INVESTIGATING THE EFFECTS OF VARIETY ON THE PISTON ROD MANUFACTURING PROCESS AT GABRIEL SA (PTY) LTD

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DECLARATION

I, the undersigned, do hereby declare that the work contained in this thesis is my own original work and has not previously, in its entirety or in part, been submitted at an University for the purpose of a degree.

BHARET MORAR   30 SEPTEMBER 1996

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SYNOPSIS

This thesis investigates the effects of variety on the manufacturing operations system of a automotive component (shock absorber) manufacturer, Gabriel South Africa Pty Ltd. Effective ways to manage this variety are also considered. By variety is meant the total number of possible states that a system can have. The measure of variety can also be considered as the extent of complexity of a system. The variety of product, people (from different cultures, backgrounds, etc.), processes machines and equipment, etc. and a continually changing environment creates a complex situation in which management decisions have to be made.

Over the last three years, 1992 to 1994, Gabriel SA Pty Ltd has implemented world class manufacturing initiatives, for example, cellular manufacture, kanban, employee involvement programs, strategic business units, a Total Quality Management System, etc., but the anticipated results of increased production throughput did not occur. A situation has developed where changes had been implemented and there is now a difference between the actual and expected results. This thesis investigates possible causes for this difference.

In order to conduct a rigorous and structured inquiry into the problem situation a theoretical research framework was developed. This framework was developed from the ideas of the American philosopher Charles Sanders Peirce (CSP) and that of Chris Argyris. Checkland's, Ackoff's et. al. views on system thinking were also used to form this framework.

There are four fundamental reasons which supports CSP's ideas in the context of this research. Firstly, CSP's scientific method offers a process to conduct rigorous inquiry into the situation as described above, i.e., the belief resulting from this process is scientific.

Secondly, his "pragmatic maxim" introduces a feature for effective management decision making. In its broadest and most familiar sense, "pragmatism" refers to the feasibility, usefulness, workability and practicality of ideas, policies, and proposals as criteria of their merit and claims to attention, i.e. achieving results in business and public affairs. CSP's pragmatism also implies that any hypothesis that is proposed must be "testable" (verifiable) in practice. It is primarily a theory of meaning in which the inquirer understands a proposition as meaning that, if a prescribed experiment is performed, a stated experience will result. For any belief that is formed their are numberless possible predictions to be tested.

The third reason is his ideas on "fallibilism" which gives cognisance of the fact that there is no belief that is permanently stable and that would never not be falsified. Fallibilism acknowledges the fact that science is in search of knowledge, and as this knowledge grows and develops, we get closer to the truth. However, we can never claim that we have attained the ultimate and final truth or reality. This acknowledgement is a prerequisite for conducting unbiased enquiry, for the development and growth of science and is the basis for continuous improvement.

Lastly, CSP's pragmatic maxim and fallibilism can be compared with a cybernetic theorem and principle respectively. His pragmatic maxim can be associated with the Ashby-Conant Theorem which states that "every good regulator of a system must be a model of that system". His fallibilism can be compared with the Darkness Principle which states that "No system can be completely known". The latter two comparisons suggest that CSP was also a systemic thinker.

Due to the complexity of the 'real-world' manufacturing environment and the above suggestion, a systems approach is adopted to develop the framework. The problem situation is in an environment where man, machine, money and materials systemically interact in an extremely complex relationship in an attempt to beat the competition. As Checkland (1981) said, "When we move beyond the physical regularities to more complex phenomena, such as those of human society, the analytical and reductionist (mechanistic) method of science develops limitations;- the reductionist 'separation' into simpler parts becomes questionable, even within the natural sciences. These concerns have basically arose from three areas, namely the problems in complexity within the physical sciences, the social sciences and the 'real-world'. It is as a response to these problems of complexity that systems thinking developed.

During the application of the immersion stage of the framework it was discovered that management believed that the major causes for production non-conformance was the many product differences, especially the effects it had on the operations system. This belief was formed from the daily "problems" experienced at the company. GSA is currently supplying approximately 800 different part numbers to the market. This range of part numbers are composed of 50 different designs made from 2500 components and 2100 subassemblies. The control and management of the work-in-progress and the inventory had become extremely difficult since some designs require specialised components, machines, tooling and processes. Based on this a methodology was sought to deal with variety.

Three systems thinking methodologies were subsequently considered. These were Stafford Beer's Viable System Model, Peter Checkland's Soft Systems Methodology and Luc Hoebeke's "work systems". From the context of this problem Beer's Viable Systems Model (VSM) was chosen since it best deals with variety. Beer's VSM is generally used for "diagnosing 'problems' of organisations, particularly those arising in complex probabilistic systems that comprise purposeful organised parts and are open to changing environments" (Flood and Jackson, 1991).

From the VSM diagnosis it became clear that "variety" is not only contributed by product variations, but by variety attributed to human factors, the processes, machines and equipment, and systems in general.;- all of which form a complex and dynamic socio-technical system which itself is continuously inter-acting in an ever-changing and dynamic environment. It was also found that this variety was generally introduced by the factors which caused downtime in the system. The performance of each of the operational units diagnosed were measured and discussed. Their respective capability and potentiality were calculated and it is shown that each of these units are theoretically capable of achieving their required production targets. The capable, potential and actual figures are summarised below:

	M, H & G	Chrome	Polish
capable	18 481	12 543	26 297
potential	15 000	15 000	15 000
actual	10 708	10 386	9 955

From the findings of the VSM diagnosis and consideration of cybernetic theorems, laws and principles the hypothesis was made that **the operational units within the system-in-focus cannot achieve requisite variety to effectively meet their daily production targets.** To check the validity of this hypothesis two tests were conducted under specified test conditions.

In the first test action research is used in the chrome section. An intervention occurs by the addition of an extra operator per chrome line. The additional operator increases the regulatory capacity of the chrome section by reducing the effects of absenteeism, by assisting with the loading and unloading of the chrome jigs, by resolving quality problems, by sharing the operator preventative maintenance responsibilities, etc. The most significant result observed is that the chrome output increased by 18%. It is shown that the chrome department is then able to achieve requisite variety and is able to produce in excess of 12000 units per day.

The second test uses a computer simulation to investigate how variety affects the "big rod" machine, harden and grind operational unit. This operational unit inherently has the capability of producing 7110 rods per day. In the simulation the loss of production due to variety effects (causes of downtime) were calculated and subtracted from the possible 7110 rods per day to obtain the resultant daily production figure. The major causes of this variety was due to the dressing and setting the grinding and regulating wheels, changing of the grinding and regulating wheels, straightening of rods, Vickers hardness first-off test, machine maintenance, unplanned meetings, waiting on work, waiting on tooling, changing of measuring clocks, operator absenteeism, surface finish problems, setting of hardener, raw material quality problems, etc. The simulation results show that the system only produces an average daily figure of 4285 rods against the average 4500 rods required, i.e. this system cannot achieve requisite variety.

From the above results the conclusion is made that **the hypothesis made above holds true**. By increasing the regulatory capacity of the chrome section the system is then able to produce in excess of 12000 units per day. In the second case it is shown how an inherently capable operational unit becomes incapable of producing its daily average target when the system is subjected to variety initiators.

Based on the above findings and conclusions the recommendations made to deal with the damaging and uncontrolled variety of the operational units are twofold;- variety control can be improved by either reducing the variety that the system is subjected to (standardisation, etc.) or by increasing the regulatory capacity of the system (quick-change tooling, extra operators, improving the machine and process capability, etc.). These recommendations are:-

* Monitor machine downtime to identify its causes.
* Develop an action plan to reduce or eliminate downtime causes.
* Conduct process capability studies of all the machines.
* Establish the true potential of machines and equipment and highlight potential bottlenecks.
* Develop a planned preventative maintenance program.
* Develop a refurbishment/replacement plan for maintenance-prone machines.
* Ensure that all new machines are capable to produce the products within specification.
* Review the product and process specifications to facilitate throughput improvements, i.e. design for manufacture. Consider quick change tooling and standardise products and processes to reduce changeover times.
* Improve the control and accuracy of information, especially the true reasons for downtime,

otherwise incorrect mental models of the system could be developed.

* Develop suppliers to reduce material shortages and raw material quality problems.
* To improve absenteeism, facilitate flexibility and improve operator skills certain operator development programs, such as cross training, Employee Involvement suggestions, etc. must be continued.

In general, what is sought is the deletion of all unnecessary variety and the intelligent control of the necessary variety, i.e. to achieve requisite variety by design and not by default (chance). A holistic variety reduction programme will only be successful if it has the full support of management, as is true for the success of any form of intervention.

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LIST OF ABBREVIATIONS

AM	After Market
assy	assembly
BU	Business Unit
BUM	Business Unit Manager
CATWOE	Customer, Actions, Transformation Process, Weltanschauung, Owner, Environmental constraints
CEA	Capital Expenditure Application
CNC	Computer Numerical Control
EI	Employee Involvement
ext.	external
ECO	Engineering Change Order
fig.	figure
GIB	Group Incentive Bonus
GSA	Gabriel South Africa Pty Ltd
GST	General Systems Theory
GTQMS	Gabriel Total Quality Management System
int.	internal
JIT	Just-In-Time
m/c	machine
MD	Managing Director
OE	Original Equipment
OR	Operational Research
PAT's	Process Action Teams
P.L.C.	Programmable Logic Control
PPM	parts per million
QA	Quality Assurance
RD	Root Definitions
SA	Systems Analysis
SE	Systems Engineering
SPC	Statistical Process Control
SSM	Soft Systems Methodology
TOPS	Team Orientated Problem Solving
TPM	Total Preventative Maintenance
TQM	Total Quality Management
VSD	Viable System Diagnosis
VSM	Viable System Model
WIP	Work-In-Progress

CHAPTER ONE: INTRODUCTION

1.1 A PROBLEM SITUATION

Edi Goldratt and R Fox (1986, page 140) in their book "The Race:" says, "The race for a competitive edge is akin to man's progress- it should be ongoing and without end. We can always do better. When we gain and apply a better understanding of how our manufacturing world works, many benefit. Progress in manufacturing and a rising standard of living have marched hand in hand since the start of the industrial revolution".

With sanctions lifted, the implications of General Agreement on Trade and Tariffs (GATT) and an open market environment, South African companies are suddenly faced with the serious challenge of international competition. Many will probably not survive this threat. The race to be better than the competition has become a real and brutal one and only the best will survive.

Gabriel South Africa Pty Limited (GSA) is a shock absorber manufacturing company and supplies shock absorbers to the Original Equipment Market (OE), After Market (AM) and the Export market. The "Gabriel" brand name is generally perceived by the public as a competitively priced, reliable and quality product.

Over the last three years the market, especially the export market, has developed a potential for the company to increase its total production output to 12000 shock absorbers per day;- an increase of approximately 20%. The company had aimed to utilise this opportunity and to meet this challenge through capital expenditure and to focus on continuous improvement.

Between 1992 and 1994 the company has implemented many world class programs, e.g., cellular manufacture, kanban, employee involvement programs, strategic business units, a Gabriel Total Quality Management System (GTQMS) etc., it still cannot produce an average of 12000 units per day. It appears that the current operations system has reached a maximum. Consequently, concerns have been risen about this "unachievable" production target and has led to the question, "what are the causes for this throughput not being met ?"

1.2 OBJECTIVES OF THE RESEARCH

The objectives of this study are thus:

1. To develop an appropriate research framework so that a meaningful and structured inquiry can be conducted.
2. To investigate what the causes for the increased throughput not occurring are.
3. To investigate whether GSA has the capacity to meet the increased demand.
4. To recommend implementable solutions to effectively deal with the causes.

The ultimate aim of this thesis is that its outcome should lead to some management action which would deal with the above problem situation.

1.3 THE RESEARCH PROCESS

The thesis starts with a background to the situation which led to this inquiry (section 1.1 and chapter 6). It is then divided into 2 core sections, Parts A and B, as shown in figure 1.1. Part A (chapters 2 to 5) is a literature survey which develops an appropriate theoretical research framework in a search for an "implementable" solution in the context of the above situation. Section B (chapters 6 to 11) is a rigorous application of this framework to the complex "real-life" situation at Gabriel South Africa Pty Ltd (GSA).

All the research which was conducted occurred at GSA. Most of the work was done in the piston rod department and the various sections within this department. The work completed in this thesis would be applicable to companies which have a similar operations system.

Generally, the complexity of the situation required that a naturalist mode of enquiry be used, hence the systems approach. Information and data was gathered from executives, managers, engineers, technicians, foremen, Chargehands and operators. The accessibility of information was readily available because the researcher was the product engineer of a newly formed support team to the piston rod department. His questions and inquiries were seen as part of his job function. The main objective of this newly-formed team was to ensure that all the services which the operational units required to achieve their daily production targets were available. In many cases information at the shopfloor level was given freely since it was taken that someone would "at last" investigate an old problem that everyone had forgotten about. This situation was extremely valuable, especially during the VSM diagnosis.

During the immersion stage of the research the technique of ethnography (semi-structured interviewing, and direct and participant observation) was used to acquire information, e.g., to gain some sense of the overall company problem. In this instance a questionnaire was developed. By using ethnographic interviews, answers to this questionnaire was obtained and cause of the problem became clearer. This proved to be an effective way to acquire a sense of the problems being experienced.

During the first test conducted the use of action research was supported by the fact that an intervention was required in the manufacturing process where it was applied, namely the chrome section. This system was a combination of many complex variables, namely, the variations in the product, in the production schedule, in the process itself, variations in the jigs, people, absenteeism, breakdowns, etc. In a second test action research was used to understand the problem in its "natural" environment by considering all the factors that had an influence on the system;- the people, there attitude and how this affects their performance, the product variation, the theoretical and practical basis for the chroming process, and how the equipment, process and operators inter-relate.

Both the above techniques have a high ecological validity (extend to generalise from actual social context of situation to another similar social context and setting). Similar problems would be valid in cases with a similar background;- a large variety from product, process and people. Both have a low internal, population and reliability validity.

During the second test a computer simulation was developed. Much of the information gathered for this test was acquired by observation, questions and conducting time studies of the various processes. The computer model was developed using a Lotus 1-2-3 spreadsheet.

From a company-researcher point of view, the investigation was viewed to be mutually beneficial to both parties, especially since the researcher was employed by the company. However, the question of maintaining secrecy about competitive developments within the company were raised. This issue was resolved by agreeing to screen the thesis for any "sensitive" (confidential) information on its completion.

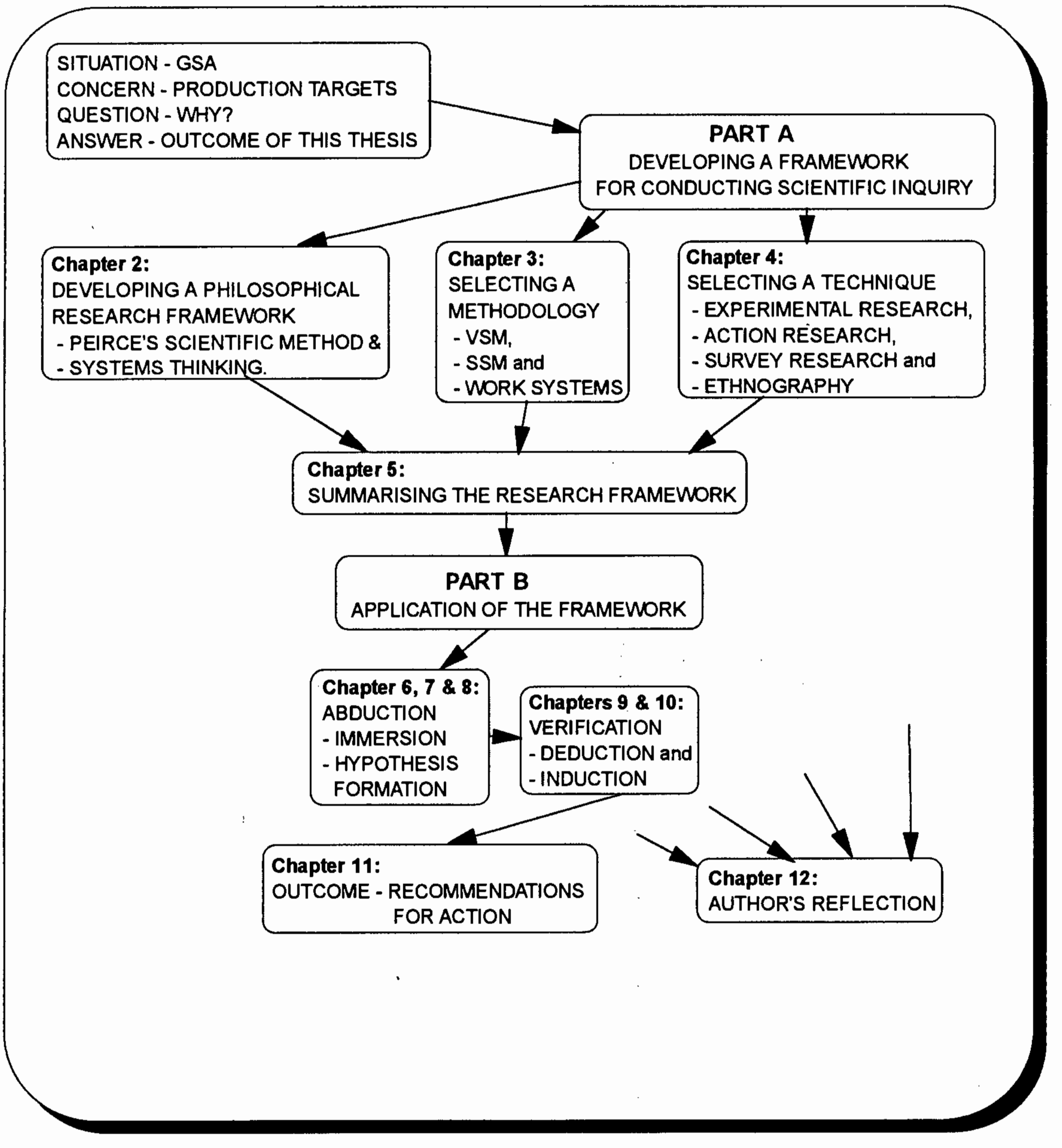


Figure 1.1 : The Thesis Cycle

1.4 PART A: DEVELOPING THE RESEARCH FRAMEWORK FROM A LITERATURE SURVEY

The research framework Part A (chapters 2 to 5) developed for this thesis was based on an extensive literature survey. Chapter 2 develops a philosophical framework for conducting inquiry into the situation from which a concern was initiated. Firstly, Charles Sanders Peirce's ideas on conducting inquiry is discussed. His proposed four methods of setting belief are described and it is shown why his "Scientific Method" is most suitable for use in this thesis. Chris Argyris' views on learning is then outlined.

Secondly, chapter 2 introduces Checkland's and Ackoff's views on system thinking as a more appropriate approach than the natural sciences, in an attempt to address the complex issues to be resolved in this situation. As mentioned earlier, the initiation of this inquiry stems from a unmanageable and complex operations environment. This chapter gives a brief history of the method of science and how the need for systems thinking developed. The problems which resulted in the development of systems thinking, namely problems within the physical sciences, the social and the "real world", are discussed. Basic systems thinking ideas are given. The chapter concludes with a statement of the relevant cybernetic laws, principles and theorems.

Chapter 3 discusses the three methodologies considered for application in this research, namely, Stafford Beer's Viable System Model (VSM), Peter Checkland's Soft Systems Methodology (SSM), and Luc Hoebeke's Work Systems. Beer's model, its five functional elements, namely, implementation, co-ordination, control, development and policy and the communications and control of information between them, are introduced. The amplification and filtering mechanisms (information control) of the model are discussed. The seven stages of the SSM process are outlined. As a continuation of both Beer and Checkland's work, Luc Hoebeke's "work systems framework" (developed from the concepts of Beer's VSM, Checkland's SSM, and Elliot Jacqe's time spans) is outlined. The chapter concludes with a discussion on why the most appropriate methodology, VSM, is selected.

During the application of the above framework it becomes necessary to employ appropriate technique's in order to gather information from the socio-technical environment. In chapter 4 some of the techniques for assimilating data, as described by Gill and Johnson, are discussed. These techniques are experimental research design, quasi-experiments and action research, analytic and descriptive surveys and ethnography. Lastly, the validity of these techniques are discussed. The techniques used to gather information from the socio-technical environment were ethnography, predominantly direct and participant observation and semi-structured interviewing. Action research was used as a technique to intervene in a situation.

Chapter 5 summarises the theoretical research framework that was developed.

1.5 PART B: APPLICATION OF THE RESEARCH FRAMEWORK

Part B of the report considers Gabriel South Africa Pty Ltd (GSA) as a case study.
Chapter 6 gives a background of the company:- its changing environment, history, products, manufacturing processes and its current concerns. To obtain a better sense of the problem a questionnaire was developed and managers interviewed. Management had developed a belief that product variation was one of the main causes for not achieving production targets. Using a systems diagram it is shown that product variety negatively affects the competitive variables and that cost, quality and delivery are intricately related.

The diagnosis of Beer's VSM, which forms the methodological basis of the research is outlined in chapter 7. The recursivity of the company is evaluated and the system-in-focus is identified. Each of the operational units which constitute the system-in-focus are also identified. The five functional elements of Beer's VSM, namely, implementation, co-ordination, control, development and policy are identified and the communications and control of information between them are discussed. The high variety at the system one level is investigated. The essential variables and the criteria of relevance are listed. The performance of each of the operational units are measured and discussed. The capability and potentiality for each of the operational units are calculated. Conclusions are then drawn.

In chapter 8 a hypothesis is formulated. It is based on the outcome of the VSM diagnosis and a review of the relevant cybernetic laws, principles and theorems. An immersion had occurred and now an hypothesis has been made;- the second stage of the Peircean Cycle.

Chapter 9 and 10, describes how the validity of this hypothesis is tested (verified);- the third stage of Peirce's scientific method. In chapter 9 action research is used and in chapter 10 a computer simulation is employed. In both cases control conditions for which the hypothesis would hold true were set up;- forming the deductive stage of the verification process. The induction stage (second stage of the verification process) was then conducted within these parameters and the results observed. Both chapters conclude that the hypothesis made is true.

Chapter 11 gives a summary of the conclusions drawn and the recommendations made in the previous chapters. A new belief has been formed and corrective action is to be taken.
Chapter 12 gives a brief reflection on the author's learning.

PART A

DEVELOPING A RESEARCH FRAMEWORK

CHAPTER TWO: DEVELOPING A PHILOSOPHICAL FRAMEWORK FOR INQUIRY

This chapter develops a philosophical framework for conducting inquiry into the situation from which a concern was initiated (as described in chapter one). Firstly, Charles Sanders Peirce's ideas on conducting inquiry is discussed. His proposed four methods of setting belief are described and it is shown why his "Scientific Method" is most suitable for use in this thesis. Chris Argyris' views on learning is also outlined. Lastly, a systems approach (as viewed by Checkland and Ackoff) is considered to deal with the complex situation from which this inquiry stemmed.

2.1 CHARLES SANDERS PEIRCE

In this era of an ever-changing competitive environment it has become imperative that managers make effective decisions to protect the existence of the organisations that they serve. The effectiveness of their decisions largely depends on the beliefs (or mental models of reality) that managers hold. What is crucial is the inquiry process that they undergo to arrive at their mental models of a situation, because, ultimately, to be effective these beliefs must be pragmatic. By pragmatic, in the latter context, is meant the feasibility, usefulness, workability and practicality of ideas, policies, and proposals as suggested by managers;- i.e., to achieve results and "getting things done" in the business environment.

The only feasible way to evaluate whether a decision was a success or a failure is to consider the consequent results. If the outcome was desirable the decision was a good one and if was not it was bad. Effective managers subconsciously do this all the time and it is this pragmatic approach which enable them to be effective. But pragmatic action is not sufficient to ensure long-term viability. What is also required is the need to be rigorous, viz. scientific before making a decision.

It is in this context that this report uses as its framework, "The Scientific Method" as described in the work by F. E. Reily of Charles Sanders Peirce (CSP). The Scientific Method is pragmatic and offers a cycle to conduct rigorous inquiry into the above situation.

2.1.1 A BRIEF HISTORY ON PEIRCE'S THINKING

Charles Sanders Peirce (1839-1914) was an extraordinary genius in both science and philosophy. His work covered a series of philosophical reflections concepts such as inquiry, reality, meaning, probability, induction, chance, law, etc. He focused on key concepts which were fundamental to the philosophical understanding of the method of scientific inquiry and its results, the philosophy of the universe and, also, the philosophy of the inquirer. (Reilly, 1970.)

Peirce regarded most of his writings as contributions to logic, which he conceived as the study of reasoning. He defined reasoning, or "thought", or "inquiry", as "the art of drawing inferences. Because he considered the objective of inquiry to discover something we do not know, from consideration of that which we already know, he argued that it is a "knowledge-seeking" activity.

To Peirce, one cannot understand scientific inquiry without understanding the scientist or inquirer. It takes a special "frame of mind" to conduct scientific inquiry. "For the scientists nature is cosmos, something great, and beautiful, and sacred, and eternal, and real. They are out to learn the truth about the ways of nature, for the sake of learning , and for no other motive" (Reilly, 1970, page 11). In his quest for the truth about reality it is not only the scientists passion to learn and acquire knowledge, but also the most effective method of learning, that is important. Peirce believes that an inquirer with the true scientific spirit will eventually use the most appropriate method sooner or later. He says, "the motive will control the method and the results will follow" and that "scientific men shake off bad habits of reasoning and reason scientifically to arrive at the truth" (Reilly, 1970).

Managers are practical men. Their job entails making quick decisions, implementing them and obtaining the required results. Therefore, a manager must believe that his decision is correct. To be able to do this he must understand the relationship between his decision and the consequent results, i.e. his approach must be pragmatic. Once he has made his decision, it must be "embraced" otherwise doubt will paralyse the action that he needs to take.

The scientist, on the other hand, works with a different spirit;- he can reject his current beliefs as soon as he finds reason to falsify them. His only aim is to develop scientific knowledge and his temperament is quite different to that of a manager who needs to achieve practical goals. The aim of inquiry is to seek the truth, but "today's" truth is not final and completely known, therefore, its ultimate aim is to seek stable beliefs which are verifiable. According to Peirce, "a man knows the world to the extend that he has stable beliefs about it" (Reilly, 1970). A belief is a paradigm that is held by an individual about something. The individual will react to certain situations based on this paradigm that he holds. If the individual is faced with a situation that is completely new he is overcome with surprise and his belief is placed in doubt, i.e.. his belief becomes unstable. He can either modify or renew his habit (belief) or paradigm, or he can use his old beliefs to justify this new phenomena he is faced with.

2.1.2 PEIRCE'S INQUIRY PROCESS

CSP's inquiry process is illustrated below. CSP claims that belief is a habit and is either stable or unstable. Inquiry begins when a man experiences a unusual and baffling phenomena.

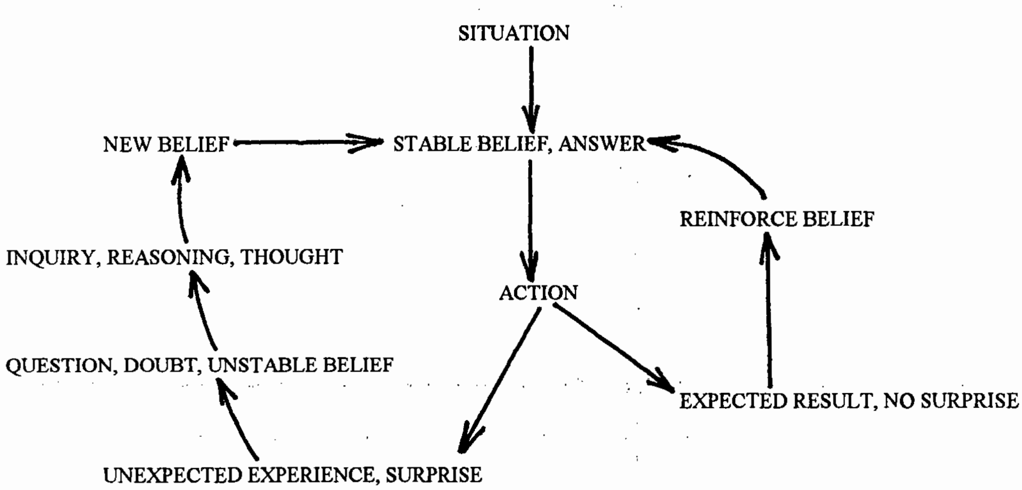


Figure 2.1 : CSP's Inquiry Process For Fixing Belief

As a result his beliefs become unstable (his belief-habit is then broken), is replaced by doubt and he starts to question the beliefs that he has. This puzzling event then causes the man of science to inquire into its explanation through a process of reasoning to seek stable beliefs. Finding an answer marks the end of a scientific investigation. The attainment of belief is only a momentary state of rest and a starting-place for new thought. CSP claims that the aim of scientific thought is to seek stable beliefs and it is thus a knowledge-seeking activity. For CSP this reasoning process is crucial for establishing stable beliefs.

Peirce believed that man generally illogically concluded things based on his past experiences or habits. He identified four methods (or more accurately, "habits of thinking") most commonly used for fixing belief, namely that of tenacity, authority, a priori and the scientific method.

The first belief, the **method of tenacity**, is formed when a particular point of view is steadily and systematically reinforced, i.e. an opinion that is developed based on "what has been before". A person maintains a rigid steadfastness in beliefs that he already holds and avoids any inquiry that may disturb his stable belief. The belief formed in this manner is not necessarily rational or logical and this form of mental conditioning does not allow the mind to try new or alternative ideas. Where change is slow, as has been in bygone years, the method of tenacity had worked well. This method can no longer cope with today's rapidly changing environment and if it where employed organisations would battle to survive and may very well become extinct. CSP considers this method of fixing belief to be the poorest of the four.

The second and probably the most frequently used form of establishing belief is that of **authority**. This method overcomes the flaw of the above method by indoctrinating people to believe what the organisation wants them to believe, and punishes those who refuse to believe. The organisation enforces its will on its employees;- a matter of "you will do as you are told, or else find a job elsewhere", or as CSP puts it, "when a complete agreement could not otherwise be reached, a general massacre of all who have not thought in a certain way has proved a very effective means of settling opinion" (Beer, 1966, page 22). People are discouraged from thinking, individual investigation forbidden and members are held in intellectual slavery. Only the "boss(es)" think and can make decisions instead of utilising the "brainpower" of all the employees in the organisation. A manager who thinks by using this method makes decisions based on his companies conventions and norms and will adopt his actions accordingly, however irrational this process may be. Both the above methods block original thought and stunt innovation which is crucial for survival and growth.

The third method, that of **apriority**, is more respectable than the above two methods. In this instance a person adopts views that he finds agreeable to his own reasoning, i.e., natural preferences are not impeded by any external authority. A person adopts views that he finds agreeable to his own reasoning. However, since it makes inquiry a matter of "fashion" or "bias", it is not adequate. Setting belief starts with a set of axioms which are assumed to be true and which he argues to be true, rather than from the experiences of others.

In all of the above three methods man is almost powerless to exert his free will in any rigorous choice;- he is denied any original thought. The first two methods are both irrational since they are not based on any logical process. The third method is rational, but none of the three are scientific;- none of them are repeatable under testing, they are neither exclusive nor exhaustive, just "a convenient set of pegs on which to hang some thoughts" (Beer, 1966, page 30). The method of tenacity uses the process of conditioning. The method of authority relies on enforcing key ideas to all the employees within an organisation for all to abide by. The method of apriority uses known axioms to base its arguments on. In all of the above the individual is almost powerless to exercise his free will in a scientifically rigorous manner.

