \* Calculate  $F/50 = L + 0.2(A/5) - 0.1$

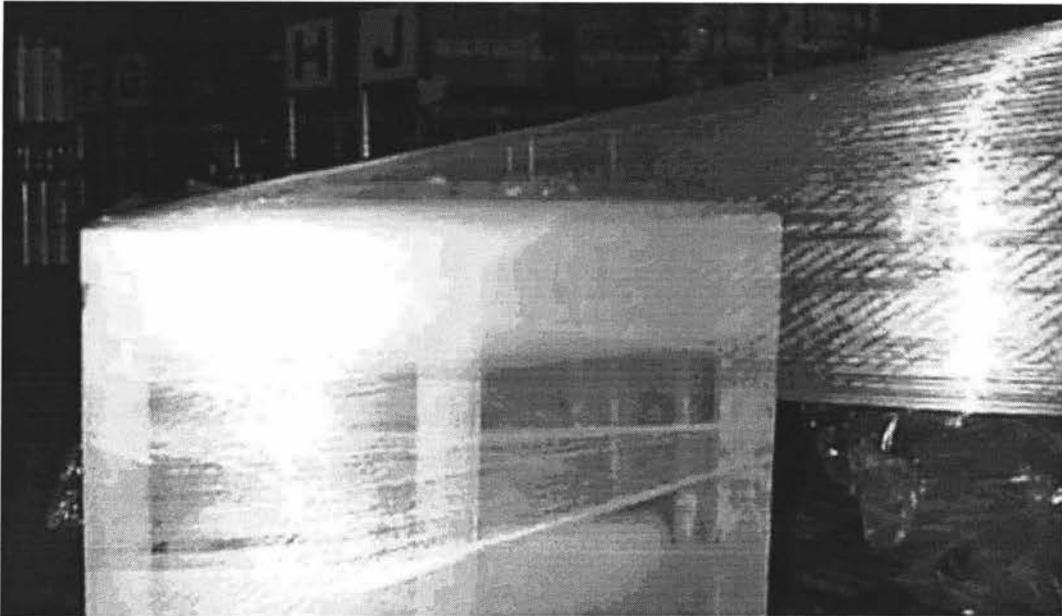
$F/50$  is the average maximum force to load of the film.

\* The general Formula for the  $F/50$  test is  $F/50 = L + [\Delta L(A/N - 0.5)]$  this can be simplified for our purposes where  $\Delta L$  and  $N$  are fixed at 0.2 and 5 respectively to be  $F/50 = L + (0.2 \cdot A/5) - 0.1$

There are no units for the results of Method 1 as the adjusted dimension is a simple machine dial with an arbitrary scale fabricated by the student for testing purposes.

Typical film performance ranged between 5.5 and 6.25.

**Figure 27: Corner Strength Test**



**Method 2**

The method described below is used to discover the films average failure rate when going around the pallet. A different method is necessary because the pre-stretch head cannot give enough force to load to break the film without a defect being present.

Steps 1-4 are as in Method 1 above.

- 5) Position the pre-stretch head in the centre of the pallet.
- 6) Start the turntable rotating and adjust the Force to Load slowly up to its maximum of 10.
- 7) Count the number of rotations of the turntable at max force to load, until the film breaks.
- 8) Repeat 3 times or until 20 revolutions are achieved without a break.
- 9) Break strength =  $\Sigma$  (number of rotations)/number of breaks

There was significant variation in the films ability in this test, some film samples making it though 20 wraps without fail, others unable to even make one.

One problem with this method came from the existence of edge tears in rolls of film. Being difficult to see before they go through the head and because of the speed at which a failure occurs it was hard to tell whether a tear was because of a poor edge or

a gel/film weakness. Inspection of the film before and after the break gave clues as to whether an edge tear was to blame, but was not conclusive. One way round this would be to video the film and replay each failure to check if it was an edge tear or not. The best way would be to get operators to regularly change the slitting blades thus minimising the number of tears altogether.