All three of these adaptive and practical methods had their place in history. CSP claims that reasoning advances in the same way that technology does;- man succeeds in making ever more intricate and more precision tools. Similarly, although he must start with his primitive beliefs and habits of reasoning, man succeeds in improving both. If scientists continue their investigation their false beliefs and bad habits of reasoning are eliminated. He says that inquiry of every type has the power of self-correction and growth. He believed that the history of human inquiry discloses a gradual refinement and improvement in the methods of inquiry, culminating in the scientific method.

Peirce claims that his scientific method has rigour which offers repeatable, exhaustive and exclusive testing which is a prerequisite for a method to be accepted by the scientific community. Rigour is the precise formulation and application of a method. It is clear and definite, testable and repeatable and is applied throughout the process of inquiry.

2.1.3 THE SCIENTIFIC METHOD

The main stages of CSP's method of science are observation (experience), abduction (immersion and hypothesis formation) and verification (deduction and induction) as shown below. Throughout this thesis this cycle will be referred to as the "Peircean Cycle".

2.1.3.1 Experience - The Basis For A Hypothesis

In order to investigate a problem one must first attain a better understanding of the problem. To accomplish this it is necessary to become totally "absorbed" in the situation. The problem

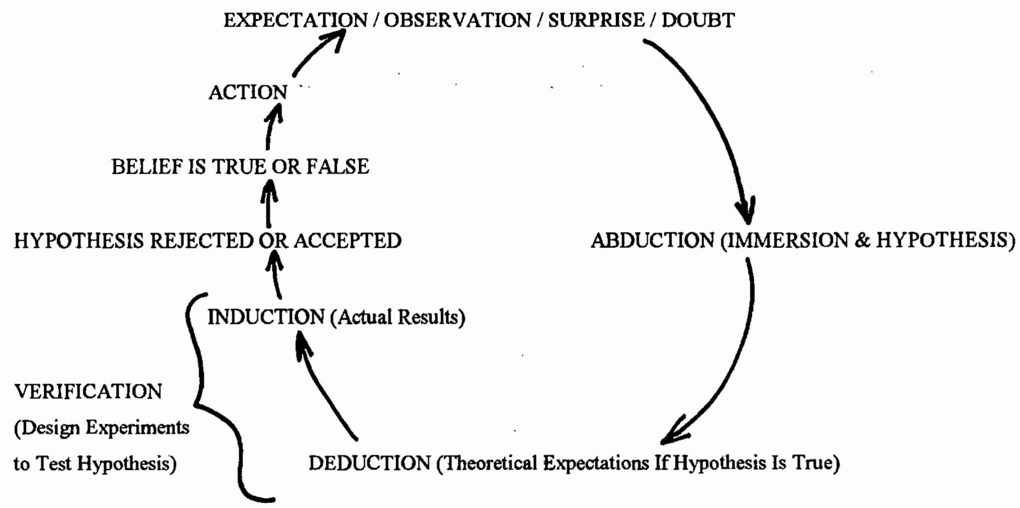


Figure 2.2 : The Method Of Science ("Peircean Cycle")

can then be accurately defined and the most appropriate action taken. Management decisions must not just be based on here-say, or guessing, it should be justified on "fact" which is based on scientific grounds and which must reflect the reality of the situation.

Peirce attributes the eagerness for learning the truth, to the dissatisfaction which doubt causes in a person, "an uneasy and dissatisfied state from which we struggle to free ourselves and pass into the state of belief" (Reilly, 1970, page 15). This struggle Peirce terms inquiry or reasoning:- the purpose of which is to remove doubt and attain stable beliefs. The inertia of past experiences generally resists change. It is the ability to learn which reducers this inertia.

This stage precedes the formation of the hypothesis or belief that is formed. CSP claims that experience is the necessary beginning of all our knowledge, since there is no human knowledge that is not based on observed facts. All knowledge has come from observation. Every inquirer brings a background of experience to his scientific work which builds up habits of expectation in individuals. Any inquirer initially has a belief and based on this belief he expects to observe certain specific occurrences in certain specific situations.

Inquiry begins when the inquirer is confronted by a surprising phenomenon. This observation causes him to doubt his beliefs and places his beliefs in instability. This stage is the first stage of the "Peircean Cycle". This doubt raises a concern. To attain a new state of belief, or to eliminate the concern, the inquirer should undertake a process of inquiry to explain the unexpected result. The answer to this question would then resolve the doubt held by the inquirer. This leads us to the next step of the scientific method, namely the abduction stage.

2.1.3.2 Abduction

The second stage is termed abduction. The abductive stage is composed of two stages, namely immersion and the actual hypothesis formulation.

(a) The Immersion Stage

As the name implies the first step means the "immersion" of the scientist in his quest to assess, understand and appreciate the phenomena he is dealing with;- to involve the right people, to ask intelligent questions, to learn about the system, to evaluate current scientific law which could explain the surprising phenomena, etc. Rigorous immersion into a situation should lead to a scientifically derived hypothesis which is a accurate solution to the "doubt" the inquirer has.

(b) The Hypothesis Formulation

The hypothesis is the explanation which attempts to explain the unexpected event as discussed above. The hypothesis emerges from the immersion stage. The value of the hypothesis that is formed is directly dependent on the depth and rigour of the inquiry that is conducted;- the more thorough the immersion the more accurate the hypothesis. CSP also suggests that man has a natural aptitude for unveiling the secrets of nature and if immersion is unbiased and sincerely conducted, the hypothesis subsequently formulated, often is a true discovery. Hypothesis that are not plausible does not pass interrogation and are discarded as unworthy of being tested. Current paradigms are questioned and unreasonable hypothesis are eliminated. This is the stage that provides new knowledge. This hypothesis is arrived at by logical reasoning;- abduction.

Abduction, deduction and induction

Abduction, deduction and induction are similar in that each contain a proposition which is a rule, a case and a result. Abduction occurs when one reasons from a concern (result) that exists in a particular situation (case) to a plausible answer (result) that would explain the concern (result) and lead to possible action in the system [result-rule-case]. Induction occurs when one reasons from an existing case to the general answer or rule which explains why a particular result or concern present in the case [case-result-rule]. Deductive reasoning occurs from a general rule to a specific concern (the expected result of the rule being true in a specific case) [rule-case-result].

Because results are known and a rule needs to be conjectured Peirce calls his hypothesis formation an abductive process which has two characteristics that need to be pointed out:-

1) an explanatory hypothesis renders the observed facts necessary or highly probable;
2) an explanatory hypothesis deals with facts which are different from the facts to be explained, and are frequently not capable to be directly observed (Reilly, 1970).35).

In the first instance, since the hypothesis is no more than probable prior to the verification stage it can be no more than a probable explanation. The hypothesis is formed with the belief of fallibilsm;- this new explanation is only temporary because in time someone else will falsify this rule and suggest a new one. For now it only needs to be verifiable.

The second characteristic of the abductive stage is its antipositivistic spirit. The explanatory hypothesis must be verifiable in practice, but its verifiability need not consist in its own direct observability. CSP's pragmaticism demands that any hypothesis that is suggested must capable of experimental verification, at least indirectly. "In logic the pragmatic maxim is a judge of the admissibility of hypothesis, and has no other function" (Reilly, 1970, page 55).

During the selection of an hypothesis there are three important aspects to consider;-

1) The most important requirement that a hypothesis must meet is that it is experimentally verifiable, whether "soft" (often indirect verifiability when dealing with social systems) or "hard" (often direct verifiability when the "true" or "classical" experiment).
2) The economy of time, money and energy is an important consideration that needs to be considered during the abductive stage. The inquirer must find a hypothesis that is broad and inclusive.
3) A good hypothesis for testing is one which, if false, can be easily proven to be false.

Once an hypothesis has been formed it must then be subjected to testing, the next stage of the Peircean Cycle.

2.1.3.3 Verification

The third stage, verification, consists of two processes, namely, deduction and induction.

(a) The Deduction Process

The first step in the scientific verification process is to design tests to evaluate the hypothesis;- referred to as the deductive stage. During this stage tests are designed to observe what would happen under specified conditions which should occur if the hypothesis holds true, i.e., theoretical predictions which will hold if the hypothesis were true. Unbiased experimental consequences of this explanatory hypothesis are then deduced. Deduction provides no new knowledge, it basically designs a thorough test which allows the hypothesis to be tested. The scientist must then see whether these predictions hold true. This is the second phase of the verification process.

(b) The Induction Process

As the name implies this stage is an inductive process. By induction the above conditions are realised in a test under specified conditions and the results observed. By inductive reasoning these conditions are then interpreted, analysed and evaluated. Conclusions are then drawn. The inferences made then form the basis of a new belief. It is from this evaluation that the inquirer elects to adopt, adjust, modify, or reject the hypothesis.

If the results are positive the hypothesis holds true and a stable belief is attained until such time in the future when new doubt will be cast on this newly-formed belief. If the results are not what was expected the hypothesis is then proven to be false and the hypothesis is rejected. The cycle then repeats itself in search for a scientifically acceptable explanation which will hold true;- at least for a while. One of the important functions of induction is that it makes an indefinite progress towards the truth, since it has a self-correcting effect. Thus, CSP's scientific method (cycle) provides a process for continuous learning. It offers a cycle to conduct inquiry into the real-life management situation that exists in the context of this case study.

2.1.4 PRAGMATISM

CSP claims that his scientific method of inquiry is pragmatic. He says, "Our idea of anything is our idea of its sensible effects". As a manager one must consider the practical implications of one's decisions, to learn from the consequences of your previous actions and change your mental model of a the complex situation being dealt with. If you do not learn from these results then you have not learned anything. This is especially true in a rapidly changing environment characterised by uncertainty, ambiguity and complexity where there is no clear and correct answer;- where the only way is to investigate, to analyse, assess and synthesise the situation, to make a decision and then to learn from the results. In these situations double loop learning (Argyris, 1994) becomes crucial for management effectiveness. (Refer section 2.1.6).

According to CSP, a man knows the world to the extend that he has stable beliefs about it, i.e., your understanding of a situation is only as good as the mental model you have of the situation. This is reflected in his pragmatic maxim which states, "Consider what effects that might conceivably have practical bearings, we conceive the object of our conception to have. Then our conception of these effects is the whole of our conception of the object" (Reilly, 1970, page 21). What CSP means is that we all have a model or idea about a situation. The accuracy of this model is dependent on how well the actual practical consequences of our actions compare against the anticipated outcome. Our understanding is only correct if what happens is what we expected to occur.

CSP's pragmatic maxim not only implies pragmatism as meant in its normal use. It requires that any proposed hypothesis must be "testable" or verifiable in practice. CSP's pragmatism is primarily a theory of meaning in which the inquirer understands a proposition as meaning that, if a prescribed experiment is performed, a stated experience will result. For any belief that is formed their are numberless possible predictions to be tested. Scientific investigation proceeds by the method of elimination and persistent testing eventually eliminates false beliefs.

CSP claimed that rigorous pragmatism eventually converges to the truth. However, he also acknowledges that their is no belief that is permanently stable and that would never not be falsified, however long scientific investigation were carried on. Such a belief would be the ultimate truth or reality. This CSP claims is not possible. We can strive towards it but we can never claim that we have attained perfect knowledge. He encompasses this impossibility in his fallibilism.

2.1.5 FALLIBILISM

Peirce's theory of scientific method producers a "fallible" result. CSP believes that, "the first step toward finding out is to acknowledge you do not know already. A desire to learn the truth of things" and "a humble confession of ignorance must initiate the enquiry" (Reilly, 1970, page 83). He defines "truth" and "reality" in terms of stable beliefs. If we claim that a belief is true, we are claiming that it is stable and will never be able to be falsified by scientific investigation, and this, CSP believes is not possible. He claims that because of the infinite number of mysteries that nature offers we can never attain an exact and universal truth.

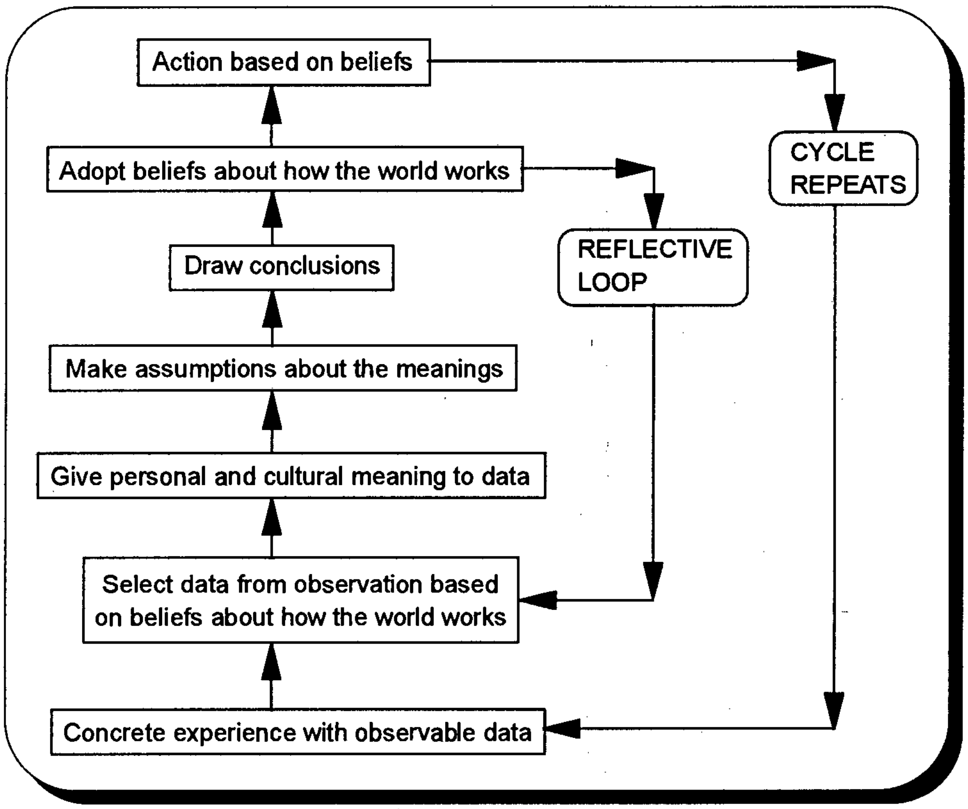
Fallibilism acknowledges the fact that science is in search of knowledge, and as this knowledge grows and develops, we get closer to the truth. However, we can never claim that we know or have attained the ultimate and final truth or reality. If we could claim the latter the knowledge of science would cease to grow. This acknowledgement is a prerequisite for conducting unbiased enquiry, for having a sincere desire to learn the truth and for the development and growth of science (and consequently, mankind). CSP's fallibilism is essential to the process of scientific inquiry since it supports the idea of continuous improvement. If carried out sufficiently, the knowledge acquired by the scientific method converges to a more real and accurate understanding or model of the truth.

This is especially true in a complex management environment where decision making is difficult and complex and often there is no one correct way. The decision is dependent a persons Weltanschauung, i.e., the stance or perspective various people take when faced with a situation based on their background, personal experiences, upbringing, culture, etc. However, a decision has to be made. The "correctness" of the decision is dependent on the level of enquiry made (immersion), the accuracy of the information and the analysis and understanding of the problem. What is important is the realisation and acceptance that once a decision is made, it is not a final one, and further action may be necessary depending on the outcome of the first decision that was made.

In real-life, knowledge is continuously growing. Every time a hypothesis is falsified and a new one replaces it, something new is learned. In this way what is known is refined or replaced. If one considers the development of the sciences over time, especially the physical sciences, this concept of CSP's fallibilism can be appreciated. Throughout history science has evolved in this way. One of the classic examples is Einstein's theory of relativity (the formula $E=mc^2$) which formed a different paradigm to Newtonian physics.

2.1.6 ARGYRIS' LEARNING MODEL

CSP believed that a persons model of reality is based on the a beliefs that he has about the world. In figure 2.1 and 2.2 we saw CSP's views on establishing belief. By his ideas on pragmatism he has shown how these beliefs influence the decisions that people take;- the better the model or belief of reality, the more effective the resultant action. These views are reflected by Argyris (1994) in his ladder of inference as shown in figure 2.3.

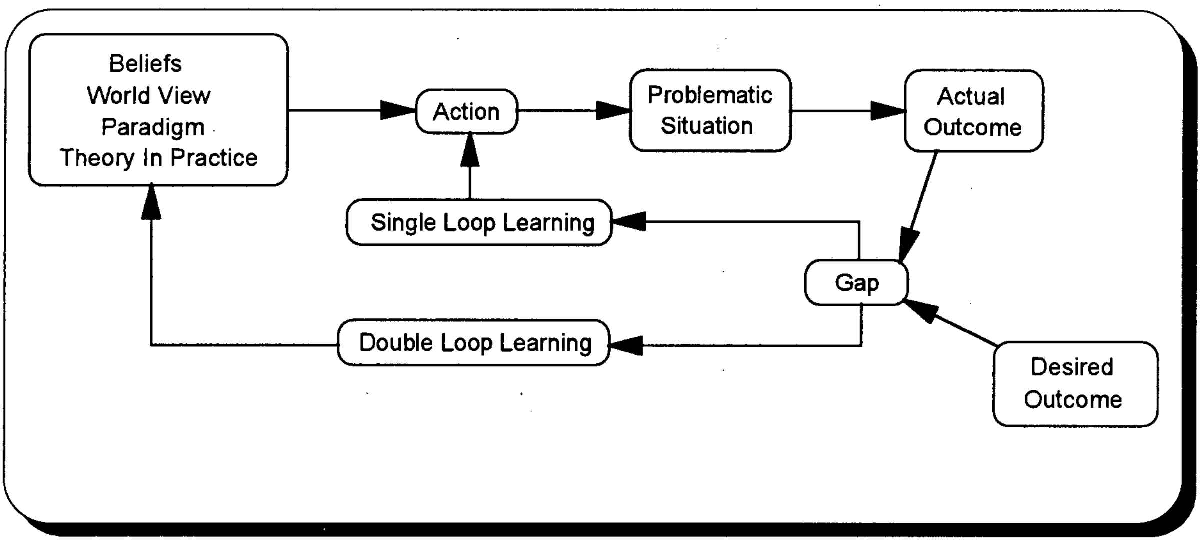


Source: Ryan, T (1995). Lecture Notes. UCT

Figure 2.3 : Argyris's Ladder Of Inference

The above diagram describes how our beliefs are formed, used, and how these mental models influence our actions and the way we see the world. It also shows how our subsequent mental are formed. Two people can observe and explain the same occurrence differently due to the different mental picture that they have of this situation. All mental models are simplifications of reality and are flawed in some way or the other. The ladder of inference explains how data from an experience is selected, given personal and cultural meaning, how assumptions and conclusions are made and drawn, and how beliefs are then adopted and action taken based on these worldviews. Argyris calls beliefs that are used as 'theories-in-use'. In a problematic situation this theory-in-use determines what action is taken. With the use of this theory-in-use a desired result is expected. The actual outcome could differ to the expected outcome.

When this happens the mental model can either be refined or changed. Argyris claims that for managers to experience meaningful learning from the results of their decisions, they must be prepared to change their mental model of a situation, i.e., double loop and not single loop learning (Argyris, 1994) must occur. Figure 2.4 illustrates these two modes of learning.



Source: Ryan, T (1995). Lecture Notes. UCT

Figure 2.4 : Argyris's Single And Double Loop Learning

Double loop learning occurs when a mental model is changed. This process involves a change in the beliefs about how the world works which leads to a new and different model. Single loop learning occurs when a current mental model is refined through a process of error detection and correction. The methods of tenacity, authority and apriori can be likened to this form of learning. Double loop learning provides a procedure for getting to the truth through a continuous learning cycle which is vital for an organisation to compete. Their mental model or belief of a particular situation is then one which is more accurate than the one which they had before they made the decision. This growth in their understanding of a situation should affect their decisions in the next similar case. The better a managers understanding of a situation the more effective his decisions.

2.1.7 PEIRCE - A SYSTEMS THINKER

CSP's pragmatic maxim and fallibilism can be compared with a cybernetic theorem and principle respectively. His pragmatic maxim can be associated with the Ashby-Conant Theorem which states that "every good regulator of a system must be a model of that system". His fallibilism can be compared with the Darkness Principle which states that "No system can be completely known". The latter comparisons suggest that CSP was also a systemic thinker.

2.1.8 CONCLUSION

Peirce believed that man generally illogically concluded things based on his past experiences. He identifies four methods most commonly used for fixing belief, namely that of tenacity, authority, a priori and the scientific method. None of the first three methods are scientific;- it has no rigour, its terms are neither exclusive or exhaustive. It was generally used because it offered convenient explanations and was formed is in response to human wilfulness, fiat or personal preference. Each of them fail to establish stable beliefs and cannot avail themselves to question and is easily falsifiable if tested by the scientific community.

In the past these methods could evolve, adapt, compete and survive. Today the pace is great and the global environment is changing at a tempo that these methods will not be able to deal with. Using Argyris' views on learning, the methods of tenacity, authority and apriori can be considered to produce single loop learning. Mental models are rarely changed through these methods. Instead the mental models that individuals have are basically modified to ensure that their beliefs are not disturbed. What is required is a method which has scientific rigour and that can be useful to the practical manager. Peirce claims that his scientific method achieves this.

CSP's scientific method can be likened to double loop learning. Here the beliefs held are changed if proven to be false, resulting in an effective process for learning and development. The scientific method as outlined by Peirce, utilises three modes of reasoning, viz. abduction, deduction and induction. The process of inquiry is initiated by doubt which is raised in a particular situation. Abduction follows and allows the inquirer to assess the situation. By immersion he is able to form a mental model of the 'real-life' situation and to accurately assess the questions which needs to be answered. All new knowledge occur due to the abductive process. Rigorous immersion into a situation should lead to a scientifically derived hypothesis which is a true solution to the doubt which the inquirer has.

Deduction provides no new knowledge, it basically designs and tests a thorough test which allows the hypothesis to be tested. Induction is the inference which is made based on the results of the test. These inferences then forms the basis of a new belief.

However, one needs to ask how valuable and permanent scientific knowledge really is. Peirce firmly asserts that scientific knowledge is not completely certain, absolutely exact or absolutely universal, hence his views on fallibilism. However, the scientific method gradually converges on the truth, but it will never become a reality. The best knowledge which we possess is uncertain and inexact. It is this concept of fallibilism which gives the scientific method the facility for continuous improvement.

In a complex managerial situation, a rapidly changing mess, we can only strive toward attaining an ultimate truth. A manager's effectiveness is his understanding of the situation. His level of understanding is based on the mental model he holds of the real-life environment. This in turn is as good as the method and rigour of inquiry he had engaged in to obtain his understanding. The desire to learn the truth is the most necessary requirement of the scientific procedure. It is also paramount that the correct method for conducting investigation be chosen, and that this investigation then rigorously be carried out according to this method. The more scientific one is, the closer to the truth one will get and the greater one's organisation's chance for survival. Peirce's scientific method offers a cycle for conducting such investigation. In all the stages of Peirce's scientific method one must be rigorous.

Part of this rigour is to select an appropriate approach to be adopted to conduct inquiry. Since the natural sciences cannot deal with the situation in which this research has to find an answer, namely complex and probabilistic socio-technical systems, the next section offers systems thinking as an alternative approach. CSP's scientific method, his pragmatic maxim and fallibilism, together with systems thinking ideas forms the basis for a theoretical framework for conducting research into this thesis.

2.2 SYSTEMS THINKING IN THE CONTEXT OF SCIENCE

The context under which this report is conducted is in an real-life manufacturing environment. The variety of product, people (from different cultures, backgrounds, etc.), processes and a continually changing environment offers a complex situation in which management decisions have to be made. In this "real" world of increasing uncertainty and growing complexity management "reality" can never be completely understood, it is too complex.

This section describes systems thinking in the context of science as viewed by Checkland (1981) in his book "Systems Thinking, Systems Practice." Ackoff's (1974) ideas on analysis (reductionism) and synthesis are given. It discusses systems thinking as a different and complementary approach to the mechanistic science, in an attempt to address the more complex social issues, in which this research needs to be conducted. It gives a brief history of science, the need for systems thinking and the development of the Systems Movement. The ideas of emergence and hierarchy, and communication and control are discussed. Finally, a summary of cybernetic laws, theorems and principles as given by Clemson (1984) are given.

2.2.1 A BRIEF HISTORY OF THE METHOD OF SCIENCE

Science can be considered to be a recognised, organised human activity, and as such is itself a 'system'. It is a institutionalised set of activities which embody the purpose of acquiring knowledge and, therefore, it is a learning system;- a system to find out things about our mysterious world. It is a particular body of knowledge which has been obtained by systematic observation and testing, of natural or physical substances, facts, laws, etc.

We owe the major characteristics of this learning process, science, to history. The Greeks contributed to the invention of rational thought, breaking the idea of the irrational authority; the medieval clerics started the conscious development of methodology and provided the beginnings of the experimental approach; the age of Newton united empiricism and theoretical explanation in a way which has made the real world comprehensible through ideas. The 20th century has reminded us that the knowledge gained is never final.

Scientists have created a pattern of activity for science which is characterised by reductionism, repeatability and refutation. "We may reduce the variety of the real-world in experiments whose results are validated by their repeatability, and we may build knowledge by the refutation of hypothesis" (Checkland, 1981, page 51). "It is the repeatability which places this knowledge in a different category to opinion, preference and speculation. It gives the activity of science a solid core which is unaffected by the irrationality, the emotionalism, and the foolishness of human beings." (Checkland, 1981, page 53).

Ackoff (1974) claims that analytical reduction, or analysis, occurs in the following stages:-

1. In order to cope with the complexities of the real-world we simplify it by taking it apart (component by component),
2. We then try and logically explain the behaviour of the parts taken separately,
3. We then try and assemble this understanding into an understanding of the whole.

2.2.2 THE NEED FOR SYSTEMS THINKING

The analytical and reductionist method of science as described above is not all-powerful and has its limitations, even within the physical sciences. The problem science faces is its ability to cope with complexity. Descartes' second rule, 'to divide up problems being examined into separate parts'- the principle most central to scientific practice assumes that this division will not distort the phenomenon being studied. It assumes that the components of the whole are the same when examined singularly as when playing their part in the whole.

For the physical world this is an reasonable assumption, and has given rise to the modern western world as we know it today. But when we move beyond the physical regularities to more complex phenomena, such as those of human society, making this separation becomes questionable. Three areas of concern are discussed, namely the problems in complexity within the physical sciences, the social sciences and the 'real-world' (management). It is in response to these problems of complexity that systems thinking developed.

2.2.2.1 Problems for science: Complexity

The world is a giant complex with dense connections between its parts. We reduce it to separate areas to deal with it. It should be remembered that it is not nature which divided itself into physics, biology, sociology, etc., but we who impose these dimensions on nature;- we do this due to our limited ability to take in the whole. It is interesting to note that when Comte placed the sciences in historical order; mathematics, astronomy, physics, chemistry, the biological sciences, and sociology, each science is more complex than the one before it. "Each rests upon the one which precedes it and prepares the way for the one which follows." (Checkland, 1981, page 62).

Over the years biologists have become conscious of the fact that an unsolved problem is presented to science by the very existence of a set of phenomenon which are higher order with respect to those of physics and chemistry. The existence of the problem of the emergence of new phenomena at higher levels of complexity is itself a major problem for the method of science, and one which reductionist thinking has not been able to solve.

Another aspect of the problem of complexity for science is that made by Partin (1968) in his discussion of "restricted" and "unrestricted" sciences. In a restricted science (physics or chemistry) a limited range of phenomena are studied, reductionist laboratory experiments are possible and far-reaching mathematically expressed hypothesis can be quantitatively measured. In an unrestricted science (biology or geology), the effects under study are so complex that designed experiments with controls are often not possible.

The scientific approach based on reductionism, repeatability, and refutation founders when faced with extremely complex phenomena which entail more interacting variables than the scientist can cope with in his experiments. "The social sciences are "unrestricted" in Partin's sense and present considerable problems for the method of science, even beyond that of mere complexity." (Checkland, 1981, page 66).

2.2.2.2 Problems for Science: Social Science

Disciplines like anthropology, economics, sociology, political science, etc. as sciences still have a status problem. The main reasons for this is the lack of general laws, theories and predictions as there are to describe the natural sciences and the division between social scientists on central issues on the logic of social inquiry and methodology.

One aspect of the problem is that, "the phenomenon involved are ones with dense connections between many different aspects, making it difficult to achieve the reduction required for a meaningful controlled experiment" (Checkland, 1981, page 67). Another major problem is the special nature of the phenomenon to be studied, namely human beings (actors), and how they interact with each other. Social actions of men (due to their attribution of meaning, i.e. their experience and background) cannot be observed and explained in the same way that physical phenomena (or animal behaviour) can. The social scientist needs to understand, at least appreciate the viewpoint (context) of the actors themselves.

A third difficult feature of social science is the problem of making predictions of social happenings. Popper argues that, "the happenings in social systems are strongly influenced by the growth of human knowledge; the future growth of knowledge is in principle unpredictable since we cannot know the not yet-known; therefore the future of social systems cannot be predicted." (Checkland, 1981, page 70). Therefore, there can be no scientific theory of historical development (theoretical history) to serve as a basis for historical prediction.

All these problems experienced with the social sciences can be attributed to one important fact, namely that human beings have a self-consciousness and because of this have the freedom of choice which is unlimited and extremely complex. An observer can never obtain an "up-to-date" state of mind of an agent he is observing . As soon as the agent agreed the correctness of the observer's account, by simply changing the state of his mind he can render that account out of date. At best social systems will reveal "trends" rather than "laws". In this situation the social scientist can only study the "logic of situations" instead of the exact social reality. However, over the years, his findings will contribute to the growth of human knowledge and lead to a more accurate reality.

As yet the method of science has not, and will not easily be applied to the investigation of social phenomena. Nabokov mentions: "It is silly to seek a basic law, even sillier to find it. Everything is fluid, everything depends on chance" (Checkland, 1981, page 71).

2.2.2.3 Problems for Science: Management

If we had a social science similar to that of the natural sciences, with tested and accepted hypothesis and laws, and a body of theory which defines the context in which these hypothesis and laws are valid, then that social science would help managers solve "real-world" problems, just as natural science is available to help technologists and engineers solve their problems.

Operational Research (the closest management science comes to having a hard scientific core) hosts a list of problematic situations, e.g., Allocation Problems, Inventory Problems, Replacement Problems, Queuing Problems, Sequencing and Routing Problems, etc. Operational Research can be defined as, "the application of the methods of science to complex problems arising in the direction and management of large systems of men, machines, materials and money in industry, business, government and defence. The distinctive approach is to develop a scientific model of the system to help management determine its policy and actions scientifically." (Checkland, 1981, page 73).

The three problems for science considered above;- complexity in general, the extension of science to cover social phenomena, and the application of scientific methodology in real-world situations have not been satisfactorily solved. It is in the quest to find an appropriate way to deal with such situations that systems thinking was initiated.

2.2.3 THE DEVELOPMENT OF SYSTEMS THINKING

The existence of the Systems Movement has been as a response to the inability of reductionist science to cope with these various forms of complexity described above. Systems Thinking is an attempt to retain much of the scientific tradition and to supplement it by tackling the problem of irreducible complexity via a form of thinking based on wholes and their properties which complements scientific reductionism. At present systems thinking must establish its "credentials". It is founded on two pairs of ideas, namely those of emergence and hierarchy, and communication and control.

2.2.3.1 Emergence and Hierarchy

During Aristotle's time "he argued that the whole was more than the sum of its parts. His teleological outlook viewed objects in the world to fulfil their inner nature or purpose" (Checkland, 1981, page 75). The history of modern biology reinstates his idea of 'purpose' as a respectable intellectual concept.