PRO-T-CON SETTING SHEET

MACHINE 9

ITEM CODE	1005194	REMEMBER TO HAND THIS SHEET IN TO YOUR SUPERVISOR		
DATE	31-1-2000			
TIME	4 PM			
OPERATOR	J. KANE			
	Settings	SET CONDITIONS	IMPROVEMENTS	IMPROVEMENTS
ZONE 1	161/160			
ZONE 2	183/170			
ZONE 3	180			
ZONE 4	180			
SCREEN BLOCK	193/195			
SCREEN CHANGER	28/30			
SCREEN ADAPTOR	195			
MELT TEMP	233/140			
MELT PRESS	309/100			
BLOCK ZONE	200			
INNER DIE	236/230			
LOWER DIE	230			
UPPER DIE	230			
P.I.B. OUTPUT Kg/hr	7.24			
ADDITIVE RPM	28.0			
EXTRUDER AMPS	15.8			
SCREW RPM	72			
HAUL OFF m/min	57.5			
FAN AIR Hz	37.0			
MASTERBATCH %	NIL			
OUTPUT Kg/hr	160.0			
P.I.B. %	4.0%			
SET GAUGE	15.8			
WEIGHBATCH WIDTH	1646			
ACTUAL WEB WIDTH	1640			
TRIM WIDTH (mm)	140			
FROST LINE HEIGHT	500			
AIRRING PRESSURE	7.0			
AIRRING TEMP	78			
FRONT WINDING TENSION	1.6			
BACK WINDING TENSION	1.6			
CALENDER TENSION	7.0			
EXACT MACHINE #	31/3			
EXACT ROTOR POT	7/10			
EXACT NIP POT				
TEMPERATURE	28			
HUMIDITY	60			
QUALITY CHARACTERISTICS				
EDGE CREASING *	2			
FACE CREASING *	2			
GEL FREQUENCY *	1			
MELT FRACTURE *	1			
PORT LINES *	1			
FILM CLARITY *	1			
FRONT ROLL QUALITY *	1			
BACK ROLL QUALITY *	1			
AVG GAUGE	13.49			
STD DEV (On-1)	0.0212			
MEASURED PIB%	3.25%			
COLOUR TEST	NIL			
SIGN OFF- ACCEPT/REJECT CHANGE				

# Appendix F

Table 4: Results of the Pro-t-con optimisations done on each of the six data sets.

Protcon Optimal Settings, Targets, Predictions and Results

	Model	4.1.1					Model	4.1.2				
EXP		4.782	3.382	2.782	1.295	3	4.804	3.381	2.809	1.324	3	
Squared		20	-10	20	-10	-10	17.683	3.526	20	-10	-10	
linear 1		206.196	182.944	147.392	205.712	80	216.597	178.228	150	205.381	80	
linear 5		162.54	217.513	133.601	191.563	180	167.579	237.446	140	194.479	180	
linear .01		20090	20014.181	20090	20011.656	20050	20090	20016.133	20090	20015.272	20050	
power 2 and interact G		59.162	81.463	59.212	11.044	10	59.382	81.119	59.605	11.042	10	
interact F + linear 1		48.766	15.454	59.559	100	20	49.446	13.606	61.041	100	20	
linear 1,2		56.624	240	10	839.868	833.562	10	240	10	789.352	893.508	
linear 2		6	8	1	25	25	1	19.326	16	25	8	
linear 3		9	8	1	22.413	25	9	2.776	1	15.868	25	
<b>Average</b>	<b>97.3</b>						<b>97.2</b>					
Targets		8000	10000	6000	4000	2000	8000	10000	6000	4000	2000	
Predictions		8140.01	9832.78	6907.11	3206.41	2164.35	8120.10	9980.88	6969.26	3247.04	2117.22	
<b>Actual</b>		<b>7417.67</b>	<b>10302.09</b>	<b>6439.69</b>	<b>4513.54</b>	<b>3120.66</b>	<b>7432.98</b>	<b>10200.68</b>	<b>6626.71</b>	<b>4452.45</b>	<b>3151.37</b>	
<b>Average/Std Dev</b>	<b>89.70</b>						<b>90.00</b>					
Targets		75	100	100	200	300	75	100	100	200	300	
Predictions		65.91	117.43	106.30	209.26	152.26	70.87	110.11	113.97	204.08	148.53	
<b>Actual</b>		<b>71.16</b>	<b>151.73</b>	<b>104.93</b>	<b>442.77</b>	<b>189.06</b>	<b>60.92</b>	<b>139.48</b>	<b>139.69</b>	<b>570.47</b>	<b>257.48</b>	
	Model	4.2.1					Model	4.2.2				
EXP		4.897	2.711	3.796	3.165	3	4.851	2.664	3.813	3.062	3	
Squared		-5.524	20	-4	8	0	-5.718	20	-4.135	8	0	
linear 1		170	60.788	10	339.397	100	170	45.018	15.486	344.281	100	
linear 5		30	114.256	532.133	236.191	200.975	30	102.719	547.456	190	40	
linear .01		20050	20010	20030	20090	20087.225	20090	20010	20030	20080	20010	
power 2 and interact G		70	80.47	40	10	20	67.203	82.773	40	10	20	
interact F + linear 1		48.146	58.508	61.852	5	5	45	78.587	32.825	15	25	
linear 1,2		270	688.005	260	30	260	270	220	260	30	260	
linear 2		6	10.365	16.762	17	14	13.137	25	1	25	25	
linear 3		6	9.692	12.772	17	14	8.336	25	14.521	25	25	
<b>Average</b>	<b>96.1</b>						<b>96.4</b>					
Targets		8000	10000	6000	4000	2000	8000	10000	6000	4000	2000	
Predictions		8020.27	9873.91	6004.87	4018.92	2393.04	7958.20	9072.37	5986.66	3936.85	1711.52	
<b>Actual</b>		<b>7600.31</b>	<b>9167.90</b>	<b>5084.57</b>	<b>5127.89</b>	<b>3011.12</b>	<b>7208.25</b>	<b>8937.35</b>	<b>5144.61</b>	<b>4996.06</b>	<b>2273.33</b>	
<b>Average/Std Dev</b>	<b>79.50</b>						<b>83.90</b>					
Targets		75	100	100	200	300	75	100	100	200	300	
Predictions		54.47	91.00	141.73	169.28	136.01	72.90	110.99	121.09	160.58	120.23	
<b>Actual</b>		<b>81.72</b>	<b>152.47</b>	<b>150.52</b>	<b>230.47</b>	<b>123.06</b>	<b>91.16</b>	<b>134.89</b>	<b>101.52</b>	<b>240.26</b>	<b>71.00</b>	
	Model	4.3.1					Model	4.3.2				
EXP		4.645	4.114	3.723	2.269	3	4.616	4.057	3.644	2.235	3	
Squared		-1.929	6.22	0.01	18.213	-4	-0.629	4.914	-0.026	16.176	-4	
linear 1		185.334	90	42.936	313.192	80	178.042	90	36.719	320.555	80	
linear 5		225.966	10	137.365	291.267	200.437	228.128	10	135.958	288.194	206.786	
linear .01		20020	20010	20050	20050	20090	20020	20010	20050	20090	20090	
power 2 and interact G		60	90	60	10	20	60	90	60	10	20	
interact F + linear 1		5	45.827	0	40	95	5	86.553	0	5	95	
linear 1,2		160.288	235.74	179.638	130	120	114.866	230	162.109	130	120	
linear 2		6	9.517	5	3	1	6	4.676	5	3	13	
linear 3		1	17	1	20	3	2	17	13	20	1	
<b>Average</b>	<b>94.4</b>						<b>94.8</b>					
Targets		8000	10000	6000	4000	2000	8000	10000	6000	4000	2000	
Predictions		7968.67	9928.89	5908.05	4036.65	2033.84	7909.16	10029.21	6207.01	4058.44	2230.57	
<b>Actual</b>		<b>7254.28</b>	<b>9809.19</b>	<b>5263.24</b>	<b>5514.36</b>	<b>2698.88</b>	<b>7107.09</b>	<b>9868.99</b>	<b>5219.37</b>	<b>5466.03</b>	<b>2752.61</b>	
<b>Average/Std Dev</b>	<b>83.60</b>						<b>84.20</b>					
Targets		75	100	100	200	300	75	100	100	200	300	
Predictions		115.48	102.73	120.32	153.35	126.99	114.20	97.01	120.46	160.17	126.52	
<b>Actual</b>		<b>95.21</b>	<b>134.07</b>	<b>96.38</b>	<b>199.62</b>	<b>117.10</b>	<b>95.31</b>	<b>111.62</b>	<b>90.26</b>	<b>178.96</b>	<b>91.52</b>	