For Hans Driesch and other vitalists the development of the organism from a single egg meant that in each developing organism resides "a mysterious spirit-like entelechy which somehow directs and controls the growth of the whole" (Checkland, 1981, page 76). This was explained by the discovery that hereditary information is stored in the deoxyribonucleic acid (commonly known as DNA) structure of animals. This "genetic coding" enabled offspring to inherit characteristics from the parents. Microscopic examination of plants and living tissue discovered the cell;- a scientific discovery which led to the modern view that in each living thing there is a hierarchy of structures;- in the sequence: molecules, organelles, cells, organs, the organism." The general model of organised complexity that evolved is that "there exists a hierarchy of levels of organisation, each more complex than the one below, a level characterised by emergent properties which do not exist at the lower level (Checkland, 1981).

Broad (1923) disentangled the emergence concept from crude vitalism and helped to establish the position that "the existence of organisms having properties as wholes call for different levels of description which correspond to different levels of reality." In 1926 Smuts covered the concepts such as entelegy by the concept of organised complexity; "every organism, every plant or animal, is a whole with a certain internal organisation and a measure of self-direction." (Checkland, 1981, page 79). Woodger (1929) considered the antithesis between vitalism and mechanism as well. He concluded that "the architecture of complexity is one of hierarchical organisation, and the emergent properties of a given level of organisation are consonant with a process of evolution which is creative." (Checkland, 1981, page 79). These writings of Broad, Smuts and Woodger illustrate the emergence of systems thinking.

Hierarchy is based on differences between one level of complexity and another. The imposition of constraints upon activities at one level to produce meaningful activity at a higher level suggests some form of regulation or control. One cannot control without communication. The next section discusses communication and control.

2.2.3.2 Communication and Control

Wiener (1948) defined cybernetics as "the entire field of control and communication theory, whether in the machine or in the animal." Weiner and Bigelow realised the importance and ubiquity of "feedback". They define feedback as "the transmission of information about the actual performance of any machine to an earlier stage in order to modify its operation." (Checkland, 1981, page 85). All control processes depend upon communication, whether it is automatic or manual. The idea of feedback is essential for effective communication. Any feedback mechanism in a viable system requires a "sensor" which is capable of detecting potentially disruptive environmental changes and an "effector" which is capable of taking remedial action. Ashby demonstrated that "continuing effective control in a changing environment requires a controller with a variety of response which can match the variety of the environmental information;- his Law of Requisite Variety." (Ashby, 1964).

2.2.3.3 The Shape of the Systems Movement.

The systems movement is the set of attempts in all areas of study (the various disciplines) to explore the consequences of holistic rather than reductionist thinking and to generalise these developing ideas. Its programme is to test the conjecture that these ideas will enable us to tackle the problem of organised complexity which the method of science finds so difficult.

Consequently, the aims of the General Systems Theory (G.S.T) were to be:

1. To investigate the isomorphic concepts, laws, and models in various fields, and to help in useful transfers from one field to another;
2. To develop adequate theoretical models in areas which lack them;
3. To eliminate the duplication of theoretical efforts in different fields;
4. To promote the unity of science through improving the communication between specialists. (Checkland, 1981, page 92).

Due to the strong reductionist mode of thinking and with no clear philosophy, systems thinking progress is slow. It must be the current task of the systems movement to develop systems thinking to a point were one is comfortable using it.

Currently there are generally four systems classes which make up the universe.

1) *Natural Systems:-* systems whose origin is in the origin of the universe and are as they are as a result of the natural forces and processes which characterise this universe.

2a) *Designed Physical Systems:-* man made systems which are the result of conscious design to achieve some objective, usually physical systems.

b) *Designed Abstract Systems:-* represent the abstract and ordered conscious product of the human mind.

3) *Human Activity Systems:-* less tangible than natural and designed systems which

involve the unique self-consciousness of the human mind.

4) *Social Systems*:- combined natural and human activity systems. As a result of the need for humans to live harmoniously within the natural environment

To accommodate systems beyond current scientific knowledge *Transcendental Systems* has been named.

According to Ackoff (1974) a system can be considered to be a set of two or more elements that satisfy the following three conditions:-

1. The behaviour of each element has an effect on the behaviour of the whole
2. The behaviour of the elements and their effects on the whole are interdependent
3. However many subgroups of the elements are found, each has an effect on the behaviour of the whole and none has an independent effect on it. As a result, the whole cannot be understood by analysis (reductionism).

The essential properties of a system is formed from the interactions of their parts and not their actions taken individually. Therefore, if a system is taken apart, it loses its essential properties, and hence, cannot be understood by analysis (Ackoff, 1974).

2.2.3.4 The Role Of Systems Thinking In Science.

The systems movement comprises any and every effort to work out the implications of using the concepts of an irreducible whole, 'a system', in any area of endeavour. It would be naive to imagine that a basic language would be consciously adopted by systems thinkers in the widely different disciplines. One can only hope that a gradual consensus on these ideas will develop.

With the realist there is outside ourselves a reality which actually does exist and which must be dealt with. As a systems thinker one must acknowledge that the reductionist method of science cannot cope with certain problems, especially the problems of the real world, as apposed to those defined in the laboratory. One must think in terms of coherently organised entities which cannot properly be reduced to mere aggregates of their components. by doing this the inter-relationships between parts are broken. A systems thinker must define the "system" and its boundaries. He must realise that his ultimate objective is the attainment of scientifically acceptable knowledge where holism replaces reductionism.

Recognition should be given to the observer's motives;- he may be a 'natural historian' (curious), manager (implement in the real world) or an engineer. He will define some entities which are coherent wholes, invent some principles of coherence, draw a boundary around an entity, and identify some mechanism of control. Any whole conceived as "a system" is, in general, a part of a hierarchy of such things - it may contain "subsystems" and itself be part of a "wider system". The observer can describe the behaviour of a system by treating his system as a 'black box' (focusing on the input and output only) or he may describe the internal state of the system.

According to Ackoff (1974) synthesis (putting things together) is a crucial feature used in systems thinking. Synthesis consists of the following three steps:-

1. Identify a metasystem of which the system under investigation is part of.
2. Explain the properties or behaviour of the metasystem.
3. Explain the properties or behaviour of the system under investigation in terms of its roles or function within its containing metasystem.

In systems thinking understanding is acquired by expanding the systems to be understood instead of reducing them to parts. Analysis focuses on structure (material properties), whereas synthesis focuses on function (inter-relationships). In summary, in a systems thinking approach, there will be:-

- an observer who gives an account of the world, or part of it, in systems terms;
- his purpose in so doing;
- his definition of his system or systems;
- the principle which makes them coherent entities;
- the means and mechanisms by which they will maintain their integrity;
- their boundaries, inputs, outputs, and components;
- their structure.
- a description of their behaviour.

2.2.4 A SUMMARY OF CYBERNETIC LAWS, PRINCIPLES AND THEOREMS (Others are listed in appendix A.0.)

This section presents a number of the laws, principles and theorems of cybernetics as summarised by Barry Clemson (1984, page 199 to 202) which are relevant to this thesis.

1. SYSTEM HOLISM PRINCIPLE: A system has holistic properties possessed by none of its parts. Each of the system parts has properties not possessed by the system as a whole.
2. DARKNESS PRINCIPLE: No system can be known completely.
4. COMPLEMENTARITY LAW: Any two different perspectives (or models) about a system will reveal truths about that system that are neither entirely independent nor entirely compatible.
5. HIERARCHY PRINCIPLE: Complex natural phenomena are organised in hierarchies with each level made up of several integral systems.
6. GODEL'S INCOMPLETENESS THEOREM: All consistent axiomatic foundations of number theory include undecidable propositions.
15. HOMEOSTASIS PRINCIPLE: A system survives only so long as all essential variables are maintained within their physiological limits.
17. REQUISITE VARIETY LAW: The control achievable by a given regulatory sub-system over a given system is limited by

    1) the variety of the regulator, and

    2) the channel capacity between the regulator and the system.

    An alternate statement of the law is that the upper limit on the amount of regulation achievable is given by the variety of the regulatory system divided by the variety of the regulated system.
18. CONANT-ASHBY THEOREM: Every good regulator of a system must be a model of that system.
19. SELF ORGANIZING SYSTEMS PRINCIPLE: Complex systems organize themselves; the characteristic structural and behavioural patterns in a complex system are primarily a result of the interactions among the system parts.
21. VIABILITY PRINCIPLE:

    Viability is a function of the balance maintained between two dimensions:

    1) autonomy of sub-systems versus integration of the system as a whole,

    2) stability versus adaptation.
22. RECURSIVE SYSTEM THEOREM: If a viable system contains a viable system, then the organisational structure must be recursive, or, in a recursive organisational structure, any viable system contains, and is contained in, a viable system.

2.2.5 CONCLUSION

The scientific approach based on reductionism, repeatability, and refutation founders when faced with extremely complex phenomena which entail more interacting variables than the scientist can cope with in his experiments, e.g. social systems. The problems with the social sciences are attributed to the self-consciousness of human beings (their freedom of choice). The reductionist method of science is not easily be applied to the investigation of social phenomena.

The existence of the Systems Movement has been as a response to the inability of reductionist science to cope with various forms of complexity. Systems Thinking is an attempt to supplement it by tackling the problem of irreducible complexity via a form of thinking based on wholes and their properties which complements scientific reductionism. At present systems thinking must establish its 'credentials'. It is founded on two pairs of ideas, those of emergence and hierarchy, and communication and control;- mostly from biology and in communication and control engineering.

The status of disciplines like anthropology, economics, sociology, political science, etc. as sciences is a question which is still problematic in itself. The main reasons for this being the lack of general laws, theories and predictions as there are to describe the natural sciences and the division between social scientists on central issues on the logic of social inquiry and methodology. If we had a available social science similar to that of the natural sciences, with tested and accepted hypothesis and laws, and a body of theory which defines the context in which these hypothesis and laws are valid, then that social science would help us solve 'real-world' (management) problems, just as natural science is available to help technologists and engineers solve their problems.

While systems thinking battles for a common language, general laws, terminology, case studies, and a "systems language" is developing. What we have thus far are a number of cybernetic laws, principles and theorems from which to work. Systems Thinking is not an attempt to replace the established reductionist approach but should be used with the physical sciences with the aim of obtaining a better understanding of our complex and ever-changing world. The next chapter considers systemic methodologies for use in this thesis.

CHAPTER THREE: SELECTING A METHODOLOGY

This chapter discusses three methodologies considered for application, namely, Stafford Beer's Viable System Model (VSM), Peter Checkland's Soft Systems Methodology (SSM) and Luc Hoebeke's Work Systems. After each of the models are described a choice of the most appropriate methodology is made.

3.1 BEER'S VIABLE SYSTEM MODEL (VSM)

The section is the synthesis of the work by Beer (1985, 1966), Flood and Jackson (1991), Clemson (1984) and Ashby (1964). It starts by giving a philosophical basis and the principles of Viable System Diagnosis. The five levels of the model and the inter-relationships between them are discussed. Lastly, a conclusion is made.

3.1.1 THE PHILOSOPHY OF VIABLE SYSTEM DIAGNOSIS

The Viable System Model (VSM) can generally be used for diagnosing "problems" of organisations, hence the term Viable System Diagnoses (VSD), particularly those arising in complex probabilistic systems that compromise purposeful organised parts and are open to a changing (dynamic) environment and yet in which there is a general or easily attainable agreement about objectives to be pursued (Flood and Jackson, 1991).

The use of cybernetics is useful when, for example, issues in a business are characterised by particular defects or pathologies, possibly localised, that are resistant to or ignored by normal treatment. In such circumstances, the viable system view assumes that natural cybernetic laws are being violated-hence the need for diagnosis and the use of cybernetic findings in reorganisation. Thus cybernetics can be considered to study the difference between effective and ineffective modes, structures and methods of organisations.

The philosophy that drives Beer's view of cybernetics concerns the kind of changes we are experiencing in the twentieth century. He thinks that new ways are needed to deal with difficulties associated with changes. The main points are summarised below;-

* Organisational and social "problems" arise because of new degrees of complexity (organisational, technological, informational, etc.) and are characterised by interdependency.
* Scientifically based management taking advantage of technological advances is vital because

traditional approaches are simply too trivial and in isolation are not well worked out. Therefore, a scientific model that is based on cybernetic principles and which encompasses many ideas from management science is fundamental in our efforts to deal with modern complexities.

* Since control is the main concern, the best approach then is to replicate a well tried and tested "control system";- the neurocybernetic processes of the human brain and nervous system as it evolved over millennia.
* Organisations ideally are ordered so as to achieve efficient and effective realisation of set goals, although these goals themselves have to be continually reconsidered in response to a rapidly changing environment through self-questioning, learning and by assessing future scenarios.

(Flood and Jackson, 1991).

3.1.2 PRINCIPLES OF VIABLE SYSTEM DIAGNOSIS

Weiner in 1947 defined cybernetics as "the science of control and communication in the animal and the machine" (Jackson, 1990). In 1959 Beer defined cybernetics as "the science of effective communication" (Beer, 1959, page 7). The principles that encompass VSD are all cybernetic in nature as highlighted above. When organisations do not perform well it is assumed that cybernetic principles are being violated. Some of these principles are outlined below.

* Recommendations endorsed by the VSM do not prescribe a specific structure, rather it is concerned with the essentials of organisation and maintenance of identity. The model can be applied to a wide range of organisations, large and small.
* The notion of "recursion" is fundamental so that vertical interdependencies can be dealt with. Recursion means that the whole system is replicated in the parts so that the same viable system principles may be used to model a sub-system (a division) in an organisation, the organisation itself or its supra-system (that of which the organisation is a part of).
* In any viable unit, horizontally inter-dependent sub-systems (divisions) are integrated and guided by the viable units "meta-system" or "higher" management levels.
* Sources of command and control are of particular concern and in VSM these sources are spread throughout the architecture of the "viable system", which enhances self-organisation

and localised management of "problems".

* Emphasis is placed on the relationship between the viable unit and its environment in terms of influencing it and being influenced by it and in particularly on using this relationship to promote learning.

(Flood and Jackson, 1991).

* Two other important aspects of cybernetic principles included in the model are the notions of feedback and that of the Law of Requisite Variety. Ashby (1970, page 207) defined this law by saying that "only variety can destroy variety". Alternatively, this law states that the variety of the controller must be equal to or greater than that which is being controlled, i.e. the amount of regulation attainable is absolutely limited by the variety of the regulator.

3.1.3 THE VIABLE SYSTEM MODEL

Before the VSM can be applied one needs to, firstly, determine precisely what the organisation (the system-in-focus) to be modelled, based on its purpose, is, and to specify its boundaries. Next, the viable parts (operational units) and the larger system which is itself a viable part, must be specified. Consider a trio of viable systems at any one time; the organisation we wish to study, that within which it is contained, and the set of organisations within it. This trio of systems is commonly referred to as the triple recursion. This recursiveness of the VSM determines its self-referential nature, i.e. their logic closes in on themselves. (Beer, 1985). The above is clearly demonstrated section 7.2.

The VSM itself is an arrangement of five broad functional elements (systems 1 to 5) that are inter-connected through a complex of information and control loops (refer Figure 5.1) to maintain internal stability and to adapt to a changing environment. The VSM also specifies the information flows amongst the parts of the model.

3.1.3.1 SYSTEM 1 - IMPLEMENTATION

System one parts are directly concerned with implementation. Each part is autonomous (self-organizing) in its own right and must, therefore, exhibit all the features of a viable system itself, including the five functions. Each operational unit can be represented as a environment, an operation to perform, a management and a set of models. This is shown in figure 3.1 and figure 3.2.

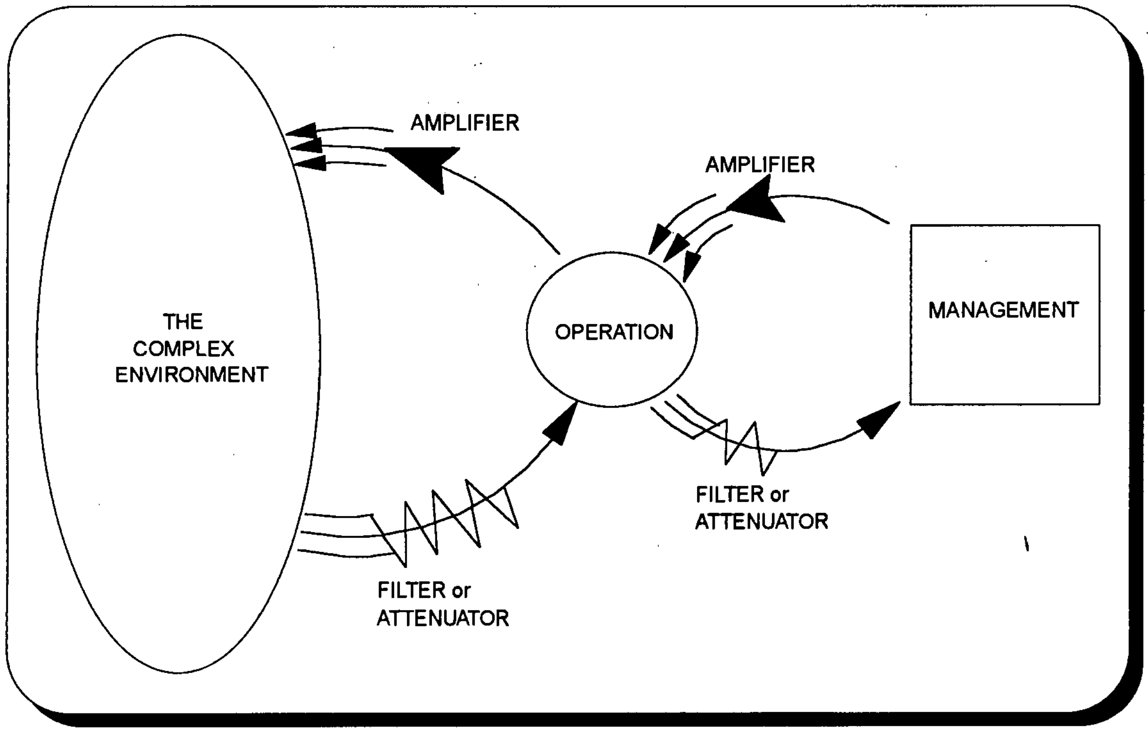


Figure 3.1 : The Environment, Operational Unit and Management

The variety of the environment greatly exceeds that of the operation that serves or exploits it, which in turn greatly exceed the variety of the management that regulates it. High variety is cut down, or attenuated (filtered out as shown in figure 3.1), to the number of possible states that the receiving entity can actual handle. (Beer, 1985, page 23). All the operational units connect to its local environment and so absorbs much of the overall environmental variety. In a similar manner the management also filters information coming from the complex operations environment. In figure 3.2 the system 1 parts (operational units) and management are shown as 1a, 1b, 1c and 1d. In a well defined information system there will be a set of explicitly designed filters to extract useful information from the massive variety of the operations system. Accountability of management to higher level management is a good example of variety attenuation.

There is also a need to amplify, or enhance, low variety to the number of possible states that the receiving entity (the environment and the operations units) needs if it is to remain regulated. This is clearly shown if figure 3.1. Notice boards, daily production meetings, memoranda, meeting minutes, etc. are examples of such activity.

3.1.3.2 SYSTEM 2 - CO-ORDINATION

System 2 co-ordinates the parts that make up system 1 in a harmonious manner and prevents the operational units from adversely affecting each other, i.e. it dampens the uncontrolled oscillations between the parts of system 1, under the direction of system 3.
System 2 is primarily necessary because feedback loops show complex oscillatory patterns based on the time lags around the various loops (Clemson, 1984, page 127).

3.1.3.3 SYSTEM 3 - CONTROL

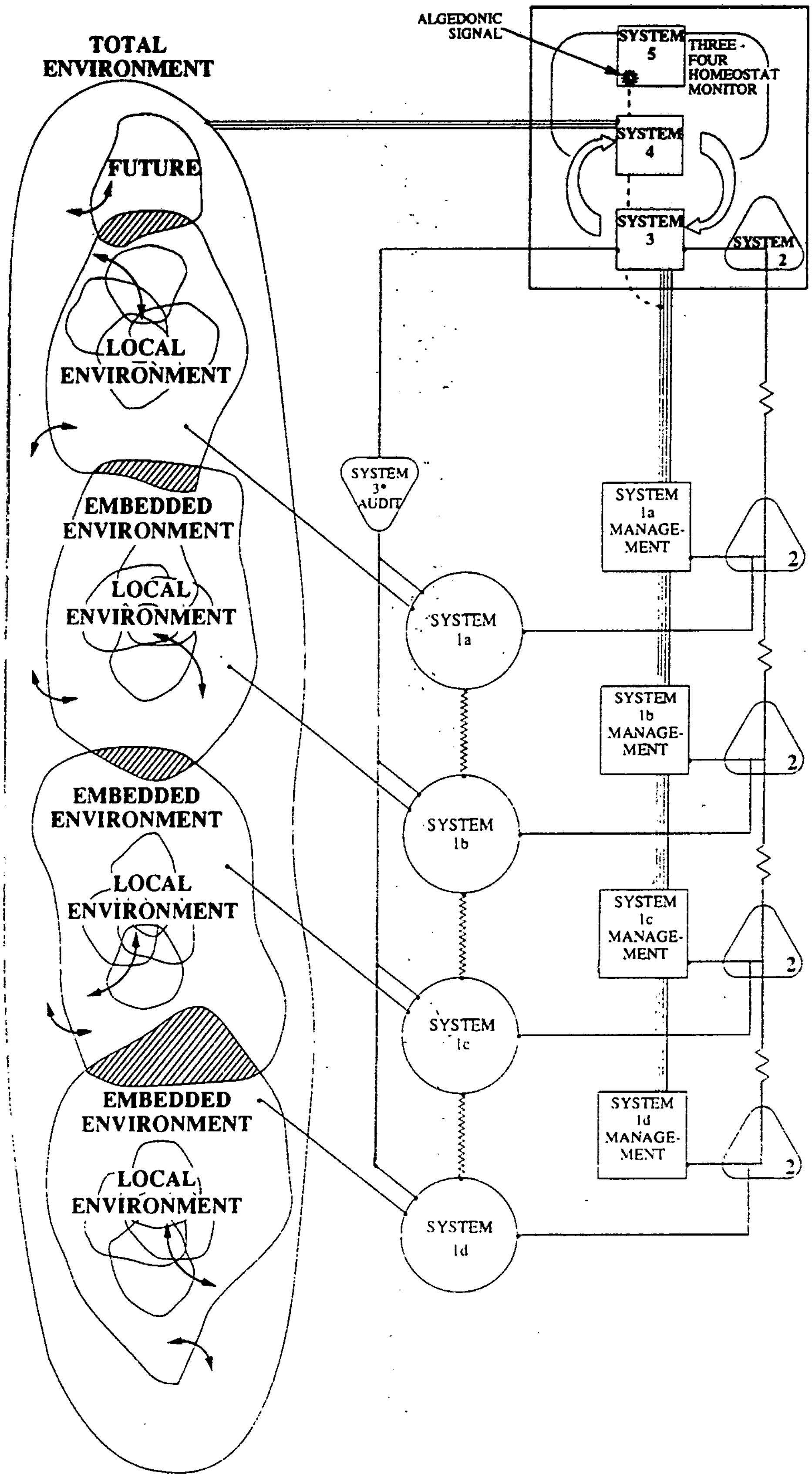
System 3 ensures that the organisation as an entity is producing the required output, namely that "things are kept running". To achieve this system 3 must ensure that the various operational units are in fact producing what they are supposed to be producing. System 3 performs a control function that ultimately maintains internal stability, i.e. it maintains the homeostasis of the system-in-focus. It considers the internal and now aspect of the organisation. To deal with (reduce) the high variety of the operational units (system 1 level) each of the operational units are treated as black boxes. The critical outputs of each operational unit are identified, its internal workings are ignored, and focus is given to its outputs as long as these outputs are acceptable.

System 3 allocates resources to ensure that its internal operational units have the resources (people, machines, raw materials, etc.) to perform their respective functions and that the system 2 function is established and operating.

This level interprets policy decisions of higher management and ensures effective implementation of these policies from higher management. This is done by conducting "audits" using the System 3* auditing channel (see figure 3.1) to assess whether the operations units are executing the tasks which stems from these policies.

3.1.3.4 SYSTEM 4 - DEVELOPMENT

System 4 serves as a development function. System 4 is about designing models. The first job for system 4 is to develop an explicit model of the organisation;- what does the system do and how does it achieve this? This model can then be used to gain some insight into the workings of the unit and can be used by the managers, at least enough to discover its flaws so that these



Source: Flood and Jackson, 1991, page 91. *Creative Problem Solving : Total Systems Intervention.*

Figure 3.2 : The Viable System Model

flaws can be corrected. In this regard system 4 embodies the Conant-Ashby Theorem 'Every good regulator must be a model of the system regulated' (Clemson, 1984, page 128).

The second function is to model the organisations problematic environment. At this level the environment and the future of the organisation is explored, e.g. market surveys, needs assessment, etc. Here the external and future is oriented towards growth and change, towards new threads and new opportunities, towards changing things around to make them more efficient or more effective (Clemson, 1984, page 107). It takes an intelligence gathering and reporting role that captures all relevant information about the systems total environment and maintains overall homeostatic stability;- in short it monitors the organisation's "health". System 4 brings together internal and external information in an "operations room", providing a proper environment for decision making.

A third function of system 4 is to deal with the future. From the model of itself and that of the environment (the market) system 4 has a base to model (predict) the organisations future needs.

This system rapidly transmits urgent information from Systems 1, 2 and 3 to System 5 and distributes environmental information upwards or downwards according to its degree of importance.

3.1.3.5 SYSTEM 5 - POLICY

Since system 3 is firmly focused on maintaining the status quo and system 4 is equally firmly focused on changing the organisation to meet market needs, conflict between them is inevitable. This tension between system 3 and 4 require a 'boss' to mediate. System 5, therefore, needs to arbitrate between the sometimes antagonistic internal and external demands on the organisation as represented by Systems 3 and 4. The primary function system 5 is to make sure that the interaction between system 3 and 4 is at an optimal level. Practically, this implies that the balance between stability and the rate of change must be about right.

To achieve this the identity, and hence purpose, of the organisation must be clearly defined. Thus, system 5 is also responsible for the organisation's policy and represents the essential qualities of the "whole system" to any "wider system" of which it is part. System 3 and 4 are logically superior to system 1 in that they have a broader view, they see the whole, and they speak a meta-language competent to resolve issues that are undecidable in the languages of the operational units. By Godel's theorem, systems 3 to 4 must also face undecidable issues. System 5 provides closure by saying 'this is the sort of outfit we are and when all else fails we decide in terms of this self image' (Clemson, 1984, page 138).

Godel's Incompleteness Theorem states that 'all consistent axiomatic foundations of number theory include undecidable propositions'. The managerial implication of this is that the language framework of a given organisation is always incomplete in the sense that decision situations arise that cannot be adequately expressed within that framework and therefore cannot be resolved by that framework. No ordinary language can be complete and self-sufficient. (Clemson, 1984, page 208).

Lastly, system 5 can also responds to any emergency signal from system 1. This signal passes through the various "filters" of systems 2, 3 and 4 and is referred as the algedonic signal (see figure 3.1).

3.1.4 CONCLUSION

Beer's VSM embodies the laws of cybernetics which is defined as the the science of effective organisation. Cybernetics describes the general principles of growth, learning and adaption in complex, dynamic systems. The Viable System Model offers an effective method to absorb variety in the manner in which the model structures systems 1 to 5. The model offers a tool to approach the design of effective communication in complex social systems. From a viewpoint of the Law of Requisite Variety, Beer's VSM deals with residual variety and highlights the important heuristic value of Ashby's Law; "Only variety can absorb variety".

The next section introduces the second methodology considered, namely, Peter Checkland's Soft Systems Methodology (SSM).

3.2 CHECKLAND'S SOFT SYSTEMS METHODOLOGY (SSM)

This section gives a brief outline of how Peter Checkland's Soft Systems Methodology (SSM) emerged from the inadequacies of the more conventional approaches. The assumptions that are made in the use of SSM are listed. The various stages of the SSM model are discussed. Lastly, conclusion are made.

3.2.1. THE EMERGENCE OF SSM

SSM is a problem solving approach developed from systems engineering when systems engineering approaches failed. This failure occurred when attempts were made to apply it to the complex, messy and ill-defined problem situations which managers have to cope with. By teleogically establishing the purpose of a object or system an engineer works back from the purpose, or objective, and creates an object or system which will achieve that objective. This kind of thinking initiated 'systems engineering' (SE) "as a series of steps in a process. These steps start by defining the need to be met and the objectives of the system which will meet them." (Checkland, 1981, page 274). Alternative systems are appraised and the best is selected for development. Finally the system is manufactured, operated and maintained. This failure of the SE approach in normal management situations led to the emergence of SSM.

'Systems Analysis' (SA) combines engineering and economics ideas to help a real-world decision maker. This approach "assumes an objective we desire to achieve; alternative systems for achieving it; costs of resources required by each system; model showing inter-dependencies of objectives, systems, resources and environment; and a criterion for choosing the preferred alternative." (Checkland, 1981, page 275).

'Operational Research' (OR) showed that it was possible to understand, if not the unique complexities which characterise social systems, at least the logic of situations, e.g.. managing queues, locating depots, deciding when to replace capital equipment, etc. The approach "seeks to apply the empirical method of natural science to real-world operations." (Checkland, 1981, page 275). It simulates the real-world using a model and manipulates this model to achieve defined objectives.

The fundamental thinking of SE, SA and OR are similar in the sense that they all seek an efficient means to achieve some known and desirable objective. This approach has been termed 'hard' systems.

In managerial problems establishing clear objectives is often not possible. SSM grew out of this search for "an approach to problem solving which would cope with messy situations in which objectives where themselves problematical." (Checkland, 1981, page 275). Also, the use of these hard systems in various situations showed that the management language of these models did not get heard in certain cultures in which they were used. This was because these methodologies only focused on the facts and logic of the situation and missed out on the 'human richness' of the situation. Any human-related interaction is complex simply because individuals are autonomous. Shared perceptions, of executive management as well as shop-floor worker, must be established, negotiated, argued and tested in a complex social process. SSM emerged as an alternative to attempt to address these soft human issues.

3.2.2 SOFT SYSTEMS METHODOLOGY

SSM is not only a system concerned with achieving objectives but it is also a learning system. It starts with an enquiry and the "learning" process itself, is about a complex problematic human situation. The objective is to take purposeful action (which is feasible to all those concerned) in the situation with the aim to improve it. Taking that action changes the problem situation. Inquiry then continues, since there are always new things to learn, and this learning is in principle never ending.

3.2.2.1 Assumptions

In any SSM application the following assumptions are made:

1. SSM is a process for managing and must therefore take a particular view of what 'managing' is and what a manager does.
2. Different individuals and groups, being autonomous, will make different evaluations which will lead to different actions.
3. 'Systems' is a concept of a whole which has properties as a single entity, so-called 'emergent properties'.
4. A set of activities linked together in a logical structure to constitute a *purposeful* whole could be taken to be a new concept of system and can be placed alongside

'natural system' and 'designed system', namely a 'human activity system'. (Checkland, 1981, page 278 and 279). To use human activity systems the readiness to talk of purposeful activity only in terms of a particular interpretation, bias, prejudice or value system means that we have to accept, firstly, that there will be multiple possible descriptions of action and, secondly, any description of purposeful activity which is be used analytically will be explicit concerning assumptions about the world which that description takes as given, i.e. we must declare the Weltanschauung which makes the description meaningful. "Weltanschauungen being the stocks of images in our heads, put there by our origins, upbringing and experience of the world, which we use to make sense of the world and which normally goes unquestioned." (Checkland, 1981, page 279).
Consequently, SSM was forced to take into account the need to describe any human activity system in relation to a particular view of the world. It had to accept that any real-world purposeful action could be mapped by several human activity system descriptions, based on different assumptions about the world.

5. "SSM learns by comparing pure models of purposeful activity (human activity systems) with perceptions of what is going on in a real world problem situation." (Checkland, 1981, page 278).