**Table 5: Trial and Error settings and results for two runs, A and B**

**Goal Seeking**

	A	B	A	B	A	B	A	B	A	B
EXP (1 to 7)	5.00	4.00	4.00	4.00	4.00	4.10	2.20	1.00	1.00	1.00
Squared (-4 to 20)	375.97	139.24	64.53	69.00	61.98	96.02	20.85	5.12	5.07	5.29
linear 1 (10 to 900)	20.00	5.00	5.00	20.00	10.00	10.00	2.00	0.00	0.00	0.00
linear 5 (10 to 900)	438.04	35.24	26.70	409.42	102.55	109.51	8.05	0.40	0.39	0.44
linear .01 (20010 to 20020)	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
power 2 and interact G (10 to 100)	209.30	209.36	201.67	202.34	201.27	204.65	208.37	206.32	206.23	206.67
interact F + linear 1 (0 to 100)	140.00	280.00	245.00	170.00	300.00	285.00	600.00	600.00	280.00	200.00
linear 1,2 (10 to 900)	704.65	1404.68	1225.84	851.17	1500.63	1427.32	3004.19	3003.16	1403.11	1003.33
linear 2 (1 to 25)	20020.00	20020.00	20020.00	20020.00	20020.00	20020.00	20020.00	20020.00	20020.00	20090.00
linear 3 (1 to 25)	200.21	200.21	200.20	50.00	200.20	200.20	200.21	200.21	200.21	200.91
random for error generation	78.00	77.00	90.00	90.00	60.00	60.00	10.00	15.00	5.00	15.00
Target Average	7092.53	6926.37	9046.84	9065.67	6027.94	6102.62	234.90	410.57	91.34	1039.22
Target Average/Std Dev	10.00	10.00	10.00	10.00	40.00	40.00	10.00	10.00	10.00	50.00
Replicates	-851.73	-841.39	-906.57	-913.23	-2372.57	-2406.20	-106.61	-155.57	-49.11	-743.11
1	10.00	10.00	10.00	10.00	100.00	130.00	335.84	220.63	10.62	220.67
2	10.93	10.94	10.17	10.23	100.13	130.46	25.00	25.00	25.00	25.00
3	1.00	20.00	25.00	25.00	25.00	25.00	51.67	51.26	51.25	51.33
4	3.86	41.87	50.33	50.47	50.25	50.93	22.00	22.00	22.00	11.00
5	2.00	1.00	22.00	22.00	13.00	25.00	68.51	67.90	67.87	35.00
6	8.79	5.81	66.50	66.70	39.38	76.39				
7	0.93	0.94	0.17	0.23	0.13	0.46	0.84	0.63	0.62	0.67
8	8000	8000	10000	10000	6000	6000	4000	4000	2000	2000
9	75	75	100	100	100	100	200	200	300	300
10	8192.5	8132.3	9986.2	9861.8	5911.8	5991.9	4026.0	4010.0	1987.0	2019.8
1	7944.71	7918.838	10144.09	10088.03	5991.5037	5918.5032	3999.9483	3975.8364	2000.90	2004.02
2	7888.27	7901.3213	10156.29	9906.90	5920.6753	6010.2937	3987.4801	4012.4251	1975.88	1996.81
3	7906.54	8098.0685	10234.74	9863.12	6042.3887	5978.2668	4026.3962	3988.0898	1974.29	2002.20
4	8053.10	8140.193	10113.70	9880.23	5984.8704	5961.3531	3986.8347	4032.105	1995.20	2010.25
5	7787.22	7901.4921	9971.97	9993.30	6102.5033	6061.3946	4004.5797	4023.9797	1999.89	2016.31
6	7853.72	7897.3601	10160.34	9805.49	6065.0012	5926.9261	3986.476	4019.4003	2004.60	2013.67
7	7878.92	7879.3081	10058.18	9849.81	6075.9306	5894.0986	3981.7343	3982.5661	1990.99	2009.67
8	8119.41	8120.473	10050.98	10115.87	6017.4857	5929.9585	4024.0248	4031.0306	2006.23	2020.81
9	7839.25	8118.5182	10255.86	9937.17	5974.0031	6049.2958	3979.4831	3986.187	1981.61	2007.93
10	7937.94	7995.3782	10196.33	10044.63	5950.586	5904.1574	4027.3632	4015.5243	1992.80	1993.96
Average	7920.91	7997.10	10134.25	9948.45	6012.49	5963.42	4000.43	4006.71	1992.24	2007.56
Std dev	99.90	110.00	87.87	106.84	58.45	59.80	19.18	21.37	11.52	8.45
Av/SD	79.29	72.70	115.34	93.12	102.86	99.73	208.62	187.49	172.86	237.51

# Appendix G

## Plackett Burman Analysis

### Gloss

Estimated Effects and Coefficients for Gloss

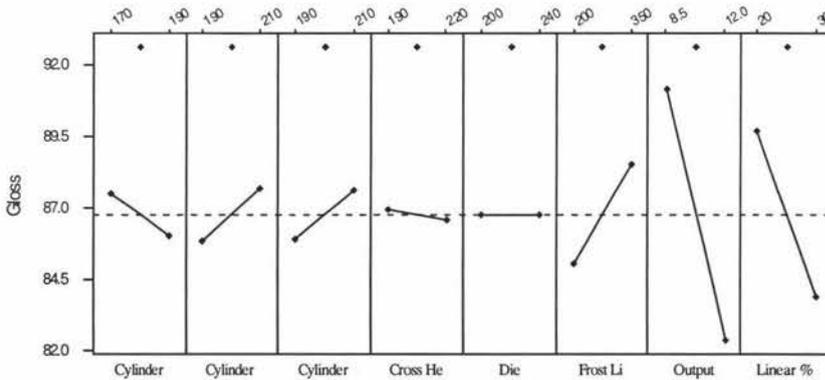
Term	Effect	Coef	StDev Coef	T	P
Constant		42.546	24.2815	1.75	0.222
RPM		-2.000	0.4027	-4.97	0.038
Extruder		1.934	0.5871	3.29	0.081
Air Ring		0.794	0.0519	15.29	0.004
Cylinder	2.163	1.082	0.5794	1.87	0.203
Cylinder	-0.052	-0.026	0.3038	-0.09	0.939
Cylinder	3.089	1.545	0.2183	7.08	0.019
Cross	2.072	1.036	0.4061	2.55	0.125
Die	0.528	0.264	0.3230	0.82	0.500
Frost	10.263	5.132	0.4414	11.63	0.007
Output	-4.077	-2.039	2.5237	-0.81	0.504
Linear	-2.359	-1.179	0.3146	-3.75	0.064

Analysis of Variance for Gloss

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Covariates	3	518.883	366.717	122.239	225.57	0.004
Main Effects	8	241.368	241.368	30.171	55.68	0.018
Residual Error	2	1.084	1.084	0.542		
Curvature	1	0.372	0.372	0.372	0.52	0.602
Lack of Fit	1	0.712	0.712	0.712		
Total	13	761.335				

• Centerpoint

### Main Effects for Gloss



### Haze

Estimated Effects and Coefficients for Haze

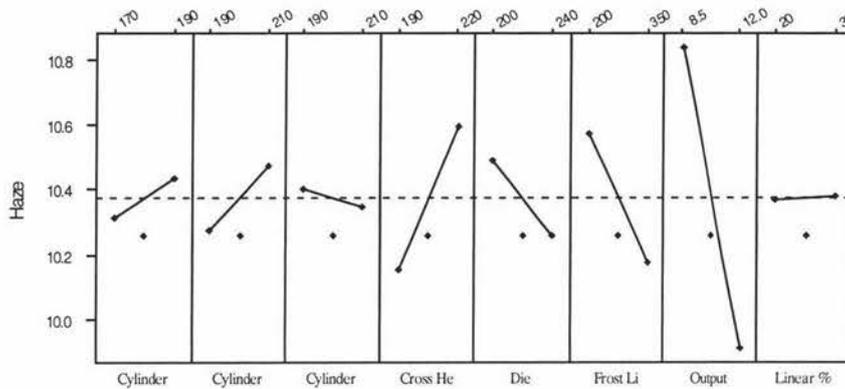
Term	Effect	Coef	StDev Coef	T	P
Constant		0.8695	1.48002	0.59	0.616
RPM		-0.1299	0.02455	-5.29	0.034
Extruder		0.4405	0.03578	12.31	0.007
Air Ring		-0.0013	0.00316	-0.41	0.720
Cylinder	0.9478	0.4739	0.03532	13.42	0.006
Cylinder	0.4322	0.2161	0.01852	11.67	0.007
Cylinder	0.0041	0.0021	0.01330	0.16	0.891
Cross	0.9088	0.4544	0.02475	18.36	0.003
Die	-0.2925	-0.1462	0.01969	-7.43	0.018
Frost	-0.1801	-0.0900	0.02690	-3.35	0.079

Output	-1.2412	-0.6206	0.15382	-4.03	0.056
Linear	-0.1632	-0.0816	0.01917	-4.25	0.051

Analysis of Variance for Haze

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Covariates	3	3.23020	0.63056	0.210188	104.40	0.010
Main Effects	8	1.39541	1.39541	0.174427	86.64	0.011
Residual Error	2	0.00403	0.00403	0.002013		
Curvature	1	0.00096	0.00096	0.000957	0.31	0.676
Lack of Fit	1	0.00307	0.00307	0.003070		
Total	13	4.62964				