SSM is an articulation of a complex social process in which assumptions about the world are teased out, challenged and tested. It is thus intrinsically a participative process, because it can only proceed by debate.

3.2.2.2 The Stages of SSM

In everyday conducting of inquiry and making decisions one relies upon one's personal experience. SSM starts by naming "root definitions" (RD), human activity systems (purposeful activity), which are relevant to solving the problem. These models of the human activity systems are compared with the real-world actions to provide debate about possible changes which would improve the problem situation. The debate focuses on the differences between the model and the real-life situation. Generally these changes are an accommodation of the various conflicts which are endemic in human situations.

These changes "must be both systematically desirable and culturally acceptable by the people in the problem situation, given the unique history of the specific situation in a particular culture." (Checkland, 1981, page 281). The results of the action taken completes a cycle of learning and action, the flux (knowledge base of newly acquired events and ideas) move on, and the cycle of inquiry, learning and action can be repeated again. The SSM process is generally separated in the following seven stages.

Stages 1 and 2 : Finding Out

This stage involves establishing and defining the problem situation. During this stage it must be remembered that the personality traits, experience, knowledge and interest of the investigator will all affect what is noticed and what is taken to be significant. The investigator must therefore attempt to conduct his inquiry in a unbiased manner.

Stage 3 : Formulating Root Definitions

This stage formally notes down the names of some purposeful human activity systems which are relevant to finding ways which will improve it. The naming of the relevant systems are termed 'root definitions ' (RDs). "The core of the RD is the transformation process (T) which changes some defined input into some defined output. What is looked for in this stage is the coherent formulation of some RDs which can be related to the CATWOE (customer, actions, Transformation processes, Weltanschauung, Owner, Environmental constraints) questions and from which models can be built" (Checkland, 1981, page 282).

Stage 4 : Conceptual Models

"The model building process consists of assembling the verbs describing the activities in the systems named in the RD and structuring them according to logical dependencies. These dependencies govern the operational part of the system which would achieve the transformation processes) named in the RD." (Checkland, 1981, page 282).

The final model is that of a system, a national entity which can adapt and survive, via processes of communication and control, in an ever-changing environment. Because of this, it is necessary to add to the operational sub-system a monitoring and control sub-system, which acts as feedback to change and/or improve them. Any system model is thus a combination of an operational system and a monitoring and control system. To monitor and control the system must be able to measure its effectiveness, efficacy and efficiency.

Lastly, one need to ensure that the concept of 'hierarchy' is considered. This idea implies that "no system can ever be conceptualised in isolation, it only exists at one level in a stratified order of sub-systems, systems and wider systems." (Checkland, 1981, page 284). At the end of this stage a number of models of activity systems are available. Some of these models are probably hierarchically related. Each of these were designed to consider a particular point of view of the world (which is reflected in the W of CATWOE).

Stage 5 : Comparing Models and Reality

The models developed in stage 4 provide new perceptions of reality and initiates fresh debate from which a solution can be sought. This is done by discussing the differences between the models and perceived reality. Since models are based on carefully expressed worldviews (due to the diversity of humans involved), the discussion directs attention to the assumptions about the world, highlights alternatives and in general provides an opportunity for re-thinking many aspects of real-world activity, i.e. the discussion allows consideration for other peoples perceptions and understanding of the situation. This stage provides the structure and substance of an organised debate about improving a situation thought of as problematic.

Stage 6 : Defining Changes

From the debate stage changes are suggested. These ideas must be systematically desirable as well as culturally acceptable. This is why it is so important to think carefully about the Weltanschauugen of each RD and model. "The W in CATWOE ensure that cultural aspects cannot be ignored" (Checkland, 1981, page 287). The chance of achieving change is considerably improved if both feasible and cultural criteria are considered, although cultural 'growth' (change) may itself occur in and by the debate stage 5 and 6. SSM can therefore be seen as a way of exploring cultures and enabling them to change.

Stage 7 : Taking Action

When some changes have been identified and accepted as 'desirable and feasible' they can be implemented. This stage completes the SSM process. Learning involves the re-application of this stage in the search of more 'real' and accurate answers.

3.2.3. CONCLUSION

SE, SA and OR aims to fulfil a defined objective, and systematically finds its way to a system to fulfil this objective. These methodologies fail when applied to complex human activity systems because they only focus on facts and the logic of the situation.

SSM takes into consideration the unique 'human factor' which introduces the complexity when dealing with real-world issues. It accepts that the real-world situations are much complex than the hard systems models. It uses the models to structure a debate in which different conflicting objectives, needs, purposes, interests and values can be discussed. In this way it tries to encompass cultural myths and meanings as well as publicly testable facts and logic. It thus seeks to articulate a process in which a compromise between conflicting interests and views can result in some action aimed at feasible improvement to be taken.

SSM is a learning and not an optimising system. The ending of a systems study using SSM is only temporarily 'complete', the flux of events and ideas moves on, there are no permanent solutions, and SSM is in principle never ending. In SSM the 'system' is not something out there in the situation but is the actual process of enquiry. Lastly, SSM offers a methodology to deal with "soft", ill-structured (messy) problems where there is no clear view of what constitutes the problem, or what action should be taken to overcome these difficulties.

The next section discusses the third methodology considered, namely, Luc Hoebeke's "work systems".

3.3 LUC HOEBEKE'S WORK SYSTEMS

From the concepts of Stafford Beer's VSM, Peter Checkland's SSM and Elliot Jacqes "Forms of Time" Luc Hoebeke developed his "work systems" framework. The model is based on human activities and relations in work systems at 9 hierarchical levels depending on the time span of the work activity. These 9 levels can be categorised into 4 "Domains", namely, the Added-value, Innovation, Value Systems and Spiritual Domains. This section discusses this framework.

3.3.1 BACKGROUND AND PURPOSE

The main reasons for Luc Hoebeke's "Work Systems" was a result of the following reasons:-

(1) An awareness that current organisational models are irrelevant for explaining the performance of the organisations being dealt with. This performance is better understood when work systems are considered;- as systems loosely coupled self-regulated semi-autonomous networks rather than static hierarchical pyramids.

(2) An urge by younger colleagues, students and clients alike, to transfer the framework Hoebeke is using to diagnose organisations. He seems to discern patterns which are self-evident for him, but are revelations for the latter people.

3) Hoebeke has started to internalise the concepts of Peter Checkland (SSM), Stafford Beer (VSM) and Elliot Jacqes (Forms of Time) to such an extend that a book of his own has developed. (Hoebeke, 1994, page 2)

Hoebeke's Contribution

By using the concepts of Peter Checkland Hoebeke discovered certain generic patterns of Human Activity Systems (HAS). He transformed these patterns into a typology of HAS in order to facilitate the use of SSM.

Hoebeke highlights two reasons why the use of VSM creates resistance to its use. "The fact that more attention is paid to what Beer calls organisational pathologies and their diagnosis is not very helpful for putting effort into improvement." (Hoebeke, 1994, page 4) In Hoebeke's experience he found the model more useful when he tried to explain problems in terms of work systems. Secondly, "Beer and his followers are still too easily seduced to apply the VSM to "big" systems" (Hoebeke, 1994, page 4).

According to Hoebeke Elliot Jaque, who provided Hoebeke with the keystone of the framework he developed, had a poor understanding of work systems. Jaque believed that in people's minds the hierarchies become embodied in real people and the way they relate. However, he does not deal with the reason for their relationship. Hoebeke's uses the latter concept to make a typology of activities as well and hopes to attain greater clarity than Jaque.

Hoebeke's "Making Work Systems Better", "aims to describe a conceptual framework that is relevant for understanding and intervening in the task-related issues of work systems" (Hoebeke, 1994, page 5). It deals mainly with the set of activities which make up a work system (a system of meaningful activities).

3.3.2 THE BASIC MODEL

In any work system there are a limited number of people one has to deal with;- each fulfilling the actor, owner and client roles. In practice the work system is a network of living people who are continuously interacting with each other and forming intricate relationships. Hoebeke defines four domains with each containing three successive strata (or process levels), namely, the added-value, innovation, value systems and spiritual domain. Together they form work systems at 9 hierarchical levels depending on the time span of the work activity.

These domains and process levels are summarised in figure 3.2. The added-value domain consists of the process levels 1 to 3. Its activities span a period of 1 day to 2 years. The innovation domain activities encompass a time span from 1 to 10 years and consists of the process levels 3 to 5. Process level 3, with a time span of 1 to 3 years, belongs to both the added-value and the innovation domains. The activities of the third domain, the value systems domain, has a time span ranging from 5 to 50 years. This domain consists of activities which range from process levels 5 to 7. Here again the process level 5 (containing of activities with a time span of 5 to 10 years) belongs to both the innovation and value systems domains, forming a necessary overlap. The last domain, the spiritual domain, consists of activities with a time span of greater than 20 years. Once again, process level 7 forms a link between the value-systems domain and the spiritual domain.

Hoebeke suggests that his four domains be considered as the four recursion levels (from Beer's VSM) of all human affairs. He claims that each domain has its own emerging characteristics as a viable system. Each of these domains creates necessary but not sufficient conditions for the activities of a lower domain, but each is operating in a quasi-autonomous way in its own set of activities. The next sections discuss each domain in detail.

3.3.3 THE ADDED-VALUE DOMAIN

This domain encompasses process levels 1 to 3 and has a time span of 1 day to 3 years. It involves all human activities between suppliers and customers. Value is added to raw materials from suppliers and then supplied to customers, i.e. it is basically the "economic" domain. The appreciation of the model expresses itself in the maintenance of the supplier-customer relation (the supplier and customer work systems), hence in the viability of its components. Supply and demand are not seen as abstract forces, but as the systemic relation between two parties who rely upon each other for fulfilling their needs. In the value-added domain the four essential output requirements identified are throughput time, volume (quantity), quality and cost.

Process Level 1: From 1 day to 3 months

Here we consider achieving a product or service as efficiently as possible with the current methods and technology, and look at methods of reducing all types of waste in the work systems. Most of the activities that occur on the shopfloor belong to this process level.
In factories, the appearance of excessive queues, inventory or material waiting for a subsequent process are all signs of inefficiency (waste) at this process level.

The basic strategic dilemma, therefore, is whether the output can be achieved with the minimum amount of waste? The output specifications as required for the customer (client) cannot be achieved anywhere else but at process level 1;- it must be made available as concretely as possible to the actors contributing to this process. A continuous interaction between the customer and the company is essential to ensure customer satisfaction.

In order to provide the essential transparency which this process level requires there is a need to have direct feedback about the efficiency (output and waste produced) of the work system. Through this control information (mechanisms) waste is kept at a minimum. Examples are kanbans, the ability of an operator to stop a process if waste (defects) occur, etc.

By using audit information we start questioning the specifications of the customer and the current production processes to achieve them and the waste that is generated in the process. This information contains possible variances that can occur and how they are dealt with by the people contributing to them. It is a good tool for detecting waste and hence, for improving efficiency. Examples are quality circles, employee involvement programmes, etc.

		TIME FRAME	
Recursion Level 1 ADDED-VALUE DOMAIN "Realm of economic activity" (Throughput time (delivery), Cost, Quality and Volume)	**Process Level 1**	***1 to 3 months.***	The transformation process and activities generally involves activities performed or executed on the "shopfloor". Involves the materialisation of product and services with presecibed means, technology and method, in the most effecient way. Efficiency is defined here as the realisation of the process with a minimum of waste. Monitor kanbans, variations from specifications. Introduce quality circles, employee involvement teams, etc.
	Process Level 2	***3 months to 1 year.***	To mould the customer requirements on above process level into minimal critical specifications. Question of efficacy are raised; - are we using correct means to achieve required output. Need to improve efficacy Use performance indicators, eg. statistical process control. Resource allocation. Most audits;- performed once per year, eg. stocktake (financial audits), quality audits, etc belong here. Activities are which will lead to efficacy improvements are developed here, eg. information technology projects.
	Process Level 3	***1 to 2 years.***	To develop alternative products and services and alternative ways of meeting the requirements and needs of known clients:- - develop (improve) procedures, tools, machines, processes, inputs and outputs. Adapt and develop products and services.
Recursion Level 2 INNOVATION DOMAIN **(Desirability, Feasibility, Transferability, and Systemicity)**	**Process Level 4**	***2 to 5 years.***	Transforming the signals of change (market trends) of the major stakeholders into new generic products and services. They reveal concretely the future which is already present and create it in that way. To introduce and disseminate innovative products and services
	Process Level 5	***5 to 10 years.***	Sensing changes in value systems, to recreate conceptually whole systems which reflects these changes and thus to create conditions for the introduction of new and innovative products and services relevant to these changes. The rules of the game for the next decade are made. A "point of no return" or bifurcation point is reached.
Recursion Level 3 VALUE-SYSTEMS DOMAIN (Generative, Tolerant, Dialectical and Congruent)	**Process Level 6**	***10 to 20 years.***	In a given area of human activities, members of referent groups debate their appreciative systems and thus create a coherent language about their area for stimulating activities in the innovation domain.
	Process Level 7	***20 to 50 years.***	Langauge, values and cultures are developed. The universal understanding of one's own mantality.
Recursion Level 4 SPIRITUAL DOMAIN	**Process Level 8**	***50 and more years.***	The universal understanding of one's own mortality.
	Process Level 9	***50 and more years.***	The universal understanding of one's own mortality.

Table 3.1 : A Summary of Hoebeke's "Work Systems"

To provide development and continuous improvement at this level all the major clients (people contributing to the process) debate the relevance of all the specifications. This is done to learn what the minimal critical specifications of the output, the input and the process itself are. Reducing the unnecessary specifications leads to greater efficiency and competitiveness. This last activity leads to the next process level.

Process Level 2: From 3 months to 1 year

The generic transformation process at this level is essentially a translation process. Here, for the first time, the difference between the users of the product of this level, i.e. the internal specifications and the requirements of the clients of the primary process, and the external clients, who specify what they want in terms of lead-time, quantity, quality and price, are investigated. At this level all "overspecified" tolerances and specifications are further evaluated and where possible are brought in line with current process capabilities.

The basic strategic dilemma for this process level is whether the process, procedures and equipment are the best suited for its intended purpose, i.e. the questions of efficacy are raised. On this level quantified descriptions, specifications, targets, etc. start to be used. Performance indicators are used to express the strategic aims on this level. Attributes of the clients requirements with regards cost, quality, delivery and quantity are measured and any contradictions between them forces the actors in the system to look for ways of achieving a better compromise between all of them.

For this process the control information requires that two feedback loops be permanently monitored. One relates to the transformation of the clients requirements in workable specifications. The other refers to the efficacy of the work system, the adequacy of the means used to achieve the output specifications (Hoebeke, 1994, page 59). This is the level where follow-up indicators are best used to steer the resources when there are deviations in the desired results. Statistical process control belongs to this level.

The audit information processes must focus on how well the resources made available to process level 1 match the customers requirements. Most formal audits which are performed at least once a year belong to this process level, e.g.. financial, quality, environmental, security, health, etc. They should not just be seen as inspection systems but as systems which leads to efficacy improvements.

The development activities at this process level are those which lead to improvements of the specifications and the resources available on process level 1. A good example is that of information technology projects.

Process Level 3: From 1 to 2 years

Process level 3 is the highest level of the added-value domain and the lowest of the innovation domain. Generally, work systems are viable if they employ activities related to the first three process levels. "They can thrive and develop on their own, as long as they can take care of the changing requirements of their clients, suppliers and employees" (Hoebeke, 1994, page 61). The added-value domain encompasses the realm of economic activities. The basic aim of the work systems in this domain is to maintain mutually satisfactory relations with the major stakeholders, namely customers, suppliers and employees. These relations are expressed in products, services and money;- the by-products of the activities which conserve and adapt the relational structure between the stakeholders.

The generic transformation process for this level focus on developing alternative products and services and alternative ways of meeting known customer needs, by adapting and improving existing products, services and technologies. At this level effectivity can be questioned: "why are we doing what we are doing?"
At this level the strategic dilemma is the choices that have to be made to allocate the means for alternative products and services and when to react to developments in the market. Actions that are normally taken to make the relevant decisions on this level are planning and contingency planning, simulations and "what-if" scenario's, market research, consumer preference inquiries, etc.

For control information purposes process, tooling, machine and procedure capabilities need to be completed to detect any abnormal trends. Input and output trends must also be monitored to detect any unusual behaviour. Short-term statistical forecast methods are adequate methods for providing control information on this level. These methods, however, only give a warning that something is going wrong and that action is needed, it does not explain the cause.

The internal audit information, for the first time, is no longer sufficient. External audits, e.g. market surveys, attendance's to trade fairs, conferences, etc. is essential (once a year or every two years) to evaluate whether what is deployed internally is still able to compete.

The development activities on this level aims to adapt and improve the products and services on an ongoing basis and, if necessary, to change the way of providing them in terms of well-tested technologies and methods.

3.3.4 INNOVATION DOMAIN

Process level 3 forms a hinge level between the value-added and innovation domain, the second recursion level. The activities on process levels 3 to 5 form their own organisational closure, i.e. they have their own emergent properties and can maintain and adapt their essential relations (autopoiesis). The term "innovation" stems from fact that the primary process with which the actors are involved with is that of consciously creating the future. Changes in the market are sensed and transformed into new products and services. Hence, the work system on this recursion level (2 to 10 years) is involved in the discovery and the creation of the added-value of the future where clients and end-users of 'future' products are not yet known.

The output criteria of the work systems on the innovation domain are desirability, feasibility, transferability and systemicity. The realisation of an innovation is only possible if all the stakeholders who will be involved themselves have a desire to achieve the innovation. The future must therefore have an ethical and aesthetic appeal. Desirability can then be measured by the degree of positive effort that both make in that relation. Feasibility can be measured by the degree of defensive effort that both the innovators and stakeholders invest in the relation. The extend to which an innovation can be "spread" in the added-value domain gives an indication of its transferability. The degree in which an innovation has considered the interfaces with other areas is a measure of systemicity.

Process Level 3: From 1 to 2 years

In the added-value domain the basic strategic dilemma was the choices that had to be made to produce alternative products and services, and how quickly we should respond to market trends. When put in terms of the innovation domain this dilemma can be described in a complementary way. Choices have to made to produce alternative products and services must be based on what the clients will be interested in.

Process Level 4: From 2 to 5 years

The generic transformation process is the transformation of the signals of change into new generic products and services. The basic strategic dilemma is the attachment or detachment from what already exist. Generally, there is always resistance to change;- the more unknown the innovation the greater the resistance. A innovative culture and commitment need to be developed to assist in this regard. Therefore, a good knowledge of the development of work systems in the added-value domain is important.

The control information is the monitoring of the reaction of the stakeholders and the timely detection of new stakeholders. Resources such as time, money and people should be seen as limits and not follow-up indicators. When a project exceeds the limits of its resources its relevance should be questioned. The audit information on process level 4 "is the first audit which has to ask whether the systems in the added-value domain are really doing what they say, and whether we understand the meaning behind any discrepancy, based upon our knowledge of changing value systems" (Hoebeke, 1994, page 84). The development activities are all those which introduce and disseminate innovative products and services. Most research activities in business belong to process level 4.

Process Level 5: From 5 to 10 years

"This is the highest level where decisions are aimed at implementation in the added-value domain. It is also the level on which the paradigm shifts which are taking place in the next domain receive their form. It is the highest executive level. The changes are system-wide and can no longer be encompassed by one domain of activities" (Hoebeke, 1994, page 86).

The generic transformation process is the conceptual creation of whole systems which are based on a need for change. These systems create conditions for the introduction of innovative products and services which were market driven. On this level the rules of the game for the next decade are consciously made.

The basic strategic dilemma is that "although immediate results are not known to verify choices, the efforts deployed on this level create a point of no return, in technical terms a bifurcation point" (Hoebeke, 1994, page 87). The choices made on this level can cause beneficiaries as well as victims among the stakeholders. As the rules of the game are altering, the future pattern of winners and losers is also changing.

The control information is the need to follow up the development of the meaning that the various stakeholders attribute to this process. "At most, every 6 months and least every year they should monitor their understanding of the outside world in which they are involved and should take action, through communication and debates, to maintain shared vision" (Hoebeke, 1994, page 88). The audit requirement is to investigate the extend that the stakeholders still adhere to the values which were the basis of their decision to transform a whole system. Debates in public forums would give such an audit. The development activities involve the creation of a new network of relations between stakeholders who were previously unknown to each other. or whose relations were completely different.

3.3.5 VALUE-SYSTEMS DOMAIN

This domain is the third recursion level. It is in this domain where the conceptual division between a set of activities and one of relations become less relevant. Innovations are not obtained anonymously, but is linked to faces. From a time span of 5 to 50 years the major process is the creation of a new language through ongoing debate. The activities of this domain are "political". Political in this context is meant "the interactions between the proponents of different value systems not to achieve a certain form of consensus or compromise but to agree that it is worth continuing the debate and its underlying relations" (Hoebeke, 1994, page 100). In the value-systems domain process and output cannot be meaningfully distinguished. The debates do not lead to a clear and well-defined output. Hoebeke refers to generative theories, tolerance, dialectical and congruent debates.

Process Level 5: From 5 to 10 years

Process level 5 forms a hinge between the innovation and value-systems domain. The basic strategic dilemma on this level is that a bifurcation point is reached, i.e. a point of no return. Through the evaluation of the innovation under consideration the value system behind it is challenged. The consequences of innovations are the ultimate test for the values which generated them in the first place, whether these consequences are good or bad.

Process Level 6: From 10 to 20 years

The generic transformation process is when "in a given area of human activities, members of referent groups debate their 'appreciative systems' (Weltanschauung) and thus create a coherent language about their area for stimulating activities in the innovation domain" (Hoebeke, 1994, page 106).

The basic strategic dilemma is the "abstract" and "idealistic" flavour which newly created value systems have. The tension between ideology and value systems is continuously present. Control information or self-regulation occur "when referent groups are able to manage their membership in terms of the relevance of the debate. Membership assessment should be undertaken at least every two years or, more frequently, annually to provide steering information." (Hoebeke, 1994, page 111).

Audit information. "The way the referent groups are spoken of in the innovation and added-value domains, the respect they deserve is the major warning to avoid the fate of many of them: to become an 'old boy's network', whose members seem to have lost touch with their own environments" (Hoebeke, 1994, page 112). On this process level the development activities become non-teological, i.e. events become purposeless.

Process Level 7: From 20 to 50 years

The generic transformation process on this level involves the development of a language, values as well as a culture all of which encompasses many areas of human activity. A culture can be defined as a group of people who share a common "appreciative system" and the same language system.

The basic strategic dilemma here is the that the development of any new culture is bound to use some of the existing language of the "Establishment", although it changes the context of its usage. The tension between the resultant rupture and displacement needs to be managed. The dilemma consists of not trying to throw out the baby with the bathwater;- there must exist a possibility of anchoring the new value system in the existing one.

The "control" and "audit" information starts breaking down on process level 7. "These mechanisms become so all-pervasive that separating them conceptually is no longer meaningful." (Hoebeke, 1994, page 116).

3.3.6 THE SPIRITUAL DOMAIN

The processes in this domain are strongly linked to individuals. The generic transformation process is "to materialise through works of art or mere behaviour the universal understanding of one's own mortality" (Hoebeke, 1994, page 130). The basic strategic dilemma is "to struggle with one's own consciousness of death in a creative way. To live with and live beyond the depression of the loneliness associated with working through one's own death by creating universally recognisable expressions of human life and death" (Hoebeke, 1994, page 130).

3.3.7 CONCLUSION

The framework that Hoebeke outlines gives a different perspective to approaching a problem. Instead of looking at departmental structures and how variety engineering would affect these departments it makes sense to consider work systems based on the relevant time-span. For application in this research process the focus would mostly be within the Added-value Domain of Hoebeke's framework. The next section selects the most appropriate methodology, of the three discussed, for use in the context of this thesis.

3.4 SELECTING THE APPROPRIATE METHODOLOGY

Since Beer's VSM (from a viewpoint of the Law of Requisite Variety) deals with residual variety and highlights the important heuristic value of Ashby's Law; "Only variety can absorb variety", the VSM is selected as the most appropriate methodology to deal with the context of the problem which initiated this inquiry (thesis).

During the use of a methodology, whether it be SSM, VSM or Work Systems one needs to use the correct technique for gathering information or data from the environment that one is studying. The next chapter discusses some techniques for use.

CHAPTER FOUR: SELECTING A TECHNIQUE FOR THE "RESEARCH PROCESS"

Management undertaking of research in business often has the difficulty of deciding which approach or strategy to use to address a specific problem, and then how to employ the relevant fieldwork to gather the necessary data. This concern then raises the question, "what is the most appropriate research technique to be employed ?". In today's competitive market it is important to select the correct technique to maximise the use of time, money and resources.

This chapter gives a brief overview of managerial problem solving and discusses the Management Research Process as viewed by Gill and Johnson (1991) in their book *"Research Methods For Managers"*. A review is given how science moved from a deductionist to an inductionist mode of thinking. It then considers some of the research techniques used, viz. experimental research design, quasi-experiments, action research, survey research and ethnography. A discussion follows and the techniques for use in this thesis are selected.

4.1 A BRIEF HISTORY TO MANAGERIAL PROBLEM SOLVING

To conduct meaningful enquiry within a uncertain, complex and unique business environment is not an easy task. Over the years there has been much controversy about appropriate approaches to the study of management as an academic discipline. To some extent this has been due to the emergence of different schools of management thought as well as to the development of different approaches to research methodology, especially in the social science.

There is no one best approach. Methodological choices are not only determined by the nature of the topic and the resources available but also by the socialisation processes to which the researcher has been exposed. The most effective resolution to a given problem depends on a large number variables. Research methodology is always a compromise between options and choices are frequently determined by the availability of resources. Management research is currently in a state of fragmentation with a high degree of task uncertainty and a low degree of co-ordination of research procedures and strategies between researches.

4.2 THE MANAGEMENT RESEARCH PROCESS

When setting about a task it is important to distinguish content (what) from the process (how). Research methods are then primarily concerned with how to tackle tasks. Despite the variety of approaches to management research they all in essence share a common problem-solving sequence which has been generally accepted. The following seven-step process was proposed by Howard and Sharp (in 1983) and consists of the following steps:-

1. Identify Broad Area
2. Select Topic
3. Decide Approach
4. Formulate Plan
5. Collect Information
6. Analyse Data
7. Present Findings. (Gill and Johnson, 1991, page 3).

It is essential and obvious that a research topic must be identified (from some broader area from which a concern had arisen) before any research work can start. The following factors should be considered:-

- The possibility of easy access,
- The time available in which to complete the research,
- The symmetry of potential outcomes,
- The researches capabilities and interest,
- The financial support to complete the research, and
- The value and scope of the research to the community at large.

4.2.1 Deciding The Approach

Theory and Practice

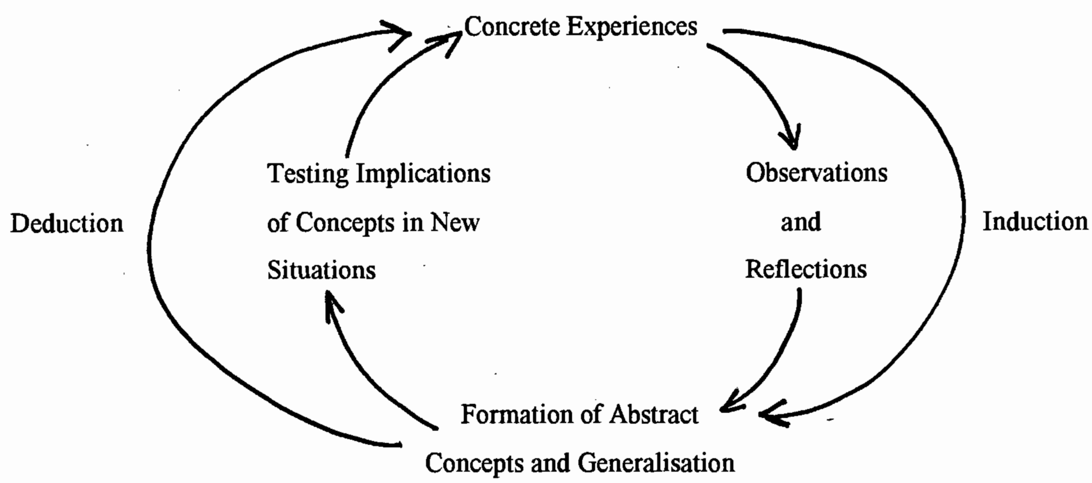
Our everyday practical lives are fundamentally interwoven with theory. The various ways in which we routinely engage in are regular attempts to create, apply and evaluate theory can be referred to as being 'theory-dependent'. This latter term should not be confused with the term 'theory-laden'. Although related, 'theory-laden' refers to the way in which prior theories and values of the observer influence what he or she 'sees'. In 1958 Hansen claimed that, "their is more to seeing than meets the eyeball". Burrel and Morgan, in 1979, highlighted that 'theory-laden' observation raises the problem that there is no neutral point from which an observer may objectively observe the world, and thus, all knowledge is knowledge from particular points of view or paradigms. (Gill and Johnson, 1991, page 23).

Both Plato and Aristotle's severed theory from practice by distinguishing between *episteme* (genuine theoretical knowledge that was an end in itself) and *doxa* (options or beliefs suitable only for the conduct of practical affairs). The latter view is very much in contradiction with CSP's pragmatism. ("Consider what effects that might conceivably have practical bearings, we conceive the object of our conception to have. Then our conception of these effects is the whole of our conception of the object").

During the seventeenth and eighteenth centuries Plato and Aristotle's view of knowledge and science lost its dominance. The emphasise changed for science to provide knowledge and theory for the control of nature. During our everyday lives we regularly attempt to understand the events that occur around us. People act in accordance with expectations. It became evident that theories are a means by which we generate expectations about the world. Managers in their everyday activities rely on their theories derived from 'common-sense' (experience) and those derived from social science research. The difference between the two are subtle and complex. This difference relate primarily to the extent that social science research incorporates the overt and rigorous search for bias (i.e., it is scientific), whereas common sense does not.

These issues provide a good starting point for considering the processes by which social science theories are constructed, evaluated and justified. For Kolb, Rubin and McIntyre (1979) the human learning process is represented in the figure 4.1. According to this cycle we can generally differentiate between research methods which are either deductive or inductive. These terms as used here relate to the reasoning process involved to form a belief.

According to Kolb's cycle, learning might start with the experience (case) of an event or stimulus. The individual then reflects upon it and try to make some sense of it. This then leads to the generalisation of explanations or answer (an inductive process). Learning could also start from a known and accepted rule. This rule is then tested (an inductive process). The testing in new situations creates new concepts which enable consequent reflection, observation and ultimately new theories. The significant aspect of this cycle is that is the attempt it makes at developing and evaluating explanatory theories about reality. In the deductive instance a hypothesis is formed prior to testing through experience. In the inductive process the Hypothesis is based on the practical world and what actually observed. (Refer section 2.1.3.2).



Source: Gill and Johnson, 1991, page 24. *Research Methods for Managers.*

Figure 4.1 : Kolb's Learning Cycle

Deduction

A deductive research method entails the development of a conceptual and theoretical structure prior to its testing through empirical observation (Gill and Johnson, 1991, page 24). Deduction in this sense corresponds to the left hand side of Kolb's learning cycle in figure 4.1. The deductive process can essentially be divided into the following stages:-

1. Forming the theory or hypothesis. (Deciding which concepts represent the most important aspects of the theory or problem under investigation).
2. Operationalisation of the concept. (Creating rules to measure the observations to determine when an instance of the concept has empirically occurred).
3. Testing the theory or hypothesis. The collection of empirical data. The testing of theory inevitably involves a finite number of observations. Logically we can never be certain whether some future observations might falsify the theory. Both Popper's maxim of 'falsification' and Peirce's theory of fallibilism supports this statement that no theory can be absolutely proven.
4. The discarding or acceptance of the theory or hypothesis by comparing the 'facts' collected from these observations against that of the assertions of the hypothesis.