• Centerpoint Main Effects for Haze



**Gauge Spread**

Estimated Effects and Coefficients for Gauge Spread

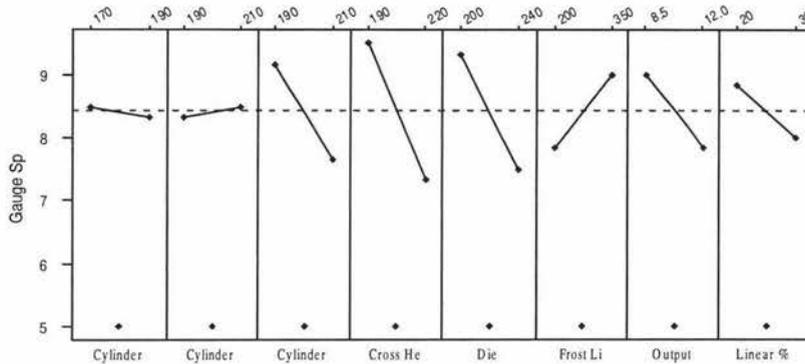
Term	Effect	Coef	StDev Coef	T	P
Constant		2.620	46.7885	0.06	0.960
RPM		-0.041	0.7760	-0.05	0.963
Extruder		0.879	1.1312	0.78	0.519
Air Ring		-0.318	0.1000	-3.18	0.086
Cylinder	1.502	0.751	1.1165	0.67	0.570
Cylinder	1.827	0.914	0.5855	1.56	0.259
Cylinder	-1.832	-0.916	0.4206	-2.18	0.161
Cross		-1.528	0.7826	-0.98	0.432
Die		-2.629	0.6224	-2.11	0.169
Frost		-1.057	0.8505	-0.62	0.598
Output		-0.556	4.8629	-0.06	0.960
Linear		-2.685	0.6061	-2.21	0.157

Analysis of Variance for Gauge Spread

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Covariates	3	15.0410	27.5711	9.19036	4.57	0.185
Main Effects	8	53.8634	53.8634	6.73293	3.35	0.250
Residual Error	2	4.0242	4.0242	2.01208		
Curvature	1	3.9991	3.9991	3.99907	159.41	0.050
Lack of Fit	1	0.0251	0.0251	0.02509		
Total	13	72.9286				

• Centerpoint

### Main Effects for Gauge Sp



## Regression Analysis

### Gloss

The regression equation is

$$\text{Gloss} = -25.3 + 0.108 \text{ Cylinder1} - 0.0026 \text{ Cylinder2} + 0.154 \text{ Cylinder3} + 0.0691 \text{ Cross Head} + 0.0132 \text{ Die} + 0.0684 \text{ Frost Line} - 1.16 \text{ Output} - 0.236 \text{ Linear \%} - 2.00 \text{ RPM} + 1.93 \text{ Extruder Amps} + 0.794 \text{ Air Ring}$$

Predictor	Coef	StDev	T	P
Constant	-25.33	31.95	-0.79	0.511
Cylinder	0.10816	0.05794	1.87	0.203
Cylinder	-0.00261	0.03038	-0.09	0.939
Cylinder	0.15447	0.02183	7.08	0.019
Cross He	0.06907	0.02707	2.55	0.125
Die	0.01319	0.01615	0.82	0.500
Frost Li	0.068423	0.005885	11.63	0.007
Output	-1.165	1.442	-0.81	0.504
Linear %	-0.23587	0.06291	-3.75	0.064
RPM	-2.0002	0.4027	-4.97	0.038
Extruder	1.9338	0.5871	3.29	0.081
Air Ring	0.79367	0.05191	15.29	0.004

S = 0.7361      R-Sq = 99.9%      R-Sq(adj) = 99.1%

### Analysis of Variance

Source	DF	SS	MS	F	P
Regression	11	760.251	69.114	127.54	0.008
Error	2	1.084	0.542		
Total	13	761.335			

### Haze

The regression equation is

$$\text{Haze} = -12.3 + 0.0474 \text{ Cylinder1} + 0.0216 \text{ Cylinder2} + 0.00021 \text{ Cylinder3} + 0.0303 \text{ Cross Head} - 0.00731 \text{ Die} - 0.00120 \text{ Frost Line} - 0.355 \text{ Output} - 0.0163 \text{ Linear \%} - 0.130 \text{ RPM} + 0.440 \text{ Extruder Amps} - 0.00130 \text{ Air Ring}$$