Note:- Step 1 above would be the "abduction" stage in CSP's scientific cycle. Step 2 above would reflect CSP's "deductive" stage, and steps 3 and 4 would constitute CSP's "induction" stage. Steps 2, 3 and 4 would constitute CSP's verification stage. (Refer section 2.1.3).

The above steps are often called the 'hypothetico-deductive method'. It emphasise that the process by which theories and hypothesis are tested and justified (i.e., the extent of scientific rigour) is more important than the concepts that the scientist starts out with. Generally, the hypothetico-deductive method is bound up with 'positivism'.

The three main characteristics of positivism are:

1. the view that, for the social sciences to advance, they must follow the hypothetico-deductive methodology, i.e. the experimental method normally used by the natural scientist.
2. The knowledge produced and explanations used in social science should be the same as those preferred by the natural sciences.
3. the social scientist must treat their subject matter, the social world, as if it were the same as the natural world of the natural scientist. (Gill and Johnson, 1991, page 32).

It is from objections to the implications and assumptions of the above characteristics of positivism that the inductive (systems thinking) approach to research arose.

Induction

Induction involves moving from the 'plane' of observation of the empirical world to the construction of explanations and theories about what was observed. In this sense, induction relates to the right hand side of the Kolb's cycle in figure 4.1. The modern justification for taking an inductive approach in the social sciences tends to revolve around two related arguments.

Firstly, within the inductive tradition explanations of social phenomena are relatively worthless unless they are grounded in observation and experience;- in a sense they must be pragmatic. Glaser and Strauss (1967), in their book 'The Discovery of Grounded Theory' argue that in contrast to the speculative and apriori nature of deductive theory, theory that inductively develops out of systemic empirical research is more likely to be plausible and accessible. (Gill and Johnson, 1991, page 33).

Secondly the deductionist concept of treating the subject matter in the social science as the same to that of the natural science is rejected;- the rejection of human beings as it-beings. The inductionist realises the fundamental difference between the subject matter of the social sciences (human beings) and that of the natural sciences (animals and physical objects);- that human action has an internal logic of its own. In the social sciences this logic must be understood to make action intelligible. The natural sciences does not have this subjective behaviour to deal with, i.e. it does not have an internal logic which the scientist must tap to understand its behaviour. He, therefore, has to impose an external logic beyond the behaviour of his or her subject matter in order to explain it. But such methodology is inappropriate.

The social world must take account of the fact that human actions are based upon the actors' interpretation of events, his or her social meanings, intentions, motives, attitudes and beliefs, i.e. we must declare the Weltanschauungen. Inductionists, therefore, reject the methodological arguments of positivism. Naturally the prescriptions of the inductionist logic is counter-argued by the positivist. They maintain that inductive research is unstructured and unreliable.

Due to the above differences, a continuum of research techniques has developed;- at the one extreme the nomothetic (deductive) and the other extreme, the ideographic (inductive).
The laboratory, quasi-experimental and action research, surveys and ethnographic techniques are discussed next.

4.2.1.1 Experimental Research Design

Experimental research design (at the deductive end of the continuum of research methods) process entails four basic steps.

1. Identify the 'theoretically dependent variable' (the particular phenomenon whose variation we are trying to understand).
2. Identify the 'theoretically independent variable' (the phenomenon whose variation explains or causes the changes in the 'theoretically dependent variable'.
3. Operationalise the dependent and independent variable.
4. Neutralise or control the 'extraneous variables'. (phenomena that might cause some of the variation observed in the dependent variable and thus provide alternative explanations of that observed variable, i.e. they constitute rival hypothesis to the ones put forward). (Gill and Johnson, 1991, page 38 and 39).

The 'true' or classical' experiment in management is relatively unusual. It is often only used in laboratory conditions, where a great deal of control and manipulation of the relevant variables can be ensured. The process of manipulating, comparing and seeking differences are at the heart of experimental logic. The experimenter begins by developing a theoretical model of the phenomena of interest by identifying the independent, dependent and extraneous variables. Having operationalised those variables the model then enables the experimenter to produce predictions which may then be tested (Gill and Johnson, 1991, page 41). The matching of 'experimental' and 'control' groups prior to any 'treatment' is vital in the control of extraneous variables and allows for some confidence regarding the validity of any consequent findings. Randomisation and systemic controls are two physical control techniques aimed at ruling out rival explanations to those being advanced in the experiment.

Three potential sources of biases can be distinguished during the course of a true experiment:

1. due to changes affecting the members on the experimental and control groups.
2. due to changes in the measurement process.
3. due to the subjects' reaction to the processes and context of the experiment.

(Gill and Johnson, 1991, page 44).

The above biases pose a devastating critique of the use of the true experiment in social science and management research. The unexpected and confusing findings of the 'Hawthorne effect' (refer glossary) is a classic example of the above biases;- illustrating the complexity involved in social science research. The weakness' of the true experiment has caused researches to develop alternative research designs. Some of the more appropriate techniques, e.g.. experimental research design, quasi-experiments, action research, survey research and ethnography, for use in social science and management research are discussed next.

4.2.1.2 Action Research And Quasi-Experiments

Quasi-Experiments

Research attempts at approximating the logic of the true experiment outside the confines of the laboratory in its natural setting have generally been called 'quasi-experiments'. The prime aim of the quasi-experiment is to analyse casual relationships between independent and dependent variables. Since its focus is on real-life, the identified control and experimental groups are naturally occurring populations.

Characteristics of the quasi-experimental approach are:

1. it avoids the artificiality of the context in which the true experiment occurs;
2. it allows research to be conducted in its natural settings;
3. it is often adopted to investigate relationships in situations where manipulation of the independent variable and/or the control of experimental groups is not ethical.

From this it appears that quasi-experimentation is a particularly useful approach to research design aimed at evaluating various types of social policy innovations or reforms.

Action Research Design

Action research is a valuable variant of the quasi-experiment, especially in management research. The research design involves a planned intervention by a researcher into some naturally occurring events. The effects of the intervention are then monitored and evaluated with the aim of discerning whether or not the action has produced the expected consequences (Gill and Johnson, 1991, page 57).

The main feature of action research is that it is problem-focused and it leads to some kind of action. It aims to help solve the practical problems of business and management as well as contributing to the existing knowledge of science. This is achieved by the joint collaboration of the researcher and industry and within a mutually accepted ethical framework.

Ethical and value dilemmas as well as role ambiguity arise from the very nature of action research, e.g.. the acceptability of the client to the researcher, the confidentiality and protection of respondents and the protection of work for a period.

4.2.1.3 Survey Research

In terms of the methodological continuum survey research occupies a intermediate position between ethnography (induction) and experimental research (deduction). Depending on the researches aims, survey research can be divided into analytical and descriptive surveys.

Analytical or explanatory surveys attempts to test a theory by taking the logic of the experiment out of the laboratory and into the field. This process must be undertaken with due attention to any existing research, theory and literature relevant to the problem. A thorough literature review is essential to a successful and internal valid analytical survey since it enables the researcher to identify any potential extraneous variables whose influence must be controlled. The control of these variables is achieved through the use of statistical techniques, such as multiple regression, during data analysis. This approach necessitates the prior measurement of all the pertinent variables through their inclusion in the questionnaire format.

A ***descriptive survey*** is primarily concerned with addressing the particular characteristics of a specific population of subjects for comparative purposes. As such they do not share the emphasis in analytical designs upon control but to secure a representative sample of the relevant population to have good population validity. Prior consideration of the relevant theory and literature is vital in determining what kinds of questions need to be asked.

Both analytical and descriptive questionnaires are concerned with identifying the 'research population'. It is from this population that subsequent findings will be generalised. A vital skill in undertaking a survey is the ability to structure forms, phrase and ask sets of questions in a manner that is intelligible to respondents. Such questions need to minimise bias and provide data that can be analysed. The survey research process can be summarised as follows:

1. Determine Questionnaire format
    - (i) Focus
    - (ii) Phraseology
    - (iii) Necessary Form of Response
    - (iv) Sequencing and General Presentation
2. Fieldwork
    - (i) Piloting Studies to correct errors and biases in questionnaire proforma
    - (ii) Contact Main Sample
    - (iii) Monitor Progress
3. Retrieval and Analysis of Data
4. Write up the Findings and the rationale behind the Research Design.

Some survey-related ethical issues, where commissioned by one interested party, e.g.. management, must be noted:

1. results may lead to decisions that affect the respondents;
2. interested parties may want to be consulted about the purpose of the survey and the

manner in which it will be conducted;

3. questions may be governed by organisational considerations;
4. providing opportunities for employees to voice their opinion may be an important consideration.

It is therefore important that the following requirements be considered:

1. The researcher should only proceed when consent and agreement from all interested parties have been received.
2. Agreement must be reached over the dissemination of results.
3. The purpose of the survey research should not be concealed.
4. Any special circumstances that might affect the interpretation of the results should be clearly reported.

4.2.1.4 Ethnography

The ethnography approach is fundamentally that of anthropology. It allows the fieldworker to use the socially acquired and shared knowledge to explain the observed patterns of human activity. It is based on what are termed naturalist modes of inquiry, such as participant observation, within a predominantly inductivist framework. (Gill and Johnson, 1991, page 93). Ethnography gives attention to the way in which people interact and collaborate in their normal working environment. Generally such work involves intensive immersion in a well-defined locality where direct participation with some of the members of the organisation, in their normal daily activities, occur.

Ethnographers place more emphasis on observation and semi-structured interviewing than on documentary and survey data. By extended participant observation an attempt is made to learn about the culture under study and interpret it in the way its members do. This approach is based upon the belief that the social world cannot be understood by studying artificial simulations of it in experiments or interviews. Ethnographers' are committed to naturalism. They argue that to explain the actions of people working in organisations, one has to understand the various cultures and sub-cultures existing in a particular organisational setting, for it is out of these, systems of meanings, beliefs, values and mores that rational action arises.

There are may aspects to the field role which an ethnography may adopt, the most important relate to the extent to which the researcher decided to 'participates' in the natural setting of subjects' behaviour, and the to which the identity and purposes of the ethnography are revealed to the subjects. The extremes of this situation decided on are:

1. Participant and non-participant observation
2. Overt and convert observation
3. Direct and indirect observation

In the case of ***participant observation*** the researcher becomes completely immersed in the social setting that he is studying. In ***non-participant observation*** the ethnograhper only observes events and processes. In the latter case he does not become involved with the interactions of the participants. In the former the ethnograhper involves himself in the lives and activities of the subjects and becomes a member of their group. He can then share their experiences since it enables the researcher to get very close to the phenomena of interest. Participant observation can enable the researcher to penetrate the various complex forms of "misinformation, fronts, evasions and lies" that are considered endemic in most social settings, including business (Gill and Johnson, 1991, page 109).

Although participant observation have significant strengths it has the danger that the researcher internalises the subjects' culture and become unable to the a dispassionate view of the events and unintentionally discards the researcher elements of the field role. In the cases of non-participant observation where the field role is limited to spectator only, the observer can fail to gain access to and understand the cultural underpinnings of the subjects' behaviours and actions.

Overt and covert observation refers to whether the subjects are aware of the presence of a researcher or not. There are two main reasons that support covert observation. Firstly, during overt observation people may act differently when they are under observation. Thus the degree of naturalism or ecological validity is reduced if covert observation is not used. However. it is for this reason that the researcher should understand his effect upon the research setting. The second reason for using covert observation is that the it would be impossible to obtain access to do research if the subjects knew one was a researcher, or knew the nature of the research.

Two of the most important decisions a researcher must make before starting research is the extent to which the work is covert and the extent to which he interacts with the subjects.

Direct observation is when the researcher observes by directly watching and listening to the behaviour of subjects. Data may also be acquired by ***indirect observation*** where the ethnographer rely on information that is reported to him by an informant, either orally or in writing. In the latter instance he does not personally witness the subjects' behaviour. ***Ethical issues*** in ethnography arise from the nature of the relationship between researcher and organisation, and between the researcher and the subjects he or she studies. Organisations may sometimes request to delete passages found to be offensives. Also, producing a more comprehensive study is never justified by putting the job of an informant at risk. At the heart of the 'contract' must lie the trust between the parties.

4.3 DISCUSSION - MAKING METHODOLOGICAL CHOICES

In deciding on the methodology of research, the nature and content of the 'problem', as well as the available resources, clearly influence this choice. It is important to be aware of the differing strengths and weakness of the various methods when an approach is selected.

The following evaluation criteria can be used to seek validity of any research findings:

1. "Internal Validity : Refers to whether or not the identified causes (stimuli) actually produce the 'effects' (responses).
2. External Validity: The extend to which any research findings can be generalised or extrapolated. Sub-divided into:

a) Population validity : extend to generalise from sample of people involved in research, to a wider population.

b) Ecological validity: extend to generalise from actual social context of research situation to other social context and settings.

3. Reliability: Refers to the consistency of results obtained in research.

(Gill and Johnson, 1991, page 120).

Applying these criteria to the research methods in this report the following summary is drawn:

	Internal Validity	Population Validity	Ecological Validity	Reliability
	1	2(a)	(b)	3
* Ideal or laboratory experiments	Strong	low	low	Strong
* Quasi experiments & Action Research	low	low	high	low
* Survey	weak	high	low	high
* Multi-methods	high	high	high	high
* Ethnography	low	low	high	low

Table 4.1 : The Validity Of Various Techniques

4.4 CONCLUSION

The selection of the appropriate research technique is complex;- there are no ideal solutions, only a series of compromises. Every situation is different, it depends on the problem, the researcher's background, the environment, etc. There are many factors which determine the choice made to select a technique and that there is no clear-cut selection procedure available.

Making methodological choices involves a consideration of the inevitable trade-offs that occur when issues of internal validity, ecological validity, population validity and reliability are considered. 'Researches' evaluations of these trade-offs, and their consequent methodological choices, need to take into account, the nature and organisational context of the substantive 'problem' to be investigated, the consideration of the resources available, as well as any potential ethical dilemmas. Each method has its strengths and weakness, and has something to offer. It is important to understand the shortcomings and strengths of the various methods and manipulate these to get efficient and useful results (to science and industry).

Lastly, the impact of the philosophical, social, political and practical influences on the researcher's conceptualisation of the research problem and his eventual selection of technique must always be sufficiently justified to gain acceptance by the scientific community.

Chapter 4 forms the last chapter in the development of the research framework. The next chapter summarises the research framework that has been developed in chapters 2 to 4.

CHAPTER FIVE: SUMMARISING THE RESEARCH FRAMEWORK

The development of the research framework can be considered to consist of three levels, namely, the philosophical, methodological and technique levels.

The philosophical level forms the basis for conducting meaningful management inquiry in the context of this thesis. It is not only the process whereby inquiry is executed but also the viewpoint (approach or school of thought) which is adopted in order to deal with the problem situation.

In this thesis the philosophical framework is formed from Charles Sanders Peirce's (CSP's) ideas on the inquiry process and Checkland's view's on systems thinking. Peirce's "scientific method" , namely, the cycle of doubt, abduction, verification and the formation of a new belief (shown below), forms the cycle for conducting pragmatic inquiry. This cycle also allows for double loop learning (Argyris, 1994) to occur;- it is a cycle whereby learning can occur, whereafter the inquirer can change his model or belief of a particular situation.

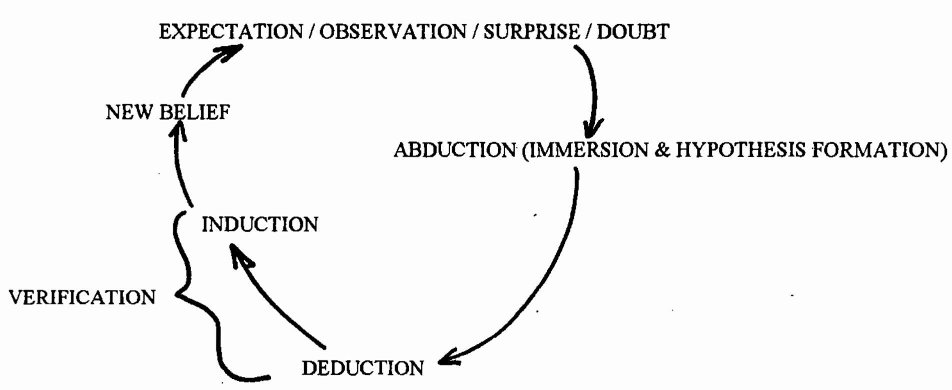


Figure 5.1 A Cycle For Conducting Inquiry - The Philosophical Level

There are four fundamental reasons which supports its use in the context of this research. Firstly, it offers a process to conduct rigorous inquiry into a situation, i.e., the belief resulting from this process is scientific. Secondly, his "pragmatic maxim" introduces a feature for effective management decision making. The third reason is his ideas on "fallibilism" which gives cognisance for continuous improvement and the development of science. Lastly, both of the latter ideas can be compared with two cybernetic laws, namely the Conant-Ashby Theorem and the Darkness Principle, respectively.

Due to the complexity of the socio-technical situation the that exists between product, men, machines, processes, company values and norms, sub-systems and systems a systems thinking approach is taken, since the analytical and mechanistic approaches have developed shortcomings when dealing with complexity. A systems thinking view is taken throughout the research process. Not only is the Peirce's inquiry process considered systemic, but systems thinking is also used in the consideration of the methodologies (VSM, SSM and Work Systems) and techniques (action research, ethnography, computer simulations, etc.) for use in this thesis. Also, during the hypothesis formulation cybernetic laws, principles and theorems are considered.

The second level need to employ a methodology to find a solution to the the type of problem as outlined in the situation of this thesis (described in chapter 3). As mentioned above all three methodologies described are systemic. The inquiry from which this thesis was initiated needed a method to effectively deal with variety. It for this reason that VSM was selected since it best dealt with variety.

At the third level, namely the technique level, the appropriate method for assimilating data during the investigation needs to be selected. In this case ethnography, action research and computer simulations are used. Again, all of these are systemic.

Figure 5.2 summarises CSP's scientific method of inquiry (the Peircean Cycle) which forms the philosophical basis for the thesis. It shows how the chapters describing the "real world" environment of GSA (Part B) reflect the framework that was developed in Part A.

If one considers the Peircean Cycle above, the observation and doubt stage was the concern at GSA which led to this report. The second stage, namely the immersion/abduction/hypothesis phase of the Peircean Cycle is covered by Part A, the literature survey, and chapters 6, 7 and 8 of Part B. Chapter 8 formulates the hypothesis. Chapters 9 and 10 both form the verification stages of CSP's scientific method;- each chapter containing a deduction and induction stage respectively. At the end of the research process a new mental model of the situation has emerged.

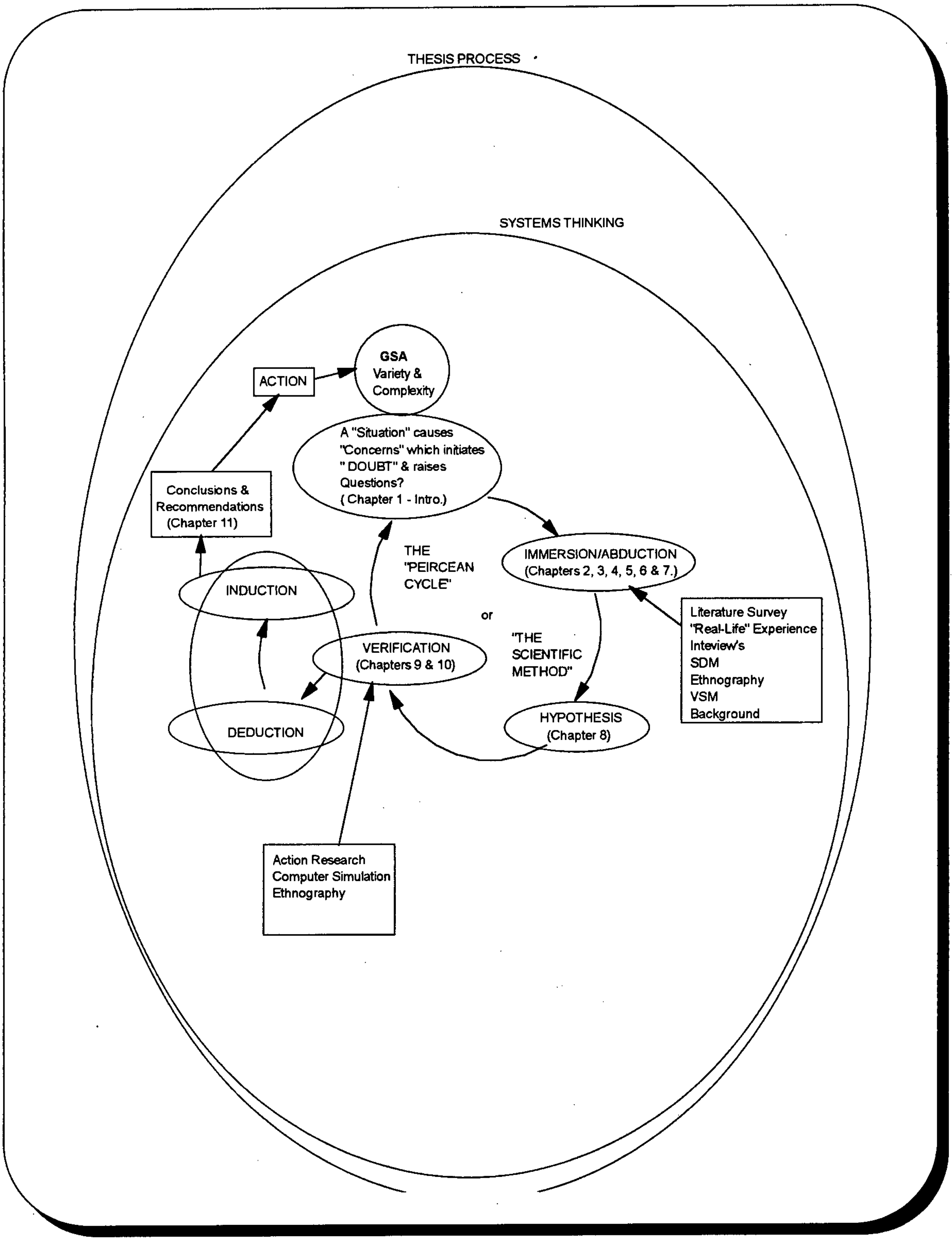


Figure 5. 2 : Application Of The Research Framework

PART B

APPLICATION OF THE RESEARCH FRAMEWORK

CHAPTER SIX: GSA - A BACKGROUND

This section gives a brief history of the company, Gabriel South Africa Pty Ltd (GSA). The design, operation and manufacture of the product GSA manufactures is described. GSA's current competitiveness from a viewpoint of cost, quality and delivery in the local and export market is discussed. Lastly, a systems diagram is drawn to obtain some sense of the problem.

6.1 GABRIEL SA:- A BRIEF HISTORY

In 1935 Harold H. Jones & Co. obtained a franchise to distribute Gabriel shock absorbers in South Africa. In 1962 GSA was established. In 1963 GSA opened its first factory in Plumstead and commenced its production of shock absorbers. By 1968 GSA had built its own factory in White Road, Retreat, Cape Town where the company is currently situated.

By the end of 1987 GSA had failed at two attempts to implement the principles of Just-In-Time (JIT;- to reduce inventory, improve material flow, easy and cheap automation, remove unnecessary labour and unproductive time, etc.). This failure was generally due to fixed management mindsets with a definite resistance to change and a lack of understanding of underlying JIT principles. Two Japanese experts on JIT were called to investigate the reasons for the previous JIT failures. They investigated the companies organisational structure and the way in which the different departments worked together. From their findings it became clear that the organisational structure would not allow competitiveness and that the centralised control had to be broken down. This need to change consequently led to the demise of the "old structure" along with its management team.

At that same time GSA's business environment was undergoing changes. In 1988 the government introduced the Phase 6 local content programme. The aim of this programme was to support the local industry and offered incentives for export. For GSA this implied a potential growth in Original Equipment (OE) and Export business. The After Market (AM) business had stabilised. In its strive to become more competitive and to maintain its local market share GSA continuously pursued to reduce costs, improve quality, to educate and train employees and become "leaner". Between 1988 and 1994 the number of employees were reduced from 560 to 335 respectively. The company's management structure shrunk from 7 Executive Managers in 1988, to only 3 by 1994.

Some of the above mentioned people reductions were achieved by the introduction of Strategic Business Units (SBU's) in 1992. These SBU's were formed around key management groups often called "plants within a plant".

Each management group became responsible for a group of products, one customer, or several lines depending on the facility size, the product or customer mix. Each management group being self-sufficient and accountable for unit performance and overall financial profitability of the company as a whole. The idea was to make the BU's profit centres providing Unit Managers with the resources (support systems) to function effectively. Each BU is composed of members from the different departments, viz. a production manager, development engineer, process engineer, quality engineer, maintenance technician and shopfloor supervisor. Now quick and decisive communications would be available to remove costly delays and promote teamwork across all levels of authority. This approach would promote design for manufacture and would enable the company to respond quicker and more efficiently to customer (market) changes (forces). It was assumed that working as a team would result in better quality being built into the product and process well before production began. Most importantly, this approach would aim at increasing profits.

After many changes to the company's organisational structure it has recently changed to only 3 SBU's, and to only 3 Executive Managers reporting to the Managing Director. They are the Human Resources/Supply, Product/Quality and Financial Executives. The latter organisational chart is shown in appendix B.1.

To date Gabriel SA has implemented manufacturing techniques such as final assembly cells, Kanban, a Group Incentive Bonus (GIB) Scheme, a Cost Reduction Scheme and extensive employee training programmes (TOPS, TQM, PAT's, etc.). The latest (1995) focus has been an Employee Involvement (EI) Training Programme and a Total Quality Management (TQM) System, called the Gabriel Total Quality Management System (GTQMS). The current goal of the company is to implement GTQMS, to improve delivery time, and to reduce inventory and product cost. The goals of GTQMS is basically to eliminate all forms of waste in the company (especially the direct production related aspects), to improve throughput and to strive for continuous improvement of the product, process and people.

The Gabriel Brand name has made its identity. It is being perceived by the public as a quality and reputable product. GSA currently manufactures and distributes the following products:

- Shock Absorbers (dual tube and monotube)
- Macpherson Struts
- Macpherson Cartridges
- Gas Springs
- Power Cushion Coil Springs (distribution only).

Figure 6.1 illustrates some of these products. Of the above products Power Cushion Coil Springs are not manufactured by the company. The distribution infrastructure delivers products to the OE plants, export markets and all the warehouse distributors who provide the distribution to all the retail outlets.

With the current situation in SA, it is expected that the OE market will either stabilise or show a decline over the next few years. The local aftermarket is growing at a rate of 5% per annum. To date, Gabriel SA has acquired 40% of the OE market and up to 65% of the local AM. Its major local competitor has approximately 40% of the remaining share of the OE market and most of the remaining AM. The balance is covered by imports.

6.2 THE PRODUCT DESIGN, OPERATION AND MANUFACTURE

Design

GSA manufactures approximately 50 different motor vehicle damper designs. The designs are determined by a combination of the inner-cylinder bore size, the piston rod diameter and the valving type. The valving type is the internal "componentry" which achieves the required customer resistance characteristic;- to obtain a balanced compromise of motor vehicle ride, comfort and handling.

A motor vehicle damper (best explained with the drawing shown in Appendix A.1) is generally composed of an inter-cylinder assembly which is made up from an inter-cylinder tube, a mounting bracket assembly, end cap, brake pipe bracket and stabiliser bracket. The inner cylinder tube, guide assembly, rod seal, piston rod and piston assembly, compression head assembly, rebound stop support and the shock oil form the internal components.

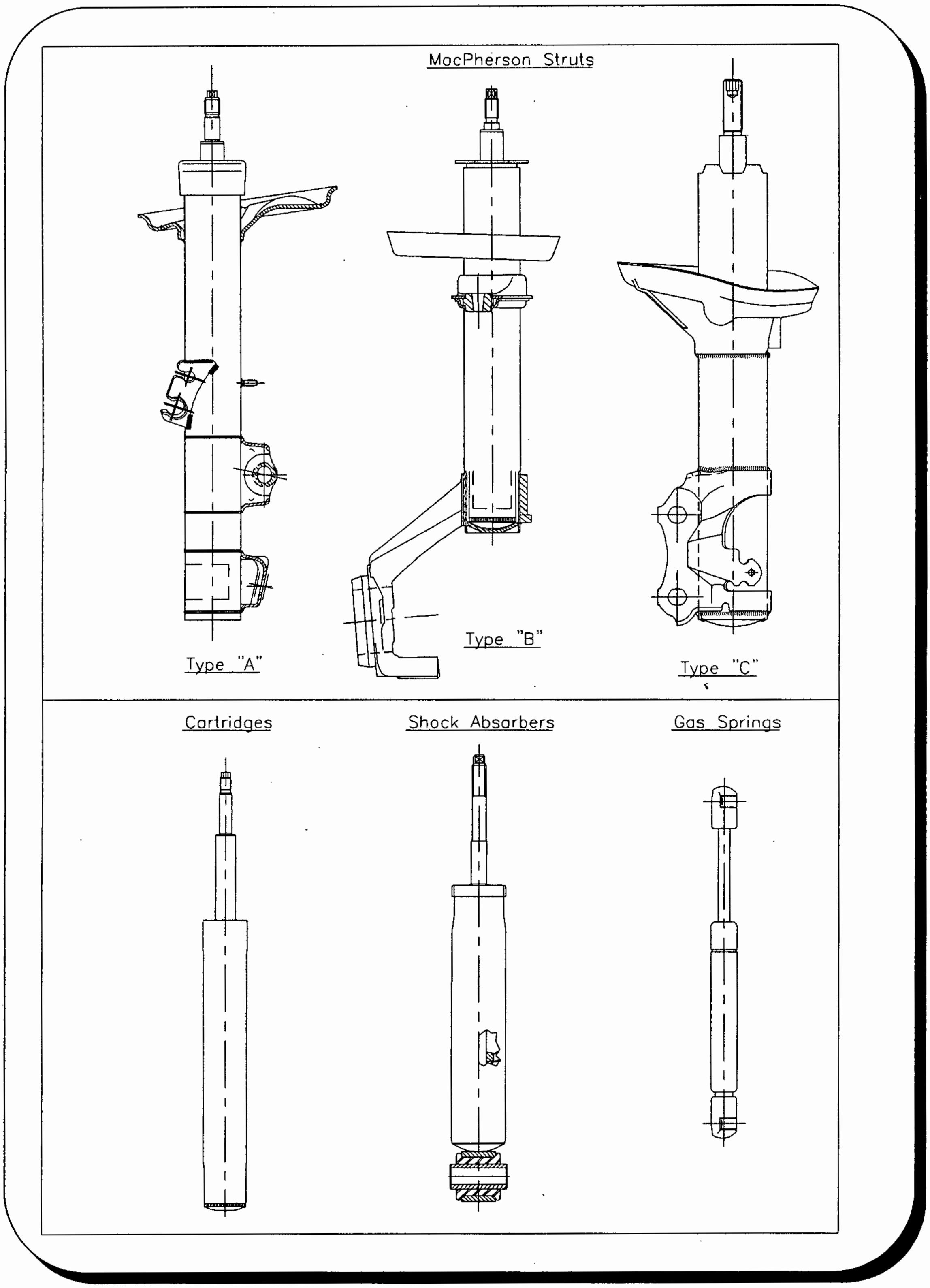


Figure 6.1 : The Product Range

A shock absorber's internal components are the same as a strut, except for the piston rod diameter. The strut rod normally has a bigger diameter because a strut is subjected to side-loading. Externally the mounting components are different and a shock absorber does not generally have a spring seat (refer Figure 6.1).