Predictor	Coef	StDev	T	P
Constant	-12.252	1.947	-6.29	0.024
Cylinder	0.047389	0.003532	13.42	0.006
Cylinder	0.021612	0.001852	11.67	0.007
Cylinder	0.000207	0.001330	0.16	0.891

Cross He	0.030292	0.001650	18.36	0.003
Die	-0.0073124	0.0009844	-7.43	0.018
Frost Li	-0.0012005	0.0003587	-3.35	0.079
Output	-0.35463	0.08790	-4.03	0.056
Linear %	-0.016316	0.003835	-4.25	0.051
RPM	-0.12989	0.02455	-5.29	0.034
Extruder	0.44049	0.03578	12.31	0.007
Air Ring	-0.001303	0.003164	-0.41	0.720

S = 0.04487      R-Sq = 99.9%      R-Sq(adj) = 99.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	11	4.62562	0.42051	208.87	0.005
Error	2	0.00403	0.00201		
Total	13	4.62964			

**Gauge Spread**

The regression equation is

$$\text{Gauge Spread} = 24.3 + 0.075 \text{ Cylinder1} + 0.0914 \text{ Cylinder2} - 0.0916 \text{ Cylinder3} - 0.0509 \text{ Cross Head} - 0.0657 \text{ Die} - 0.0070 \text{ Frost Line} - 0.16 \text{ Output} - 0.269 \text{ Linear \%} - 0.041 \text{ RPM} + 0.88 \text{ Extruder Amps} - 0.318 \text{ Air Ring}$$

Predictor	Coef	StDev	T	P
Constant	24.33	61.56	0.40	0.731
Cylinder	0.0751	0.1116	0.67	0.570
Cylinder	0.09136	0.05855	1.56	0.259
Cylinder	-0.09161	0.04206	-2.18	0.161
Cross He	-0.05093	0.05217	-0.98	0.432
Die	-0.06572	0.03112	-2.11	0.169
Frost Li	-0.00704	0.01134	-0.62	0.598
Output	-0.159	2.779	-0.06	0.960
Linear %	-0.2685	0.1212	-2.21	0.157
RPM	-0.0411	0.7760	-0.05	0.963
Extruder	0.879	1.131	0.78	0.519
Air Ring	-0.3177	0.1000	-3.18	0.086

S = 1.418      R-Sq = 94.5%      R-Sq(adj) = 64.1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	11	68.904	6.264	3.11	0.268
Error	2	4.024	2.012		
Total	13	72.929			

TABLE 2.1. THE FOUR STAGES OF QUALITY.