A combination of 6 different bore sizes and 3 rod diameters are used for the struts and cartridges. The shock absorbers utilise 11 different inner-cylinder diameters with 8 piston rod sizes. There are 2 gas spring bore sizes which use 1 rod size per bore. In total 21 valving types are used. These combinations are summarised in table 6.1. Together, this combination of inner-cylinder diameter, the piston rod diameter and the valving type constitute the 50 designs mentioned above. The introduction of these diameters will become clear in chapter 7. With these 50 basic designs the company is supplying a range of approximately 800 different damper numbers to the market which is composed of about 2500 component numbers and 2100 subassemblies.

Operation

A motor vehicle damper (shock absorber or strut) is a sealed cylinder of hydraulic fluid with a "valved" piston and compression head on the inside with a piston rod protruding on the outside. The bottom end is attached to the vehicle axle and the upper end to the body of the vehicle by way of a steel rod to the piston inside the strut. Basically the unit is extended and compressed each time the vehicle's wheels follow an irregularity in the road surface.

The same applies when the vehicle's body bounces on the suspension. The recoil and compression resistance values required at the different piston speeds are determined by the motor vehicle manufacturer (a function of the vehicle damping characteristics). A more detailed description of the operation of a strut damper (typical of the other Gabriel products) is contained in appendix A.2.

Manufacture and Assembly

GSA is composed of the 5 conventional departments, viz. Finance, Marketing, Manufacturing, Product Engineering and Quality, and Human Resources. Manufacturing is divided into three Business Units (BU's), namely the Rods and Press (BU1 or Internal Supply), the Final

Assembly (BU2) and the Paint and Pack (BU3) Business Units.

INNER CYLINDER	PISTON ROD DIAMETER	VALVING DIAMETER	TYPE
STRUTS and CARTRIDGES	25	20	A
	27	20	B
	30	20 and 22	C, D and E
	32	20 and 22	F, G, H and I
	35	25	J
	36	22 and 25	K and L
SHOCKS	25	11 and 12,5	A
	26	11	M
	27	11 and 12,5	N
	30	12,5	C
	32	13 and 15	G and H
	35	14	J
	36	11	O
	41	17	P
	46	11	Q
	52	22	R
	66	28,5	S
GAS SPRINGS	16	8	T
	19	10	U

Table 6.1 : Combination of Cylinder and Rod Diameters

The Rods and Press BU1 is responsible for the supply of all internally manufactured components. The Stores (which serves as a support function) is responsible for all the externally acquired components. BU1 is discussed in more detail in the chapter on VSM.

The final assembly of the products occur in the various cells of BU2. This process involves the assembly of the piston rod, piston, piston band, inner cylinder, guide and rod seal, compression head assembly and oil into the strut in an established sequence of operations. The units are then crimped or spun close. The last two operations are the gas fill (pressurisation of units depending on the application) and the projection welding (of the striker plate to the crimped struts) or the fitment of the dust caps (to shock absorbers). To complete the unit it is moved to the paint line where the unit is washed, phosphated, sprayed, baked, packed and despatched. This function is fulfilled by BU3.

6.3 GSA's CURRENT COMPETITIVENESS

This section broadly discusses GSA's competitiveness in the global and local markets. Currently GSA's export production contributes to 15% of its total manufacturing. The OE market constitutes 28% and the bulk of the remaining volume is manufactured for the AM:- shown in the following pie chart, figure 6.2.

C, Q & D in the Export Market

On the international market GSA's struts are generally competitive. There are four main reasons for this. The first is the Rand-exchange rate (due to the consistent low Rand against other currencies). This devaluation of the Rand over the last few years has effectively allowed GSA to maintain their product selling price. This makes the cost of tooling, required for struts, relatively cheap compared to the cost for the same tooling in the competitive country.

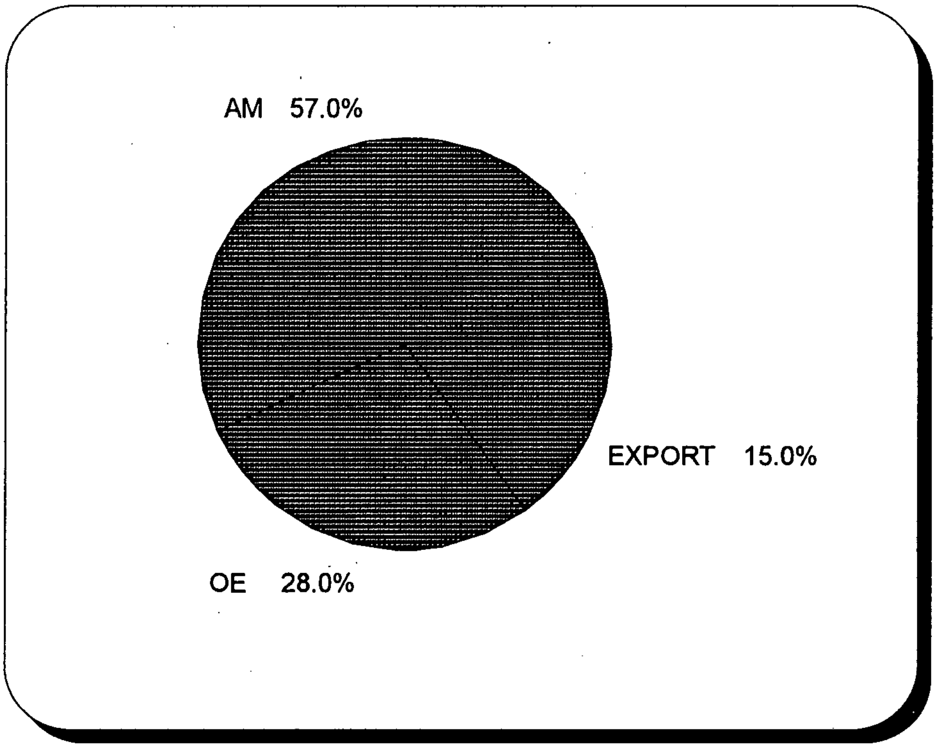


Figure 6.2 : The AM, OE and Export Manufacturing Mix

Secondly, without the money retrieved from the export incentive scheme it would be difficult to compete in some export markets. This is especially true where a world-class delivery of less than one day is achieved. The delivery time to the customer appears to fluctuate from 'good' to 'fair' depending on the time of the year and other factors relating to the operations system.

Thirdly, some of the products GSA manufacture is aimed for a niche market;- GSA manufactures struts where the production volumes are too small and not feasible for the overseas "high volume" competitors. Lastly, in the export market, GSA has become known for their quality products.

The factors mentioned above make GSA's strut prices attractive to the export market. However, this is not the case for shock absorbers. In the USA, for example, the average price of a shock absorber equates GSA's material cost.

The Local Market

Locally their is only one major competitor. GSA has 65% of the local AM market share and its competitor 28%. Parts and Accessories, and imports make up the remaining 7%. This market share is shown in figure 6.3. The OE market is shared almost evenly between GSA and its major local competitor, approximately 40% each. The remaining 20% are imported units. This proportion is continually changing depending on the OE car sales. GSA predominantly supplies the OE for the European motor vehicle manufacturers and its competitor, predominantly that of the Japanese car manufactures. This is generally due to the agreements that have been set up between the local and the "approved" overseas (approved by the parent motor vehicle company) shock absorber manufacturer.

On some products GSA's prices beat the competitions, on others GSA's products are more expensive. Market research which has been conducted has indicated that the average consumer is prepared to pay more, even if the consumer has to wait for the Gabriel brand, rather than that of its competitor. The reason for this is that GSA has shown excellent customer service, has produced quality products and has always covered an 'almost complete' vehicle damper range as required by the market.

Cost

With the new Phase VII local content incentive programme the profit margins to export may not be feasible. Market forces are indicating price reduction needs for the future. For the present the best minimum acceptable requirement is to maintain prices. To be able to do this GSA will have to absorb the costs internally by becoming more effective in all possible ways.

Quality

Although it appears that our quality is perceived as being good, both locally and internationally, the scrap is currently at 1,75 %. This is considered high when compared to a world class figure 0,5%. Within the company, the AM process quality is perceived to be of a lower quality than that of the products built for the OE and Export markets. All market forces, locally and abroad, are demanding better quality products. The latter perception must change.

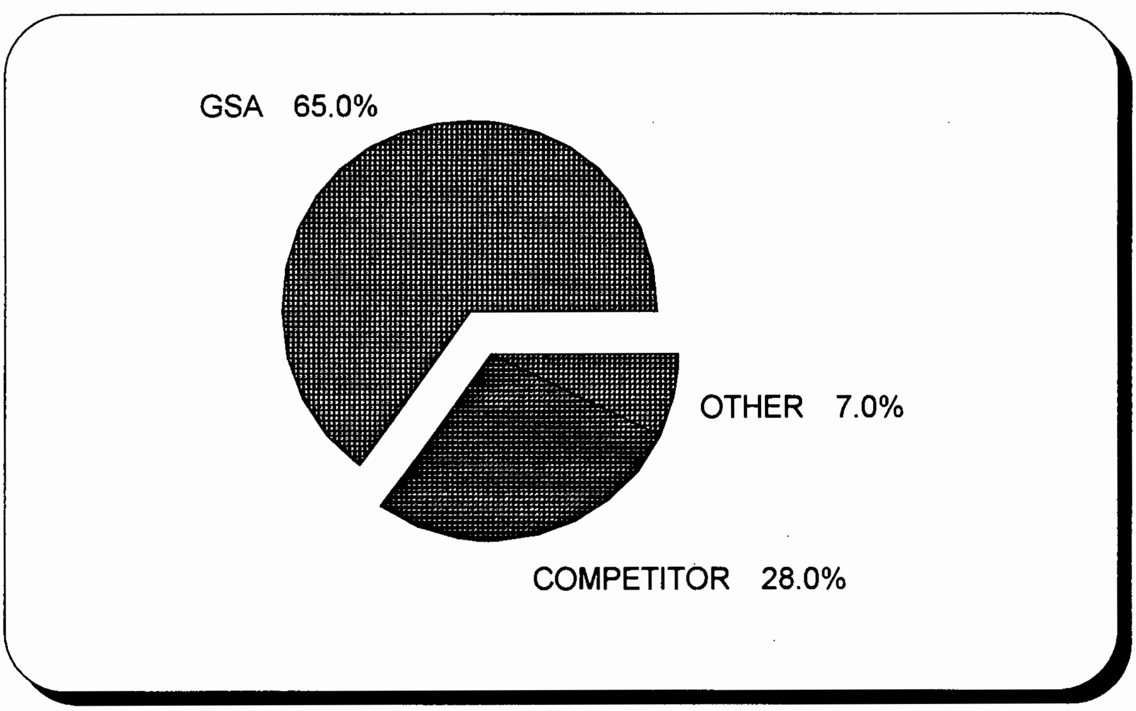


Figure 6.3 : Local After Market Share

Delivery

The export market delivery expectation is 4 weeks 'ready-for-shipment' from the date that the order is placed. Currently GSA is taking anything between 6 to 15 weeks depending on the type of product and the time for which it is required. In 1994 the orderfill ended at 95 %. In 1995 it has dropped to 50 to 40 %. By orderfill is meant the ratio between orders despatched against what has been placed by customers, expressed as a percentage. Obviously the order fill is influenced by erratic orders which are placed since the company cannot respond immediately to sudden market demands. However, it is a reflection of what could have been sold at any point the figure is calculated. It also causes customer dissatisfaction if orders had been taken and GSA cannot meet promised delivery dates. In the local market GSA has an delivery as quick as one day depending on product type, finished goods inventory (availability), the location of the customer, etc.

In summary, the company is currently in a 'healthy' financial position. However, it is living in a dynamic environment. With the requirements of GATT, the implications of the Phase VII Local Content Programme, the local motor vehicle sales, etc. the company cannot afford to become complacent. GSA needs to become more efficient, increase its productivity levels, reduce costs, improve its overall quality and ensure continuous on-time delivery. The company must anticipate and make use of growth and expansion opportunities when faced with this opportunity, as is currently the case with GSA. This also serves to protect GSA's current market from foreign market entrants. If GSA cannot do this the company may not be here in this fast-changing and 'opening' market.

6.4 UNDERSTANDING THE EFFECTS OF PRODUCT VARIATION ON GSA's COMPETITIVENESS

Throughout this thesis competitiveness is measured by how well the company can meet the variables of cost, quality and delivery.

From regular daily production meetings a belief had developed that the main reason for not achieving production target was due to the complexity of managing the product mix that the company has to manufacture. To develop some sense of how this product variation affects GSA's operations system the following questions were asked to some senior managers, who were daily affected by the effects of this product variation, during a semi-structured interview (ethnography).

1. In your opinion, how does the current variety of designs, components and processes affect GSA's operations system?
2. What action would you take to overcome this problem?

The responses to these questions are listed in appendix A.3. These responses were further reconciled and the systems diagram in figure 6.4 was developed. This diagram shows the major inter-relationships between the various variables in the operations system. For simplicity not all relationships are shown. The idea is to show how product variation influences the 3 major competitive factors, viz. cost, quality and delivery which themselves are inter-related.

Firstly, customer satisfaction is dependent on cost, quality, delivery and flexibility. By flexibility is meant the ability of GSA, due to the large number of designs available, to supply a wide customer base. One of the reasons for this large variation in product design had come about when new products were introduced, under licence, due to the associated short development time (lead-time) and due to specific customer requirements.

A lack of cost, quality, delivery and flexibility effectiveness, or a lack of a combination of these, can cause major customer (market) dissatisfaction. Customer dissatisfaction, in turn, leads to fewer orders being placed by the customer, resulting in lost business and a loss in profits. This implies less money available (if any) for business growth, in the sense of employee training (quality improvements and systems), product improvements (research and development), operations capacity improvements, and reducing product cost (economy of scale) by improving throughput and delivery.

Cost-Customer Loop:- An unacceptable cost results in a dissatisfied customer, resulting in fewer orders and less profit. Less money is spend on quality, resulting in greater scrap, warranty returns, etc. This affects throughput, delivery and cost making the customer even unhappier, forcing him to place even lesser orders, etc.

Quality-Customer Loop:- Poor quality causes dissatisfied customers and leads to a similar situation as described above. In today's competitive market more and more customers are becoming quality conscious to the extent that bad quality has become unforgivable. Good quality has become an expectation and the consumer is prepared to pay more for a better quality product. This is especially true in countries where inflation is high (two-digit figure), e.g. South Africa.

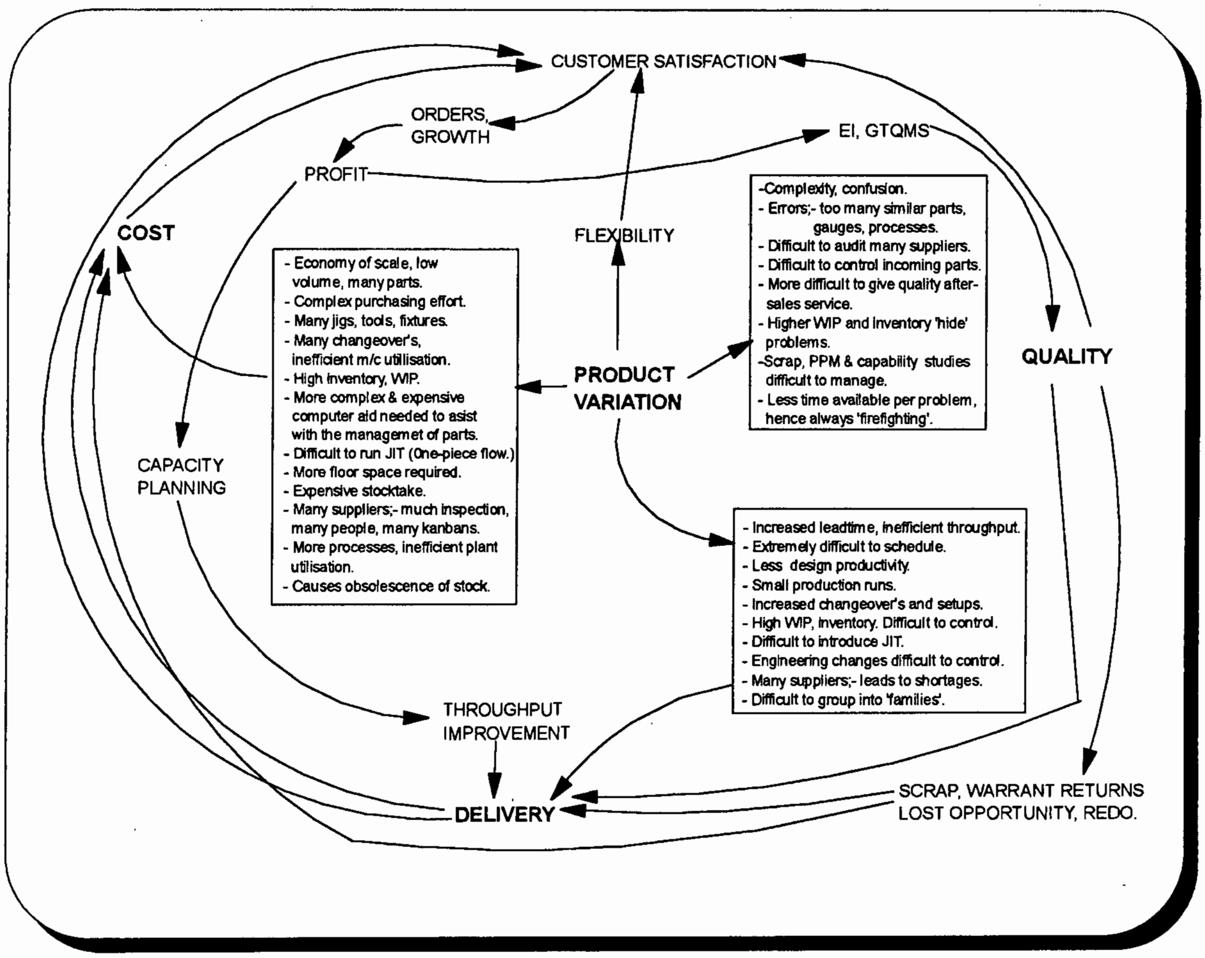


Figure 6.4 : Systems Diagram of Effects of Product Variation

Product Variation directly affects cost in the following ways:-

-Components are generally more expensive if volumes are low.
(economy of scales, low volume and many parts)

- It makes purchasing complex and difficult.
- Many jigs, fixtures and tools are required.
- Results in many changeovers, i e. a condition of inefficient machine utilisation.
- Leads to higher inventory and WIP.
- Generally, more complex and expensive computer system is required to assist with the management of this variety.
- Due to many changeovers it is difficult to run JIT (one-piece-flow).
- Greater floor space is required

All these factors also affect quality and cost as shown in the diagram in figure 6.4.

Product Variation directly affects quality in the following ways:-

- Complexity creates confusion, and confusion results in errors. There are too many similar components, processes, gauges, drawings, etc.
- Product variety leads to a host of problems;- human resources and effort are used up in a daily never ending 'fire-fighting' cycle which never really solves anything. There is only a superficial understanding of problems. Consequently, less time is available for product and process improvements.
- Scrap, PPM and capability studies (general SPC) become difficult to record.
- Due to the product variety there are many suppliers and it becomes costly and difficult to regularly audit them and also to inspect incoming parts.
- The above factors affecting poor quality results in scrap, PPM and warranty returns and leads to rework and lost opportunity. This impacts on both cost and delivery.

Product Variation directly affects delivery in the following ways:-

- Increased variety makes it extremely difficult to schedule.
- Small production runs become necessary and many costly changeovers (set-ups) are required. This results in reduced productivity and efficiency and higher WIP and inventory, both of which affects quality and cost.
- Increased WIP and inventory implies more difficult and complex stock control.
- ECO changes become difficult to manage.
- JIT and the benefits of improved lead-time become difficult to implement.
- Variety of part suppliers results in the need to manage many suppliers and many components and material shortages become inevitable.

The above factors adversely affect cost and quality as well.

Product Variation directly affects flexibility in the following ways:-

- It allows the supply to a wide customer base, i.e. greater market share.
- It assists with the timeous implementation of a new product.
- It reducers the development time for new products.
- It allows a compatible components to be used when shortages occur.
- It gives the customer "exactly what he wants".

In this instance the above factors positively affects customer satisfaction, although it has a negative effect on cost and delivery.

6.5 CONCLUSION

Cost, quality and delivery are closely related and are, in a sense, inseparable. An improvement in any one will result in the improvement of the other, and vice-versa. Product variety and its effects on cost, quality and delivery impacts the system at all levels throughout the company.

It must be remembered, though, that one of the main reasons why the company has earned its reputation in the marketplace has been due to its ability to supply the very broad spectrum of shock absorbers that the OE, AM and Export market demand. The market demands product variety, but throughput and profitability demand standardisation. This conflict is not an easy one to resolve. "What is sought is a best compromise, the definite deletion of all unnecessary variety and the intelligent control of the necessary variety." (Lockyer, 1974) .

The next chapter uses Stafford Beer's VSM to diagnose the relevant business units.

CHAPTER SEVEN : VIABLE SYSTEM DIAGNOSIS OF THE RODS DEPARTMENT

7.1 INTRODUCTION

Appendix B.1 shows the current organisational structure for GSA. As mentioned in the previous chapter Manufacturing is divided into three Business Units, namely the Rods and Press BU (BU1 or Internal Supply), the Final Assembly BU (BU2) and the Paint and Pack BU (BU3).

BU1 is responsible for the supply of all internally manufactured components, BU2 for the final assembly of the dampers and BU3 for paint, pack and despatch. The stores serve as a support function and is responsible for all the externally acquired components. Human Resources, Quality Assurance, Finance and Engineering all form a support network to production. The Marketing Department represents the external customers of GSA.

Investigation of the plant has shown that the final assembly cells (viz. the struts, shocks, monotube, gas springs and the cartridge assembly cells) are capable of achieving their respective contributions (quantities) to meet the demand for 12000 units. To achieve this, however, they need all the components to be available when required, in the correct quantities and quality from the respective supply departments, viz. the tubing, rods, press, and bulk stores. It is believed that it is this latter requirement which prevent the company from attaining the 12000 units per day.

This is one of the reasons that focus is directed at the supply departments, viz. piston rods, press parts, tubing and stores. (Due to the extent of complexity (product variety, process, equipment and material flow), the fact that the area is a supply department, which has the longest lead-time (generally 5 to 7 days), with the highest scrap level (cost as a percentage of sale) and the most strategic area in the plant, it was decided to study the piston rod manufacturing department.) The scrap for this department, in comparison to the other company departments, is shown in appendix B.2. What this graph does not show is that the rod section also has the second highest parts per million (PPM) figure in the factory;- the highest being the press department.

What follows is a Viable Systems Model of the piston rod manufacturing department. To diagnose the faults of the complex rod department is complicated. To do this one needs to divide the procedure into two parts, viz. the systems identification and the actual diagnoses of the system.

7.2 SYSTEM IDENTIFICATION

7.2.1 RECURSIVITY AT GSA

A viable system is composed of a subsystem engaged in producing the organism, and a supportive system which is responsible for maintaining its internal stability (homeostasis). In looking at GSA the three BU's form the subsystems which produce the viable company which manufactures motor vehicle dampers. Cost control, quality control, inventory management and finance control are all examples of homeostatic regulation in the viable system.

The basic purpose of GSA is to manufacture and supply motor vehicle dampers to the market and to make a profit. GSA as a whole enjoys sufficient autonomy to be viable. It is able to maintain a separate existence. The strut assembly cells manufacture struts, the shock absorber assembly cells manufactures shock absorbers and the rod department producers piston rods for these assembly cells.

The levels of Recursion are shown in figure 7.1. The three BU's, Internal Supply (BU1), Final Assembly (BU2) and Paint and Pack (BU3) constitute GSA's viable manufacturing business unit. Within the BU1 there are two viable systems, namely the Press and Rods Departments. The Rods Department is composed of four operational units, and their respective "parts" are illustrated in figure 1. The four operational units of the piston rod department serve the piston rod department. The piston rod department in turn serves the bigger system (BU1), which together with BU2 and BU3, have to serve their "higher" system, GSA. All the international companies, world-wide, must in turn serve their "higher" system, Arvin. The figure only illustrates the level up to GSA as a viable company.

Figure 7.1 highlights the self-referential feature of viable systems;- "their logic closes in on itself". In this characteristic lies the explanation for the maintenance of identity, the facility of self-repair, self-awareness, and recursively itself (reaches some level of totality if taken far enough). It also illustrates the connectivity between the various levels.

7.2.2 THE ROD DEPARTMENT AS THE "SYSTEM-IN-FOCUS"

The first step in using the VSM is to determine the purpose, then taking the purpose as given, to determine the relevant system for achieving this purpose. This is called the "system-in-focus" and

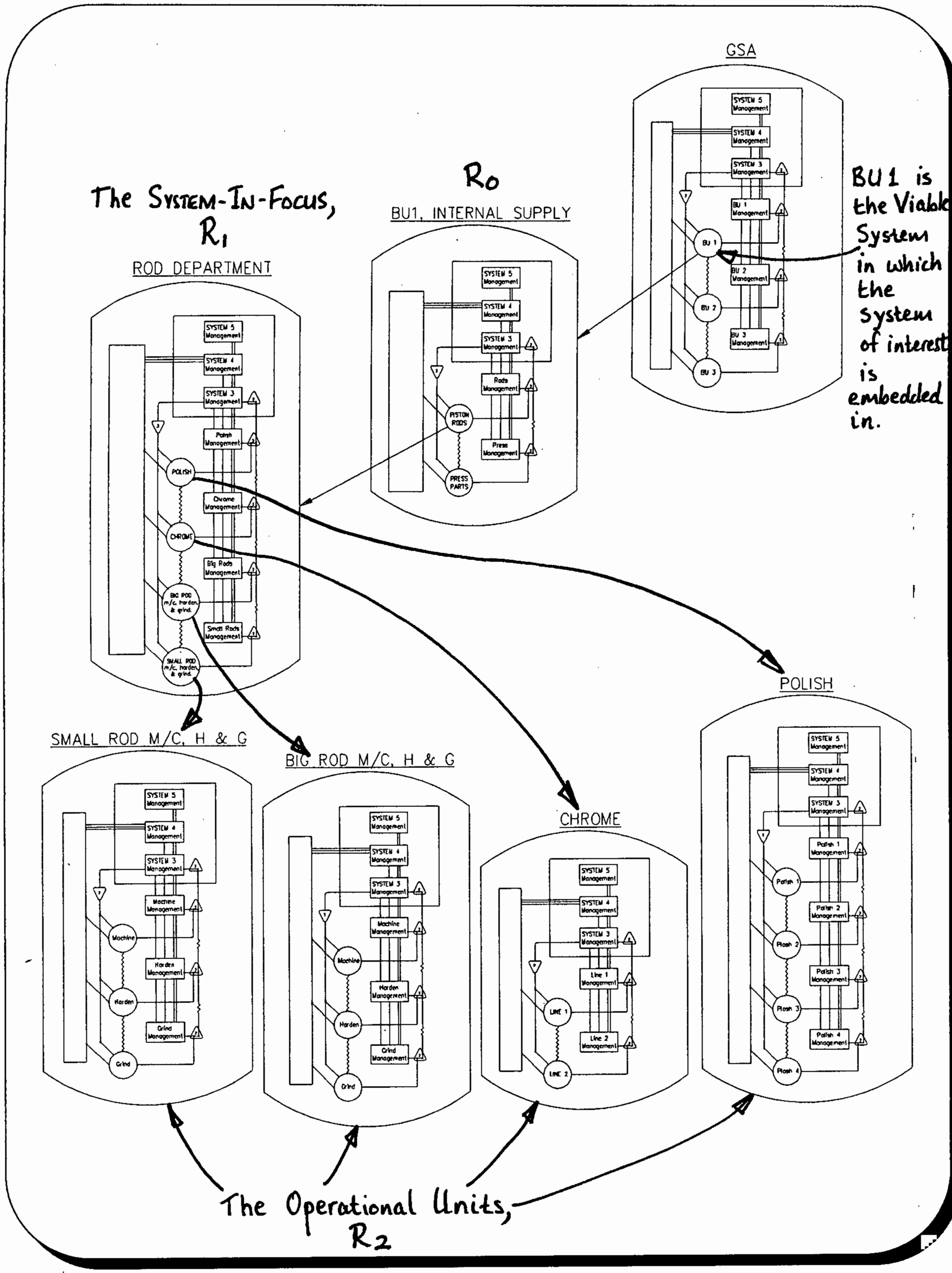


Figure 7.1 : The Levels of Recursion

the system in focus is said to be at "recursion level 1". In this case, the 'system-in-focus' (which is the area of concern) has as its purpose, to manufacture piston rods for the final assembly cells;- of the correct quality, the correct quantity, and on-time. Refer figure 7.2 below.

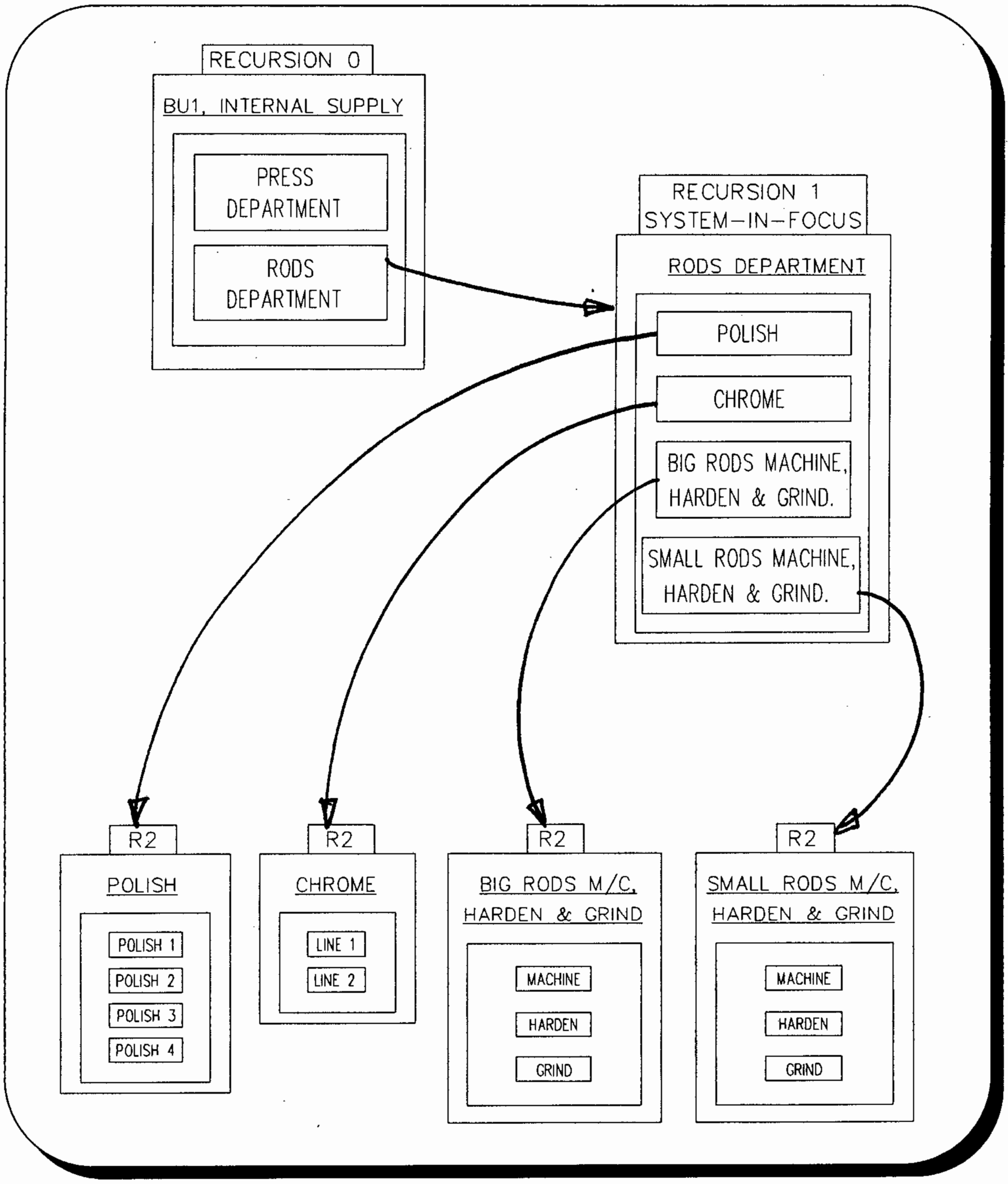


Figure 7.2 : The Triple Recursion (R0, R1 and R2)

The system-in-focus (R1, piston rod manufacturing) is the centre of a higher level of recursion (R0 which is BU 1), in which it is embedded. R1 contains a set of viable systems (R2, the operational units) which exists at the next lower level of recursion. This triple recursion (RO, R1 and R2) establishes the systemic boundaries for the rod department. The diagram in figure 7.2 also lists the operational units involved in the manufacture of piston rods. The environments of the system-in-focus are its suppliers, subcontractors, customer's, the supporting engineering companies and the support departments within GSA. The following sections look at the rod department within the framework of Beer's VSM and develops systems 1 to 5.

7.3 SYSTEM DIAGNOSIS

To conduct a diagnostic investigation into the system it is necessary to study systems 1 to 5 of the "system-in-focus". These five levels of the system-in-focus, the rods department, is shown in figure 7.3. These five levels are:-

- system one (implementation),
- system two (co-ordination),
- system three (control),
- system four (development), and
- system five (policy or intelligence).

7.3.1 SYSTEM 1 - IMPLEMENTATION

The 'system-in-focus' must manufacture and supply good quality piston rods to the final assembly cells as required.

7.3.1.1 IDENTIFICATION, PURPOSE AND DESCRIPTION OF THE OPERATIONAL PARTS

The viable operational parts of system 1, which on a day-to-day basis, ensures that the overall purpose of the system-in-focus is achieved are:-

- "big rods" machining, hardening-and-grinding,
- "small rods" machining, hardening-and-grinding,
- chroming, and
- polishing.

Note: Throughout this report "big rods" will refer to 17 to 28,5mm diameter rods and "small rods" will refer to 8 to 15mm diameter rods.

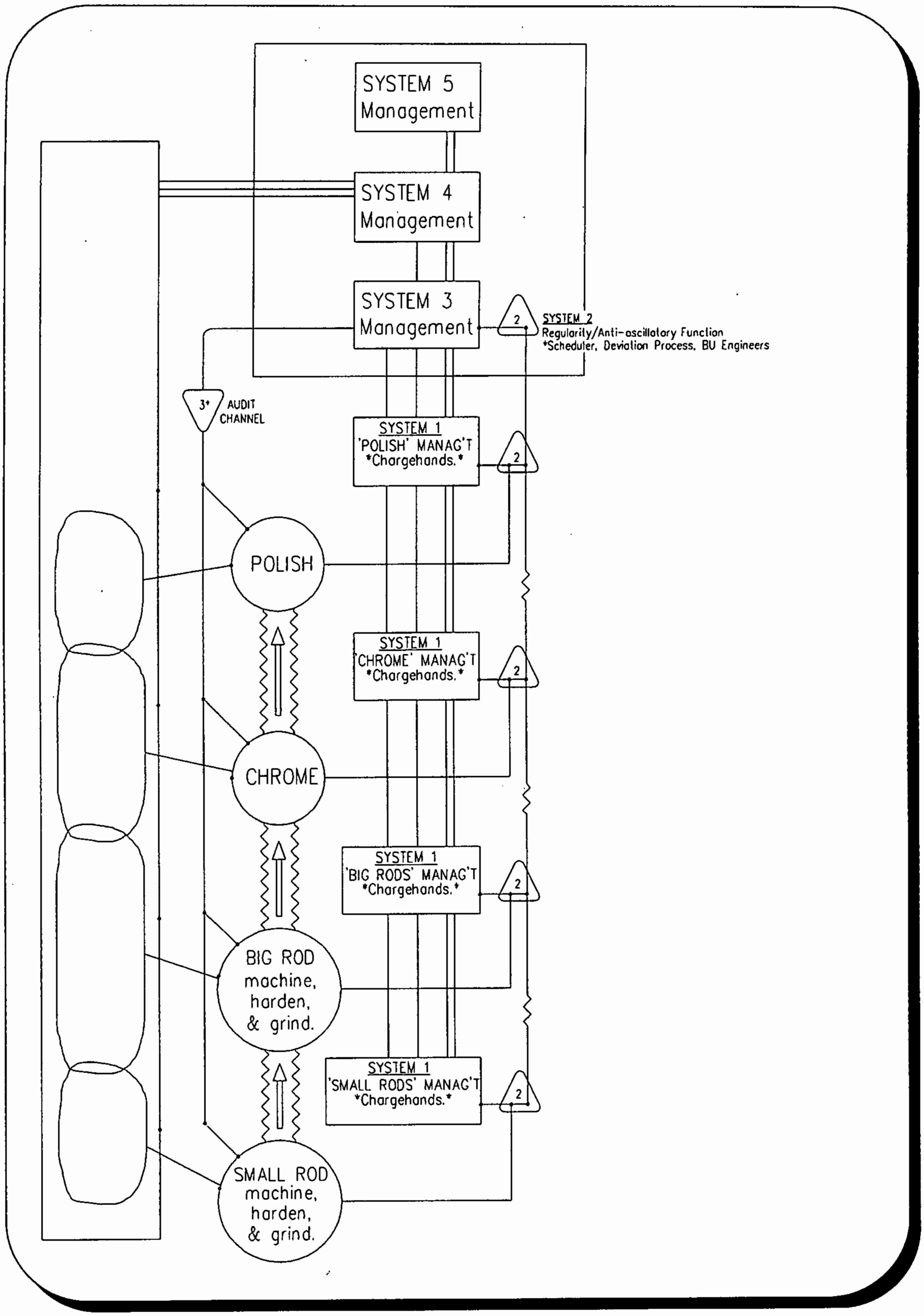


Figure 7.3 : Beer's Viable System Model of the Piston Rod Department

The process flow for the manufacture of a piston rod is shown in the diagram below:

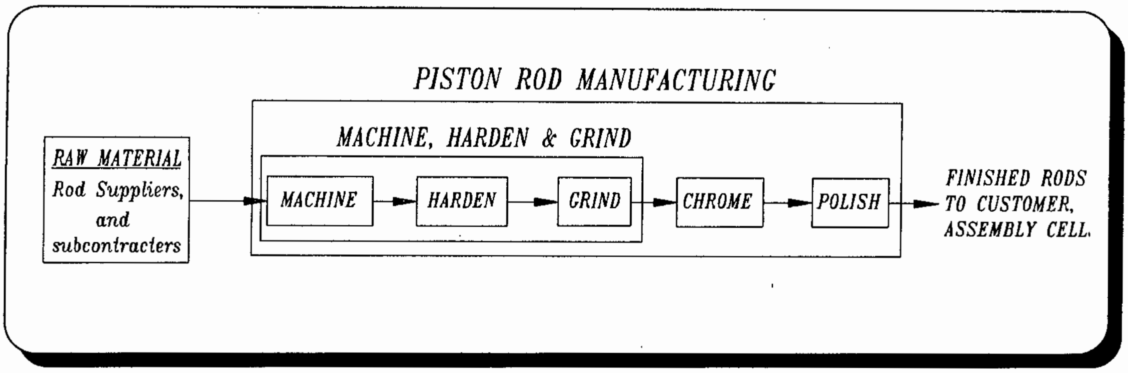


Figure 7.4 : Process Flow of Piston Rod Manufacture

A more detailed layout diagram of the piston rod department with its four operational units, is shown in appendix B.3. To facilitate the understanding of the process a typical big and small piston rod drawing, with the detailed design and manufacturing requirements, is shown in figure 7.5.

The rods are cut to length ("big" rods the rods are received from the subcontractor as cropped rods ready for machining), machined, induction hardened, ground, chrome plated and then, finally, polished to the final diameter and surface finish. Each process is dependent on the preceding process.

Thereafter, the completed rods are placed in a kanban rack, until they are required by the respective assembly cells. In the assembly cells the piston rods are then fitted with a crimped or welded rebound stop support, prior to fitment to the damper. These operational units are dealt with in more detail in the following sections.

(a) "Big" Rods Machining, Hardening And Grinding
(Refer Appendix B.4 for detailed layout drawing)

A detailed layout drawing of the big rods machining, hardening and grinding is shown in appendix B.3. This operational unit processes the 17, 20, 22 25 and 28,5 mm diameter piston rods for the cartridge, strut and 'special unit' assembly cells. The big rod line is totally to the involved in the production of these rod diameters except the 17mm rod. The 17mm rod is drilled in the small rod operational unit. As the name implies, the process involves the machining, induction hardening and grinding of these rods. The rods are then ready for the next process, namely chroming. By nature of the manufacturing process, the big rod line can be divided into two sections, viz. machining, and

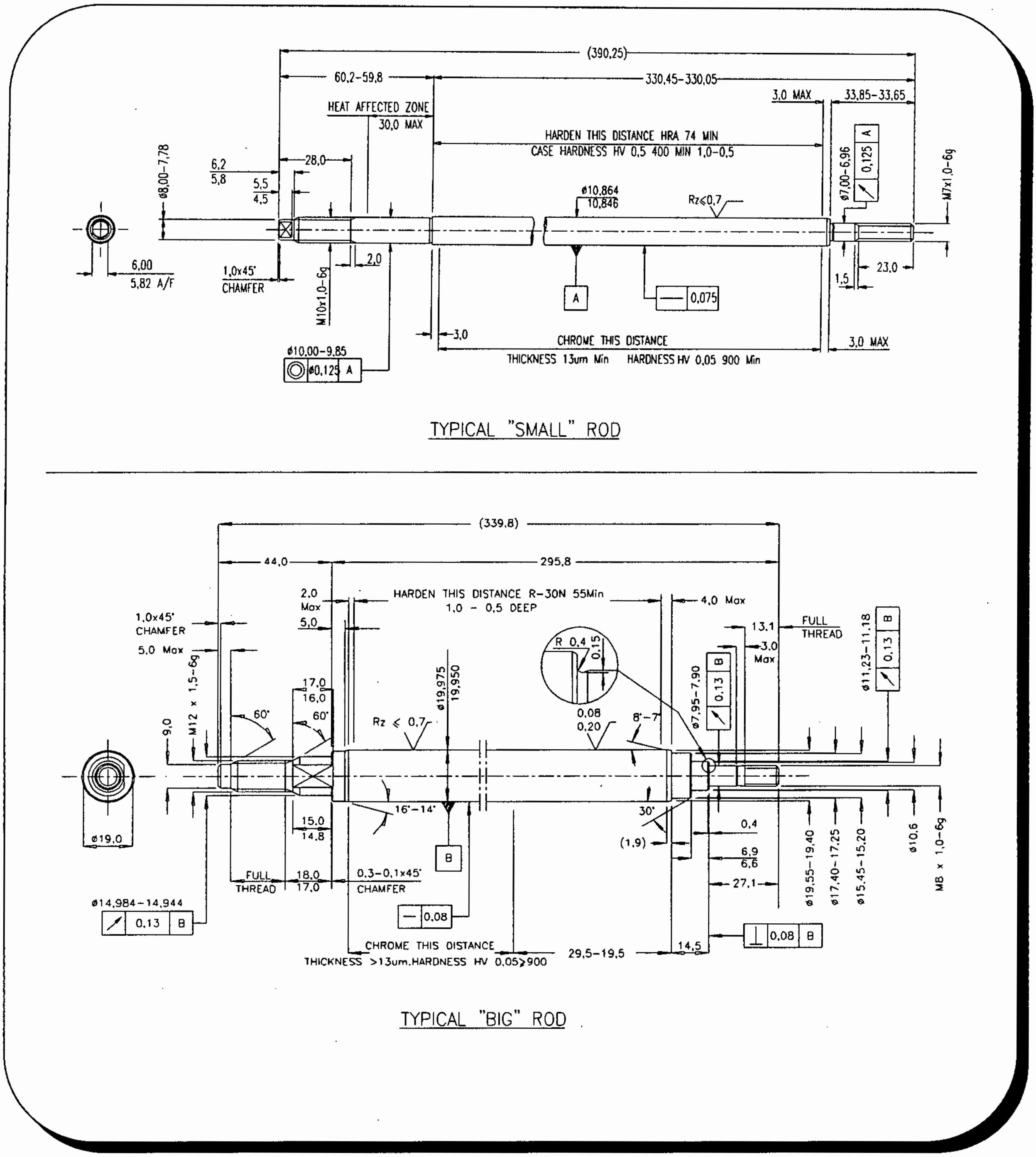


Figure 7.5 : Detail of Typical Piston Rod

hardening-and-grind.

(a.1) "Big" Rods Machining (Refer Appendix B.4)

The purpose of machining is to machine the stud end and piston ends as per drawing. GSA does not carry inventory for any of the big rod diameters. Only the 20 mm diameter rods are machined internally. The cropping operation (cutting to length) of these rods are completed by two external suppliers, Cambro and Maxwell. Cambro not only carries all the big rod material, but is responsible for the machining of all the 17, 22, 25 and 28.5 mm piston rods as well. The 17mm rods are the only rods that are processed in both the small and big rod line. See section (b) on 17mm rods. GSA is currently machining 50% of its total big rods requirement.

The machining is achieved by two CNC Cells. There are 3 CNC's per cell. Each produces approximately 50 rods per hour. The first CNC machines the piston end, the second the stud end, and the third producers the hexagon, slot or flat as required on the stud end of the piston rod. The total machining potential is discussed further in section 7.3.1.8 on the performance of the operational units.

(a.2) "Big" Rods Hardening And Grinding (Refer Appendix B.4)

After the machining operation, the rods are then induction hardened, straightened (as required), and ground to the specified diameter and surface finish.

The purpose of hardening and grinding are:-

- to harden the machined piston rods to the required length, depth and hardness,
- to straighten the bent rods (when necessary) to within specification, and
- to grind the rods to the specified diameter and surface finish.

The hardening process hardens the outer core of the rod to a specified depth. This is done to protect the rod from surface damage and to increase the rigidity of the piston rod. The rod is passed through an induction coil (of the correct diameter). As the rod passes through the coil a current is passed through it and the outer core is hardened. The rod is then water-quenched as it exits the induction coil. At times, rods bend ("bow") during hardening. These rods then have to be straightened. This is a laborious manual process and is done off-line by the operator. The rods are then fed along a conveyor to the grinders.

There are two grinders. Between these two grinders the required amount of material is removed from the rod. The second grinder also provides the surface finish necessary for the next process, viz. chroming. The hardened and ground rods which are now ready to be chromed are placed in a staging area. The chrome section then collect the rods which they need to chrome.

(b) Small Rods Machining, Hardening And Grinding
(Refer Appendix B.5 for detailed layout drawing)

The Small Rod Line exclusively deals with the processing of the 8, 10, 11, 12.7, 13, 14, 15 and 17mm piston rods for the shock absorber assembly cells. As mentioned before the 17mm rods are the only rods that are processed in both the small and big rod line. The cropped and machined 17mm rods are "threaded" and "drilled" (restriction holes) in the small rod area, and then moved to the big rod line for the hardening and grinding operations.

The flow of material in the small rod line is much more complex than that of the big rod line. The small rod line needs to process twice the quantity as the big rod line but it has twice the number of rod diameters as the big rod line. The piston and stud end variations are also greater.

(b.1) "Small" Rods Machining (Refer Appendix B.5)

The small rod section is comparatively more complex. GSA does not carry any of the material required for the 8, 10, 13, 15 and 17 mm piston rods. The completed 8 and 10 mm machined piston rods (used for the gas springs) are supplied by Maxwell. The 13,15 and 17 mm machined rods are supplied by Cambro. GSA machines the 11, 12.7 and 14 mm rods. This constitutes 75% of the total small rod production. Some rods are machined to length on the cut-offs by GSA, send to Cambro for machining, and then returned for the proceeding processes.

The small piston rod ends have a greater variety compared to that of the big rod line. On the stud end some have a CNC-machined end, some have a simple heel, and some have an additional groove machined in the stud end of the rod. On the piston end there are various size threads, some rods need to have stepped holes drilled into the rod and others not. Once the small rods are ready for hardening they are moved into a staging area from which the hardeners will select the work that they require.

(b.2) "Small" Rods Hardening And Grinding (Refer Appendix B.5)

The purpose of hardening and grinding have been outlined in section a.2 and will not be repeated here.

The hardening process itself is very much like that of the big rod hardening except that the coils are smaller in diameter. The amount of straightening that is required is also much greater than that of the big rod line. This is due to the smaller rod diameter. Generally, the longer and thinner the piston rods are the more they tend to bend. Most of the small rods are straightened by the Bronx rod straightener. Some rods require a hand operation to remove the bend, as in the case with more severely bent or grooved rods. The grooved rod normally "snaps" at the groove when fed through the Bronx (i.e. the piston rod straightening machine).

As for the big rods, they are then fed along a conveyor to the first of three grinders. These three grinders remove the required amount of material from the rod. The third grinder provides the surface finish necessary for chroming. The hardened and ground rods which are now ready to be chromed are then placed in a "small rod" staging area. The chrome section collects the prioritised rods for chroming.

(c) Chroming

(Refer Appendix B.6 for detailed layout drawing)

The purpose of the chrome section is to hard chrome the piston rod to the following specifications:

- to the required thickness,
- to the specified chromed length,
- to the specified adhesion.

The chrome section has two chroming lines. One is predominantly used for chrome plating the big rods and the other is used for the small rods. There are 12 process tanks and one dry dock per chrome line. On some occasions small rods are loaded onto the big line and vice-versa. This is obviously done at a longer changeover time and is only done when there are no better options. Only the big rods are placed in a hydrogen de-embrittlement oven for 2½ to 3 hours after chroming. Thereafter, the chrome process is complete and the rods are placed in the big rod staging area, ready for the final process, namely polishing. The small rods need not be baked and they are moved into the staging area ready for polishing.

(d) Polishing (Refer Appendix B.7 for detailed layout drawing)

The polishing section is the last operation of piston rod manufacture. Its purpose is to polish the rods to the final surface finish and diameter as specified.

As shown in appendix B.7, there are four rod polishing grinders and one superfinisher. Two of these grinders are used for small rods and two for big rods. This big and small rod split is the norm in the chrome section as well. However, it does happen that the grinders are used for either big or small rods, especially the 17mm rod.

The superfinisher is used for superfinishing big or small rods. After polishing, the rods are 100% inspected. The quality approved rods are then passed into the kanban racks, ready for final assembly usage.

(e) Discussion

These five primary operations: machining, hardening, grinding, chroming and polishing occur in the sequence above and is responsible for manufacturing a complete a piston rod. The four operational units discussed above are all potential viable systems since they can be 'farmed off' as Beer explains in "Diagnosing The System" (Beer, 1985).

The common purpose for these operational units then is to process their respective work as scheduled, to the correct quality and specification and to deliver on time to the next operation. The quality of a piston rod produced from these operational units is critical to the durability of a damper, viz. chrome thickness and surface finish affects the durability of the rod seal. Bad machining would affect fitment to the vehicle and induction hardening protects the rod from handling damage during assembly. All these processes are necessary and important and have as their function to serve the higher level of recursion, namely to produce a good quality and durable motor vehicle damper. The performance of these operational units is dealt with later.

7.3.1.2 The Internal and External Environment

The environment of the operational units are:

The suppliers:-

- raw material from suppliers
- machined rods from subcontractorsl

The customer's:-

- one operational unit relative to the other
- the assembly cells

GSA's "external" customers

The supporting engineering companies:-

Chemical and engineering companies

Tooling companies

Grinding wheel compaies

The support departments (as mentioned earlier) within GSA itself.

7.3.1.3 Local Management's Accountability and Responsibility

The localised management of the operational 'parts' in this scenario are the respective Chargehands (also known as the Cell Leaders) for the "big" and "small" rods machining, hardening and grinding, the chrome, and the polishing departments. Accountability can be defined as the liability to answer for results achieved. It is something which may never be delegated. Responsibility is to be morally bound to fulfil specified duties. Authority can be defined as the right to act or command.

The localised management's function of system one should really be that of a line function, namely to ensure that the planned daily production requirement is achieved. They must ensure that the scheduled work is completed by the required time and that the achieving the required quality and with the available or allocated resources. The Chargehands are accountable for any underachieved daily targets.

System 1 managers appear to understand their accountability to system 2 and system 3 managers, although they cannot always effectively account for non-conformance. The reason for this is not clear. One reason could be the cell leader often performs the duties of an full-time operator instead of performing a supportive role to his operators. The cell leaders actual day-to-day duties should be an advisory-type function. He should continuously ask what his operators need in order to perform their tasks. This information should then be given to system 2 managers for immediate action. Another reason could be that the support team (engineers and most of the maintenance crew) are new to the rods department and are still busy "finding their feet".

They also do not accept full responsibility for their sections. They do not see themselves as responsible to look after, to manage and to take the blame on behalf of the operators (as parents would of their children). It appears that they have not been clearly given this responsibility by higher management. Their job descriptions do not define them as "managers" of their respective operational units.

The management team (the BU manager, the production scheduler, engineers and most of the maintenance crew) are new to the rods department and job descriptions have not yet been clearly defined.

7.3.1.4 Constraints

The major constraints that prevent the operational unit cell leaders from achieving their daily objectives are:-

1. Repeated unplanned machine breakdowns
2. Absenteeism
3. Material shortages
4. Changeovers
5. Available Resources (equipment, process, people)
6. Drawing specifications
7. Level of operator training and education
8. Tooling unavailability
9. Autocratic goals from system 3 management
10. Grinding wheel changes

7.3.1.5 Introducing Variety (Refer Appendix B.8 and B.9)

By variety is meant the total number of possible states of a system, or of an element of the system. It is a measure of the complexity of a system. (Beer, 1981).

At the system 1 level variety is high. Variety is introduced by, amongst others (e.g. holidays and material supply), essentially 3 initiating variables, namely the product, the equipment and process, and human factors (Refer appendix B.8). All of these cause different magnitudes of downtime. The manner in which the various product characteristics introduce variety into the system is illustrated in appendix B.9. Both the latter variety initiators are discussed below.

(a) Big And Small Rods Machine, Harden And Grind

Since this operational unit has three core processes they are discussed separately, viz. machining, hardening and grinding.

(a.1) *Machining*

The product affects this operation by the set-up change required due to the change in the piston rod diameter, length and the piston and stud-end variations. A set-up change involves the selection of the relevant CNC program. Firstly the inserts, threadrolls and milling tools are changed. Secondly, the feeder is set for the new rod length. This changeover normally takes 15 to 30 minutes.

The process and equipment variety initiators are the causes for downtime, e.g. maintenance, tooling and drawing unavailability, quality problems, no operator instructions, meetings, etc.

The human element is generally attributed to operator inefficiencies, e.g. skill levels, training, absenteeism, attitude, motivation, etc.

The latter two variety initiators occur randomly and currently cannot be prevented.

(a.2) *Hardening*

During hardening the product variation is introduced by differences in the rod diameter, the overall rod length, the depth and magnitude of the surface hardness specified. The latter two variables are closely related. The depth of hardness and the surface hardness is controlled by altering the feed speed through the hardener, the greater the depth, the slower the speed. The other machine variables such as the current, etc. is seldom altered. The changeover for a new rod diameter is more complicated than the change of the rod length or depth of hardness. The induction coil has to be changed and a new first-off is necessary. This process takes ±30 minutes.

The process variety initiators are coolant temperature variations, coil burnouts, rod straightening and maintenance. It is difficult to anticipate and control maintenance, since there is no planned maintenance done on the machines.

The human variables are the same as in the above case.

(a.3) ***Grinding***

The many rod diameters and lengths are the main product variety initiators for grinding. A diameter change results in the grinders set-up changes, and a length variation results in a throughput variation.

The main process causes upsetting the grinding lines are the need for repeated dressing of the grinding and regulating wheels, wheel changeovers and maintenance. It is sometimes necessary to replace a newly replaced wheel due to its poor quality. The resultant downtime, when this occurs, can then be as high as 7 hours. Also, on the small rod grinding line, there are 3 grinders. One needs a wheel change every 3 months which takes 3,5 hours to change. The other two need a wheel change every 3 weeks. The duration of this change is approximately 30 minutes.

The human variables are the same as mentioned for machining above. In the case of the hardener and grinder, operating these machines to achieve the required diameter and surface finish, is still very much a "black art". Very few operators are sufficiently skilled to perform this task. The experienced operator is even more crucial when changeovers occur and grinding wheels are replaced. Because of this the process is operator dependent.

(b) Chroming

Product difference which affect the state of the system are, firstly, the diameter of the rod. Big rods are predominantly chromed on Line 1 and the small rods on Line 2. This is not a fixed rule. Depending on the unavailability of either big or small rods or the urgent product required by the assembly cell or maintenance of one line, rods are them chromed on either line. Secondly, the piston end of the rod initiates a changeover of the rod holders on the jigs. Lastly, the chrome thickness specified determines the cycle time for the jigs. There are basically 4 chrome thickness specifications, viz. 13µm, 10µm, 8µm and 5µm. This requirement is fed into the computer which controls the rate of chrome deposition.

The main process variety initiators are general maintenance.

The human variety causes are again operator efficiency levels, absenteeism, attitude and motivation. The effects of the latter two variables are discussed further in the section on action research, chapter 10.

(c) Polishing

As for grinding, different rod diameters result in set-up changes at the polishers as well. A length change results in piston rod throughput variations. In addition to this product related variety is also initiated by different surface finish specifications.

The process and human variety contributors are covered in the above sections. Absenteeism is generally dealt with by using a "temporary" operator.

7.3.1.6 Defining The Essential Variables

"In each species the many physiological variables differ widely in their relevance to survival. Every species has a number of variables which are closely related to survival and which are closely linked dynamically so that marked changes in any one leads sooner or later to marked changes in the others. These important and closely linked variables are referred to as the essential variables of the animal" (Ashby, 1954, page 41).

Essential variables are essential for the existence of a business. They affect the steady state of a system. For the system to maintain a state of equilibrium, it must regulate certain critical variables in order to maintain internal homeostasis. What is further required is to determine the upper and lower limits for each essential variable to maintain internal homeostasis. If it goes out of these limits the system then becomes unstable.

To determine the essential variables of the system-in-focus one needs to consider its purpose;- to deliver the correct piston rods in the correct quantity and on time, of the correct quality and cost.

Any measure which can indicate that the 'system' is not satisfying its customer, i.e. not fulfilling its purpose, will constitute an essential variable.

In the case of piston rod manufacture at GSA these essential variables (measures) are:-

1. Throughput - daily production quantity, orderfill, delivery.
2. Quality - scrap (as a % of cost of sales), PPM (parts per million), capability studies.
3. Cost - Rand value compared against competition, Labour as a percentage of sales, inventory turnover, WIP.
4. Innovation - all forms of new ideas towards continuous improvement, suggestions per employee, percentage of work team on EI Team and the number of employees cross-trained.

Not achieving throughput means not having rods available in the kanban racks and this has the major consequence of the assembly cells not producing their daily targets. This in turn means that GSA will not be producing as planned. Currently this is the most important measure at GSA. It will be remembered that this report was initiated out of the concern that the production figure of 12000 was not consistently achieved. This report will therefore focus on this measure to establish the performance of the respective operational units.

It has already been mentioned that one of the reasons for considering the rod manufacturing department was its high scrap and PPM value. Appendix B.2 showed that the rod department had the highest scrap value for the whole company. It also has the second highest PPM figure. It must be noted that two reasons for the high scrap value is, firstly, that the cost is grouped for the small and big rod machining, chrome and polish. Secondly, the value of a piston rod is high in comparison to any other component. Due to the time constraint, and the need for this report stemming from a "quantity" concern, this report will not track quality, cost and innovation.

It was shown in chapter 6.4 (and figure 6.4) how well these four competitive variable are interrelated. These essential variables regulate each other via the mechanism of a complex set of interlocking feedback loops. They also give the system its particular distinctive characteristics. Since they are so closely linked and regulate each other, if one is driven out of its limit, the others sooner or later go out of regulation also. In the extreme case when any one of the essential variables remain outside of its normal acceptable bounds for too long, the system can be destroyed.

The following comments on cost and innovation will be made though. From a cost point of view we have seen that GSA is generally competitive. However, this is the cost of a complete motor vehicle damper and not a piston rod. One can assume that the cost of the rod is competitive since it constitutes about 10 to 20% of the total cost of a damper. The cost is 'internal' in this case and is not directly determined by the customer (assy cells) as such. For the exercise of this report cost will not be tracked. It is will suffice to comment on the inaccuracy of the current costing method (R64 per hour for any process within the factory). All rods, irrespective of the "hassle" they cause are costed the same, viz. material cost x R64 per hour. No consideration is given to the actual changeover cost associated with a particular rod. It would be advised that a more realistic activity-based costing method be considered.

Innovation is people orientated. The measures of innovation indicate the extent to which an organisation believes in the ability of its people:- a "sense" of how far an organisation has come out of its positivistic era (where people were treated as machines). Innovation is generally measured by the level of training and education of the workforce, Employee Involvement (EI) programmes and the level of employee improvement suggestions (especially implemented suggestions), etc.

In summary, all four of these competitive measures, throughput (a direct measure of delivery), quality, cost and innovation, are extremely well inter-related (as shown in the systems dynamic loop in figure 6.4). An improvement in one variable will result in an improvement in the other, or vice-versa. It is worth mentioning that within GSA's GTQMS, all of the measures mentioned above, are now being monitored. At this point in time throughput is the most important essential variable and this report will use daily production quantities to appraise the performance of the system-in-focus.

7.3.1.7 Determining The Criteria Of Relevance

All the contributing factors which negatively affects the upper and lower limits of the essential variables, and threatens homeostasis, are criteria of relevance.

The most common and general criteria of relevance to piston rod manufacture are the following factors:-

1. Downtime - all unacceptable causes of zero production
2. Absenteeism
3. Material shortages
4. Operator errors
5. Available Resources
6. Drawing specifications
7. Level of operator training and education
8. Tooling unavailability
9. Lack of immediate engineering support.
10. Changeover's.
11. Unplanned machine breakdowns.

It is noted that all of these are also the constraints that the operational units have. The extend of downtime resulting from these criteria are tabulated in appendix B.8. In the computer simulation chapter they are monitored for a few weeks.

7.3.1.8 Operational Unit Performance

The purpose of the operational units has been discussed in section 7.3.1.1 and they will not be repeated here. This section will look at performance of the 4 operational units. Their performance will be judged by how well they meet their respective daily production figures.

The average daily piston rod required by the customer (the assembly cells) was taken to be 12000 completed rod. This would then be the requirement for the total machined, hardened and ground rods, for chrome and for polish. Using ±10% as a "realistic" and "fair" figure the upper and lower target limits were set at 13200 max. and 10800 minimum.

Based on the customer requirements, big rods constituted 4500 of total daily production requirement and small rods 7500 rods per day. Using ±10% again a maximum and minimum limit was calculated at 4950 and 4050 respectively for the big rod machine, harden and grind operational unit. Similarly the average, maximum and minimum production figures for the small rod machine, harden and grind is 7500, 8250 and 7650 respectively.

The production outputs for each of these operational units were tracked and graphs generated to get some sense of how well the operational units were performing. Refer appendix B.10 and appendix B.11 for the average daily production figures for the respective operational units from week 5 to week 36. Appendix B.12 shows a tabulation of the production figures for weeks 5 to 36. They are discussed below.