Area	STAGE 1 Innocence	STAGE 2 Awakening	STAGE 3 Commitment/ Implementation	STAGE 4 World Class
1. Management	<ul style="list-style-type: none"> <li>Quality, a necessary evil</li> <li>Problem detection/sorting</li> </ul>	<ul style="list-style-type: none"> <li>Quality, a cost</li> <li>Problem correction</li> </ul>	<ul style="list-style-type: none"> <li>Quality, an economic imperative</li> <li>Resources to prevention</li> </ul>	<ul style="list-style-type: none"> <li>Quality, a superordinate value</li> <li>Prevention—a way of life</li> </ul>
2. Organization	<ul style="list-style-type: none"> <li>Vertical Management</li> <li>QC—the policeman</li> </ul>	<ul style="list-style-type: none"> <li>Matrix Management</li> <li>QA has quality responsibility, but little authority</li> </ul>	<ul style="list-style-type: none"> <li>AD hoc problem-solving teams</li> <li>Quality responsibility deployed to line functions</li> </ul>	<ul style="list-style-type: none"> <li>Teams and focused factories</li> <li>All employees responsible for quality</li> </ul>
3. System/Measurement	<ul style="list-style-type: none"> <li>QC manuals</li> <li>No quality costs</li> </ul>	<ul style="list-style-type: none"> <li>QA policy/established</li> <li>Quality costs gathered</li> </ul>	<ul style="list-style-type: none"> <li>QA system established/implemented/audited</li> <li>Cost of poor quality reduced over 50%</li> </ul>	<ul style="list-style-type: none"> <li>Continuous, never-ending improvement</li> <li>Intangible quality costs attacked</li> </ul>
4. Tools	<ul style="list-style-type: none"> <li>Data pollution, little analysis</li> <li>No SPC</li> </ul>	<ul style="list-style-type: none"> <li>7 QC tools</li> <li>Elementary SPC—control charts</li> </ul>	<ul style="list-style-type: none"> <li>Design of experiments (DOE)</li> <li>SPC: positrol, precontrol</li> </ul>	<ul style="list-style-type: none"> <li>Design DOE</li> <li>QFD, MEOST</li> <li>Poka-Yoke, NOAC, TPM</li> </ul>
5. Customer	<ul style="list-style-type: none"> <li>Profit over customer satisfaction</li> <li>Selling vs. marketing</li> <li>Voice of the engineer dominates</li> </ul>	<ul style="list-style-type: none"> <li>Customer inputs sought</li> <li>Customer measurements started</li> </ul>	<ul style="list-style-type: none"> <li>Voice of the customer researched thru quality function deployment, conjoint analysis, etc.</li> </ul>	<ul style="list-style-type: none"> <li>Customer enthusiasm</li> <li>Next operation as “customer” pervades the organization</li> </ul>
6. Design	<ul style="list-style-type: none"> <li>“Toss over the wall” to production</li> <li>Concentration only on performance parameters</li> <li>Reliability techniques unknown</li> </ul>	<ul style="list-style-type: none"> <li>Eng./Mfg. teams for new products</li> <li>FMEAs, FTAs</li> </ul>	<ul style="list-style-type: none"> <li>Design for manufacturability</li> <li>Accelerated life tests</li> </ul>	<ul style="list-style-type: none"> <li>Design for zero variation and zero failures</li> <li>Multiple environment overstress test</li> <li>User-friendly built-in diagnostics</li> </ul>
7. Supplier	<ul style="list-style-type: none"> <li>Adversarial relationships</li> <li>Table-pound for price</li> <li>AQLs: 1 to 2%</li> </ul>	<ul style="list-style-type: none"> <li>Start of mutual trust and reduced supplier base</li> <li>ALQs below 0.5%</li> </ul>	<ul style="list-style-type: none"> <li>Partnership suppliers</li> <li>1 supplier per pt. no.</li> <li>AQLs below 100 ppm</li> </ul>	<ul style="list-style-type: none"> <li>Supplier an extension of company</li> <li>Quality, cost, and cycle time help to suppliers</li> <li>Self-certified suppliers</li> </ul>
8. Process/Manufacturing	<ul style="list-style-type: none"> <li>High scrap, rework</li> <li>Poor yields</li> <li>Low uptime</li> <li><math>Cp_k</math> unknown</li> </ul>	<ul style="list-style-type: none"> <li>80–90% yield</li> <li><math>Cp_k &lt; 1.0</math></li> </ul>	<ul style="list-style-type: none"> <li>Total defects/unit measurement</li> <li><math>Cp_k</math> 1.33 to 2.0</li> <li>FOE concept introduced</li> </ul>	<ul style="list-style-type: none"> <li>Scrap eliminated</li> <li>Insp./test greatly reduced</li> <li><math>Cp_k &gt; 5.0</math></li> <li>FOE &gt; 85%</li> </ul>
9. Support Services	<ul style="list-style-type: none"> <li>Poor quality, high cost, long cycle time</li> <li>No measurements</li> </ul>	<ul style="list-style-type: none"> <li>Next Operation as Customer (NOAC) concept introduced</li> <li>Steering committee, process owners, and improvement teams established</li> </ul>	<ul style="list-style-type: none"> <li>Internal customers measure internal supplier performance</li> <li>Quality, cost, and cycle time improvement tools used</li> </ul>	<ul style="list-style-type: none"> <li>Internal customer evaluation replaces boss evaluation</li> <li>Financial incentives/penalties established within NOAC</li> </ul>
10. People	<ul style="list-style-type: none"> <li>People—pair of hands</li> <li>Mgmt. overbearing</li> <li>Pervasive fear</li> <li>No training</li> </ul>	<ul style="list-style-type: none"> <li>Quality circles</li> <li>Mgmt. still not involved with people</li> <li>Sporadic training</li> </ul>	<ul style="list-style-type: none"> <li>Mgmt. participatory</li> <li>Workers involved, multiskilled</li> <li>Gain sharing</li> <li>Training implemented on the job with measured results</li> </ul>	<ul style="list-style-type: none"> <li>“Every employee a manager”</li> <li>Self-Directed Work Teams</li> <li>Mgr. as consultant, not boss</li> <li>From management to leadership</li> </ul>