(a) Big rod machine, harden and grind

Appendix B.10 tracks the average daily graph of this section. From the table the actual daily average is shown as 3895, which is 605 units below target. The values vary from a maximum of 5463 to a minimum of 2671, a difference of 605 (or -13,44%) units underachieved. The standard deviation for the variation is 672 and its six standard deviations 4032 against a tolerance spread of 900 units. The erratic shape of the graph illustrates the variation.

(b) Small rods machine, harden and grind

The performance graph for this area over week 5 to week 36 are shown in figure B.10. As in (a) above it shows that this operational unit cannot maintain a consistent build of 7500 per day. The average actual value over this period is 6813 with a maximum of 9952 and a minimum of 4729. The graph clearly shows the total variation of 5233 which is 76,66% of the actual mean.

The combined figure for the above two operational units is 10708 against the 12000 average. This graph is shown with that of the chrome and polish in appendix B.11.

(c) Chrome

The actual daily average chrome figure obtained between week 5 and week 36 is 10386. The variation of 4863 units (maximum 12929 - minimum 8066) is shown on the graph in appendix B.11.

(d) Polish

Appendix B.11 illustrates the performance for the chrome section over week 5 to week 36. It is underachieving by 2045 units per day on average. (An actual mean of 9955 against 12000 rods/per required).

(e) Discussion

The first imminent observation is the erratic form of all the graphs. The variations for the operational units are summarised as follows:-

(Total)	Average	Maximum	Minimum	Average Required	Shortfall
grind	10 708	13 512	8 351	12 000	1 292
chrome	10 386	12 929	8 066	12 000	1 614
polish	9 955	12129	5 843	12 000	2 045

It is obvious that non of the above units are able to maintain an average production output of 12000 units/day (or 4500 units/day and 7500 units/day on big and small machine, harden and grind respectively.)

It must be noted that the current measurement for the hardener, grinders and polishers are number of rods per hour. However, the process operation occurs in metres per hour. Consequently, if the length of the piston rod varies the output will vary accordingly. Due to rod length variations, this figure can vary considerably.

Consider the big rod and grinding capable rate of 3 metres/minute. The equates to 180 metres/hr. The length variation for big rods are 506mm to 250mm with an average weighted length of 379mm. This translates to a maximum and minimum of 720 and 355 ground rods per hour. The average rate being 474 (180/0,379) rods per hour. This rod length change constitutes a difference of 365 ground rods per hour. Based on a 15 hours worked per day, at 3 metres/minute, and no downtime for the 15 hours, this in principle can results in a variation of 5475 rods per day.

Hence, for the grind and polish sections, maybe the measurements should be metres/hour to reduce this daily variation. However, this will not resolve the problem of the average of 12000 rods/day. Over the period of 5 to 36 weeks the "long" and "short" rods should average to give 12000 rods, if these sections were capable. This area is further discussed in the computer simulation in chapter 8.

The chrome section also has a similar situation. The throughput measurement is rods/hour, whereas the actual process is governed by the microns of chrome to be deposited (the variations being 5, 8, 10 or 13 microns) per rod and the number of rods loaded per jig (48 or 80). Example: A jig with a 13μm requirement will take approximately twice as long as one with a 5μm requirement if loaded with the same quantity of rods/jig. Also, some rods can be loaded on a jig which takes 80 rods instead of 48 rods. In this case 67% more rods are produced per hour. A large percentage of the chrome variation could be due to these two factors. The actual variation can be as low as 320 rods/hour (60*48/9) to as high as 960 rods/ hour (60*80/5).

Again, over a period of time (week 5 to 36 should be sufficient) the average daily value obtained should give "some indication" whether the operational unit is capable or not. In all of the above situations the graphs indicate that the operational units have not been able to produce a consistent daily average of 12000 rods/day.

These factors greatly affect the performance of the operational units as well as the overall piston rod manufacture. This inconsistent output also causes great frustration of the cell leaders who are never now what their output will be and for the BUM who cannot offer the customer a more consistent supply of rods.

Lastly, the 'systems' (rods department) is measured by the number of rods it producer's per day (week). Based on the need of fulfilling the customers real need it should be measured by the quantity of rods/part number/day (or hour;- to achieve the "on time' customer requirement). This raises an important question, "are the respective processes capable and what are their potential ?"

7.3.1.9 The Operational Units' Capability And Potentiality

The units within the system were analysed to determine their actual, capable and potential outputs. These measures are essential to focus on the long-term survival and viability of the organisation as outlined by Beer in the Brain of the Firm. These measures are fundamental in re-prioritising and planning long-term capital expenditure needs. This is essential if throughput is a problem and where virtually all machines are running at almost maximum available time (at 21,75 hours out of 24 hours per day, and at times, weekends as well). Equipment are stretched to its limit.

This section attempts to define the capability and potential of the four operational units. The methods used to gain knowledge to answer the question raised in the above section were participative observation (ethnography). Since the author was a team member to the system-in-focus ethnography was possible, and the author's point of view, most appropriate.

Firstly, we need to define the following measurement terms:

Actuality: Simply "what we are managing to do now, with existing resources, under existing constraint" (Beer, 1981, page 163).
All of the above section dealt with actuality;- the current production figures.

Capability: "This is what we could be doing (still right now) with existing resources, under existing constraints, if we really worked at it" (Beer, 1981, page 163).
Reaching capability can be achieved by developing the supplier (less shortages), design for manufacture, the use of quick change tooling, improving overall quality by working to a TQM principle, developing a more effective ECO process (system), etc.

Potentiality: "This is what we ought to be doing by developing our resources and removing constraints, although still operating within the bounds of what is already known to be feasible" (Beer, 1981, page 163).
To attain potentiality we need to rethink process and equipment utilisation. Also remove bottlenecks.

"Productivity = Actuality / Capability.
Latency = Capability / Potentiality.
Performance = Actuality / Potentiality = Latency x Productivity" (Beer, 1981, page 163).

About these measures:

1. These are the kind of measures we need, and they may be applied in general to divisional (BU's) performance or the individual (operational elements) activities.
2. They may also be applied segmentally to various aspects of work, e.g. efforts of labour force and technological capacities of the plant. In that case these segmental

indices may be subsequently multiplied together to overall performance measure.

3. However, the raw data is obtained, it may involve work studies and operational research on a considerable scale, the resulting measures are simple to compute. Measures of achievement.
4. Detect the manager who does everything to wreck the industrial enterprise. He is the irresponsible "Cost Cutter". He raises productivity (on a short term), acquires a marvellous reputation, not by increasing actual achievement but by lowering capability. This he does by squandering latent resources. He cuts budgets, he "lets go" valuable men, he fails to implement research results should this involve the slightest effort, expenditure or risk. Thus, he triumphs as a tough, practical man. In the orthodox (traditional) scheme of reporting. No measures will reveal the damage he has done. There is no element in either the profit and loss account or balance sheet (traditional accounting system) which declares him to be murdering the company's reputation in the marketplace." (Beer, 1981, pag 164 to 166).

Having said this the actuality, capability and potentiality of each operational area was calculated. The results of these calculations are summarised below. Refer to appendix B.13 for the detailed calculations of each operational unit.

Summary:-

	M, H & G	**Chrome**	**Polish**
actual	**10 708**	**10 386**	**9 955**
capable	**18 481**	**12 543**	**26 297**
potential	**15 000**	**15 000**	**15 000**

The actual values are the average daily production values for weeks 5 to 36. Note that these values are for big and small rods.

Note that in each of the calculations for capability the following was considered:-

- The available hours per day was taken as 15 (Refer appendix B.14 for the calculation). This time makes allowance lunch breaks, 2 tea breaks, Green Area meetings, one 30-minutes EI meeting per week, and is based on an 85% efficiency.
- The assumption was made that the their would be no downtime;- this exercise is for comparison only.

- A "weighted" average rod length was used in each case.
- The rates taken were based on the average cycle times measured for the relevant process.

The potential results are based on figures which could be produced by the elimination of bottlenecks in the system (improvements made to the process and equipment by substantial capital expenditure over a period of time). Considering that the maximum production figure obtained was 13 512 rods per day by the machine, harden and grind section; the fact that the average idealistic capability for the three processes is 18 862 rods per day; an arbitrary potential figure of 15 000 rods per day was selected. An attempt to obtain a more realistic potential figure is beyond the scope of this report. All the throughput rates would be equal to the throughput rate of the fastest process in the overall system. An ideal situation to strive for.

Since chrome could potentially be constraining the performance of the overall system, the productivity, latency and performance of the rod manufacturing department (system-in-focus) uses the figures for chrome in the following calculation. It must be noted that when downtime is considered, this may not be the case. Observations made led the author to suspect that chrome could be a potential constraint.

Productivity = actual/capable = 10 386/12 543 = 0,83.
Latency = capable/potential = 12 543/15 000 = 0,84.
Performance = actual/potential = 10 386/15000 = 0,69.
Performance here is as defined by the above calculation. When used otherwise it refers to productivity as measured by the above formula.

The above findings suggest that:-

1. The chrome section appears to be a bottleneck under its current operational situation.
2. The operational units of the system-in-focus cannot control the variety introduced to the system. As a consequence of this, these operational units cannot achieve a consistent average daily production figure of 12000 units per day.

7.3.2 SYSTEM 2 - CO-ORDINATION

System 2 serves a co-ordinating function only. System 2 attenuates information vertically upwards and amplifiers information downwards. (BUM to foremen to operational units, and vice-versa.). System 2 in the rods department is well developed.

The daily production goals are given directly to operational units by the production scheduler via the foremen. The transducers of this information are kanban cards which are issued to the shopfloor. The co-ordination of the operational unit is largely handled by the cell leaders, the foremen and the scheduler (production control function). Between them they can reorganise the re-priorities for the four sections when required. In this way they absorb much of the variety which the BUM would otherwise have to deal with. This often involves the rescheduling of the rod programme due to some "material shortage problem" or machine breakdown experienced by the customer (the assy cells). Most times rescheduling negatively affects the throughput of the overall system. This unplanned variety introduction creates costly and time-consuming changes.

They control uncontrolled oscillations and update the plan to meet whatever difficulties are encountered. This constant updating of the plan on the central command axis is essential otherwise the overall organisational plan (as a whole) cannot be met. In this case where the operational units are dependent on each other to complete a usable piston rod they inform each other (the process before and after or the customer and supplier) of changes they make otherwise all three of them will try and change their plans to suit each other. Also, system 2 is well monitored by system 3 who does not allow it to hunt too aimlessly.

System 3 management meets with system 1 (operational unit managers or cell leaders), system 2 managers (foremen and scheduler) and the support staff (process-, quality-, product-engineer and the maintenance staff) on a daily basis (every morning) to determine the following:-

- an update of the previous days production build,
- reasons for non-conformance,
- to establish the days priorities for the operational units to focus on,
- absenteeism,
- anticipated problems for the day, and
- maintenance and engineering related priorities.

Based on the information system 3 management receive from this meeting the BUM has a fairly accurate idea of how the overall system is functioning. If required system 3 management will then intervene to correct matters. This intervention is mostly with regards production performance since this is how the rods department is measured. It is really a matter of, "tell me how you measure me and I will perform accordingly".

Deviations from drawing specifications and quality requirements are dealt with by the product and quality engineer who report to the internal supply bum. For example, when a component in the process is incorrect a deviation is raised by the chargehand (cell leader) or the operator. He takes it to the development engineer, who approves or rejects the deviation. It is then "walked around' to the affected level 3 people for their approval and comments. Once approved it is then returned to the operator and copies are circulated to all involved. The deviation process is not bureaucratic and "paper" intensive. In fact it a extremely flexible one. The development engineer (having verbally discussed the implications of the deviation with the relevant people concerned, where discussion with them is required) often gives production verbal approval to go-ahead whilst the deviation is 'walked around' to obtain the relevant signatures required for approval.

Machine breakdowns are handled by the process engineer and the maintenance personnel who also report to the internal supply BUM. The Strategic Business Unit management structure (previously explained, also refer organisational chart;- appendix B.1) is an effective way to react rapidly to overcoming shopfloor problems and to assist co-ordination. It also facilitates the improvement of communication and promote the development of 'teamwork'. This well established and functioning system 2 is a very efficient method to deal with variety.

The greatest constraints that system 2 managers have are:-

1. Grinder changeovers
2. Induction hardener downtime
3. Rescheduling priorities
4. Material shortages

The effects of these variety initiators were discussed in detail in section 7.3.1.5.

7.3.3 SYSTEM 3 - CONTROL

First and foremost, the objectives of the 'system-in-focus' is to ensure that the daily production targets are met so that the assembly cells (the customer to the rods department) can meet their planned orderfill for that day. The completed piston rod must also comply with the quality and technical specifications as laid down for that respective piston rod. System 3 maintains homeostasis and ensures that the internal stability of the system-in-focus is not jeopardised at any time.

System 3 management must also ensure that higher level management policies, e.g. TQM and EI, are implemented at the operational unit level. This is a typical downward amplification information flow.
System 3 management are performed by the BU Manager, the product, process and quality engineers and the scheduler. System 3 exercises its authority by providing the information (the BUM and scheduler) required by the operational units to produce their daily production targets. This is a form of amplification.

This information is triggered by the rod department production scheduler. His information is initiated by a weekly program from the "master" scheduler who loads the factory with shock absorber numbers. For AM the Kanban pull system started in the finished goods stores. The production requirement for the OE dampers are based on the regular weekly releases from the Motor Manufacturing Plants. Export production is dependent on the export orders accepted. The operational units performance is gauged daily by the completed units from the respective sections against the planned targets.

The process, quality and product engineers are continually busy to implement higher level policies (e.g. the EI and TQM programme) throughout the system-in-focus and to make process, quality and product improvements. All of these aiding to the improvement in cost, quality and delivery (throughput).

The rods department (Internal Supply BU) has a annual financial budget to work within. If the BU need to exceed its annual financial budget then they have to submit a justification, with cost validations and payback period, to system 4 and 5 management for approval. The rod departments higher level management forms the system 3 management of the Recursion Level R1, where GSA is the system-in-focus.

Some of the measures used to monitor the overall BU viability are:-

- the daily production output
- the scrap figure
- the PPM figure
- the overheads for the rods department
- the WIP and raw material.

The recording of the above measures are all attenuated vertically upwards.

Audits are carried out on the production quantities achieved, the quality system and WIP.

The progress of the goals to be achieved by the BU are reported to the Managing Director (MD). The MD forms part of the system 4 management. An example is the current purchase and implementation of two new CNC's for the big rod line. They must produce rods to justify their purchase. The BU's production performance is gauged daily by the completed units from the respective assembly cells compared with the planned build for the day. Both these functions are upward filtering information types to the higher level management.

Shopfloor moral and concerns are monitored through the Green Areas to the BUM (system 3 management). He in turn deals with this through the supporting Human Resources Department who then provides assistance as required, e.g.. new or additional equipment and training needs to achieve certain goals. This is a typical two-way communication between system 1 and 3.

Daily quality problems which result in products being out of specification are handled through the control of a "deviation" process. This process serves as a co-ordinating function. In certain instances this form also initiates a corrective action report to resolve the cause of the problem. If the problem is critical this report goes to level 4 management for a strategic solution.
In the case of an extremely critical situation system 3 can warn system 5 via the algedonic signal. An example of such an instance the piston rod department recently had was the quality and shortage problems experienced when the rod material supplier was changed. System 5 was

immediately alerted since this situation had serious implications for the whole company. In this case system 4 and 5 intervention was necessary and their intervention did occur.

7.3.4 SYSTEM 4 - DEVELOPMENT

The development function for the piston rod department is not clearly defined. Since there are no higher management above the BUM, this function is performed by the BUM and the system 4 managers of the GSA Recursion. System 4 being composed of the executive management team. The system 4 activities are listed below:-

- The capacity development of the rods department
- Needs assessment;- to remain competitive rods be manufactured as cheaply as possible
- Requirements for competitive advantage, low WIP, higher throughput, GTQPS and I.E.
- Development of people (realising potential, training, succession planning)
- Corrective Plans for areas within BU's based on analysis of warranty returns (PPM.), e.g.. corrective action for shock absorber leaking due to chrome defect on piston rod which led to rod seal damage.
- Better ways of satisfy the customer, assembly cells, orderfill

Although executive management is extensively involved at levels 3 and 1 problems and is usually too busy fire-fighting, the above does not occur effectively.

Two CNC's and transfer units has recently been purchased for the machining of 11mm piston rods. The reason for purchasing the CNC's were to enable the company to reduce the subcontracting of rods and thereby to reduce the cost per rod, especially with the expectation that the demand for 11mm rods will increase. Secondly, the company would be in control of one of its strategic components. What has not happened in this case is that no detailed project plan had been drawn up for this project;- not only for the purchase of these two CNC's but the manufacture and "inter-linking" of the CNC electronics with the electronic control of the rod transfer unit.

It is the author's opinion that proper project planning is a systemic thinking tool. It involves the planning of people, processes, machines and equipment, etc. It facilitates the thinking of various aspects and phases of the project in great detail and identifies relationships of various aspects of the project. Also, the "cost-quality-delivery triangle" (well known in project management) is manipulated for the most efficient utilisation of resources at different stages of the project to achieve the project objectives.

7.3.5 SYSTEM 5 - POLICY or IDENTITY

The identity of the BU is determined by the BUM with the System 5 managers (the same as that of system 4 managers - the Recursion of GSA) as well as the policies which are laid down by the parent company, Arvin (One Recursion above GSA as Recursion 1). A good example is the GTQMS programme. All Arvin subsidiaries work within this framework and have the same goals to meet to become world-class.

At GSA a strategic plan is drawn up every year with a 3 year horizon. This plan is revised annually. In the past this plan had been autocratically passed to level 4 and parts of system 3. In this regard system 5 is well developed.

7.4 CONCLUSION

From the analysis of the various operational units and the diagnosis of Beer's five functional elements the following conclusions are made:

(1) Evaluation of the various operational units revealed that in practice non of the these units were able to produce a daily average of 12000 rods per day.

(2) The variation of the graphs produced and the calculation of the capability figures for the operational units of the system-in-focus, suggests that the system cannot control the variety which is introduced into the system, namely it does not have the requisite variety to deal with the variety that the system is subjected to.

(3) From the calculation of the capability figures for the chrome department it seems that this operational unit prevents the rod manufacturing department to achieve the throughput of the 'overall system'.

(4) System 2 to 5 appears to be well developed.

(5) Except for system 1, the rod department, as the system-in-focus, fits well within Beer's VSM.

This chapter completes the immersion stage. The next chapter formulates an hypothesis based on these conclusions.

CHAPTER EIGHT: FORMULATING AN HYPOTHESIS

GSA needs to produce an average of 12000 units per day. This chapter, based on the investigation of the previous chapters, formulates an hypothesis which would explain why GSA cannot achieve this target.

Firstly, during the initial immersion stages it was the author's intuition that induction hardening was a bottleneck, on both the small and big machine, harden and grind lines. Another viewpoint was that machining was a bottleneck which could be true if there were no subcontractor's. In an area with such great complexity all of this is mere guesswork without the necessary rigorous immersion. The system-in-focus, the piston rod manufacturing department, is loaded with 12000 units per day, treated as a "black box" and is required to produce this output. With the high variety that each of the operational units of the system is subjected to one needs to "open up" these black boxes to try and establish what is happening.

Through overt observation and direct participation (ethnography), and the VSM diagnosis the possible causes for not achieving this average daily production target were investigated. The evaluation of the various operational units revealed that in practice non of the these units were able to produce an average of 12000 rods per day, even though they had the capability to do so. The actuality, capability and potentiality figures are repeated here.

	M, H & G	Chrome	Polish
actual	**10 708**	**10 386**	**9 955**
capable	**18 481**	**12 543**	**26 297**
potential	**15 000**	**15 000**	**15 000**

From the conclusions made by the analysis of the various operational units it becomes apparent that a possible reason for these units not being able to produce a daily average of 12000 rods per day could be due to the fact that the system cannot control the variety which the system has to deal with (i.e. certain phenomena within the system is uncontrolled).

It is found that this variety was generally introduced by the criteria of relevance which prevented the operational units from achieving their daily target. These criteria were basically all the causes of production downtime, namely unplanned machine breakdowns, absenteeism, material shortages, changeovers due to different product types, available resources (equipment, process, people), lack of clear drawing specifications, operator errors, level of operator training and education, tooling unavailability and wear, bad quality of raw materials, lack of immediate engineering support and changeovers due to the process (e.g. grinding wheel changes), etc. All these contributing factors negatively affects the upper and lower limits of the essential variables, and threatens homeostasis.

Lastly, some of the systems thinking laws, theorems or principles which deals directly with the above are reviewed before a hypothesis is made.

(1) The Requisite Variety Law.

The control achievable by a given regulatory sub-system over a given system is limited by a) the variety of the regulator, and

b) the channel capacity between the regulator and the system.

An alternate statement of the law is that the upper limit on the amount of regulation achievable is given by the variety of the regulatory system divided by the variety of the regulated system (Clemson, 1984, page 216).

(2) The Conant-Ashby Theorem.

Every good regulator of a system must be a model of that system. (Clemson, 1984, page 218).

(3) The Homeostasis Principle.

A system survives only so long as all essential variables are maintained within their physiological limits. (Clemson, 1984, page 215).

The first law seems to be the most appropriate law to explain the conclusions made from the VSM diagnosis, since it deals with variety, the cause of management concern. The second law complements the first since it raises the question, "how can a systems variety be regulated if the higher level management of the system does not understand (cannot model) the root cause for this harmful variety?" The third law is relevant to this inquiry because variety is affecting the physiological limits of the most significant essential variable of the system, throughput.

From the above discussion the hypothesis is consequently made is that **the operational units within the system-in-focus cannot achieve <u>requisite variety</u> to effectively meet their daily production targets.** The following two chapters sets out to test this hypothesis.

CHAPTER NINE: ACTION RESEARCH TO TEST THAT VARIETY AFFECTS CHROME

From discussions on the operational performance of the chrome department (see VSM paragraph 7.3.1.8) and from calculations based on observations made of the area, it came as a surprise when together, this data suggested that the chrome section could be constraining the 'overall system'. If this was true it had serious implications for the piston rod manufacturing department, since it would involve major capital investment. To improve the throughput, the operational units "capability" would have to be improved. It is for these reasons that this operational unit is used to test the hypothesis.

This chapter attempts to verify the hypothesis made in the previous chapter, namely that the chrome section does not have adequate regulatory capacity to effectively control the variety that the system is subjected to, and as a result of this creates a bottleneck. Firstly, consideration is given to the main reasons for this deduction. It then explains the process and layout for the chrome area. Using action research a test is set up and conducted to test this hypothesis. Operators are involved since they are considered as an important part of the system to decide on the procedure of conducting the test. Using their input a test is set up whereby intervention is made. The conditions of the test are ensured and the test is implemented. The outcome of the test is observed and from this conclusions are drawn. Lastly, recommendations are made.

9.1 IDENTIFYING CHROME AS A BOTTLENECK

The suggestion that the chrome department was a potential bottleneck and constrained the rod manufacturing department came as a surprise to the author. There was a general rejection of this hypothesis by the people involved with the chrome department. They firmly believed that the chrome section can produce 12 000 chromed rods per day. Obviously everyone had their own views why the section was not producing an average of 12 000 rods per day.

The following four observations supported this suggestion:-

(1) WIP ready for chroming (big and small ground rods) were accumulating in the staging area at the beginning of the chroming process.

(2) The process after chrome plating (namely polish) was regularly waiting on work from the chrome section.

(3) Calculations based on monitoring the process and on information acquired from people (the operators, the process engineer and the scheduler) involved with the process on a daily bases reflect that under the current situation the maximum rods possible is 4800 and 7743 big and small rods per day respectively. Refer to appendix B.13 for these calculations. With changeovers and downtime, these figures reduce to average production quantities of 3780 (79% of 4800) and 6606 (85% of 7743) for big and small rods, respectively. This average is taken over the period between week 5 and 36. Refer to appendix C.1 for these production figures.

(4) Historically, chrome has always had to work more overtime than the other operational units.

If chrome were a bottleneck this would have major implications for the performance of the rod manufacturing department. Due to the points 1 to 4 above and the latter concern, chrome being a bottleneck had to be tested. A discussion ensured with system 2 and system 3 management. It was agreed that at that point in time chrome was having a problem producing its target of an average 12000 rods per day. Whether chrome was indeed a bottleneck was debated. It was agreed that a test would be conducted and that the operators participation would be ensured.

9.2 THE CHROME PLATING PROCESS

First, the chrome plating process needs to be described. Refer to appendix B.6 for layout drawing. The Chrome department has two chroming lines. One line is predominantly used for big diameter piston rods and the other for the smaller diameter piston rods. There are three load and off-load stations at the beginning of each chrome line. Each line has two computer controlled carriers which move 9 jigs between the 12 tanks and the load-off-load station.

The 12 tanks are listed below in the sequence that the chroming process occurs:

(a) Soak Cleaner - holds a strong caustic (soapy) solution for degreasing stubborn dirt and fat.

(b) Electrolytic Cleaner - also a caustic solution, but uses a reverse current and electrolytically "etches" and removes dirt from the rod.

(c) Rinse 1 - a continuously flowing water bath for rinsing the rods.

(d) Rinse 2 - the same as (c)

(e) Edge Tank - this tank has chrome salts only i.e. there is no catalyst. This tank prepares the surface of the rods so that it is free from oxides or impurities.

(f), (g) or (h) Plating tank - each chrome line has 3 plating tanks. These tanks are the tanks which do the actual hard chromium electroplating. Any jig of rods will only pass through one of these. The tank temperature is maintained at between 50-60°C.

(i) Dragout tank - basically water solution for rinsing the rods.

(j) Rinse 1 - as for (i)

(k) Rinse 2 - as for (i) and (j)

Note: There is a major difference between the "rinse" tanks in (c) and (d) and (i), (j) and (k). The latter three tanks get contaminated with chrome solutions, whereas tanks (c) and (d) basically remove dirt and grease.

(l) Hot Rinse - this last rinsing tank contains stagnant hot water so that the rods can dry by water evaporation once the jig is removed from this tank.

(m) Transfer Station - this last tank is "dry" (no tank). It facilitates the evaporation process so that the rods are dry and "handable" when removed from the jig.

The very first operation is the loading of the piston rods onto the jigs. There are basically two jigs. One can hold 48 rods (generally big rods), and the second holds 80 rods (mainly gas spring rods, i.e.. 8 and 10mm). Once the rods are loaded, the operator feeds the P.L.C. with the following data:

- the number of rods per jig
- the chrome thickness required
- the rod length
- the diameter of the piston rod.

Using this data the P.L.C. then "tags" the jig and calculates the current density (Amps/dm^2) needed inside the tank to chrome the piston rods on that jig. The formula used for the deposition rate is:- Deposition rate = current (in amperes) *100 / (¶ * diameter * length * no. of rods)

From experience, the optimum chrome deposition occurs at approximately 55 Amps/dm^2 and is shown in the diagram below.

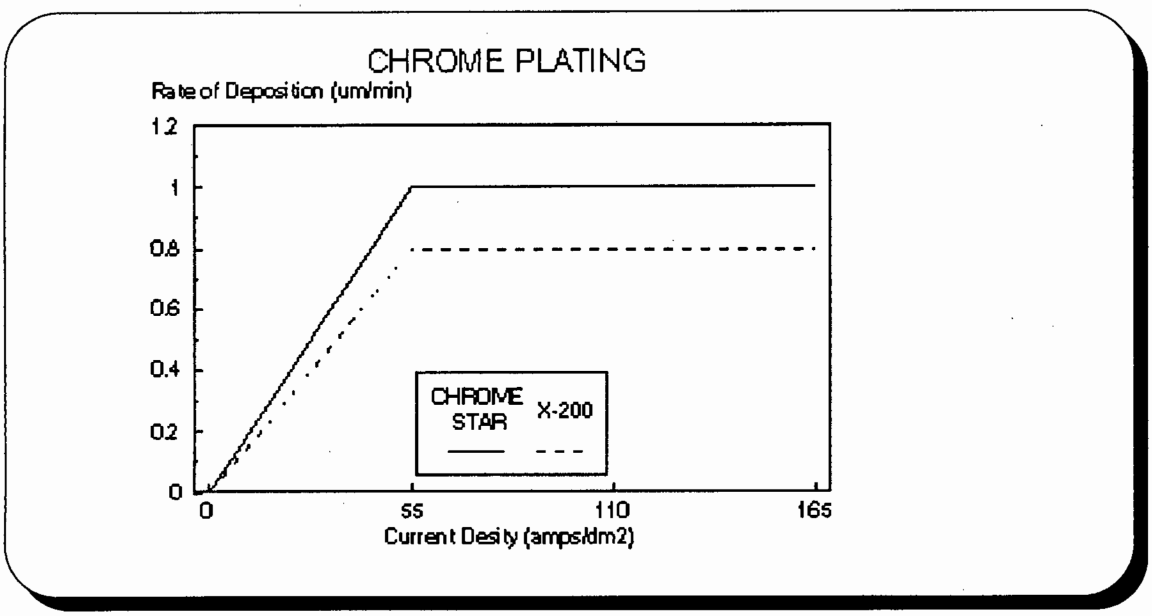


Figure 9.1 : Chrome Deposition

The small rod chrome line uses a chrome solution, Chrome Star. With this solution a maximum deposition rate of 1µm/min is achieved at 55 Amps/dm^2. The big rod line uses a different chrome solution, X-200 and achieves a maximum deposition rate of 0,8 µm/min. The success of hard chrome plating is dependant on the temperature, the current density (Amp/dm^2), the piston rod surface finish, the accuracy of data entry, the chrome concentration and the cleanliness of the tank solutions.

9.3 SETTING UP A TEST USING ACTION RESEARCH

Due to the complexity created by the chroming process, the people interface with the process, the variety of product range, the random downtime and the lack of time to try any sophisticated modelling it was decided that the most appropriate method to test this situation would be to conduct some real life action research. The reason for this is that action research involves a planned intervention into naturally occurring events. The effects can then be monitored and evaluated to see whether the action has produced the expected consequences. Action research also leads to eventual action, based on what was learned during the research.

A meeting was set up with the product and process engineer, the scheduler, the foreman and the personnel of the chrome section. It was necessary to ensure that the operators were involved to eliminate any other unforeseen factors which may be causing the under-performance of the chrome operational unit. The question put to them was, "what do they need to increase the throughput through the chrome section?" The discussion that followed was an interesting one.

The major points discussed were:-

- Throughput could be improved if they were given an extra operator per line. The operators in the chrome section strongly felt that they were being overworked, that the work was labour intensive, and that they are unable to "create miracles" to obtain the required production, which they were not enthusiastic to do since their efforts were not appreciated anyway.
- Consideration should be given for three more of the 80-rod small rod jigs. They could then load other small-rod diameters on this jig.
- The engineers need to design jigs to facilitate quick-change loading and unloading to reduce downtime.
- Replace X-200 solution in the big rod line with the "Star chrome" solution.
- The suggestion for operators to work staggered lunch and tea breaks, and to work overtime beyond the current extended hours was flatly rejected. There was an ongoing dissatisfaction among the operators in the section.
- Consideration should be given to the installation of an additional chrome tank.
- Jigs should not be loaded if the remaining batch quantity cannot fill a jig.
- Reduce the specification for the chrome thickness on the piston rods.
- Standardise the piston end of the rod which screw into the jig to reduce changeovers. One 48-rod holding jig takes about 30 minutes to changeover.

Most of the above changes were long-term (at least a few months). Therefore, it is beyond the scope of this report. The last issue of the jig loading would be difficult to manage.
A plan was to be put in action so that more material could be processed and staged in front of the chrome area. Appendix B.11 shows how the rod machine, harden and grind section increased their output in week 36 to "put" work in front of the chrome area. This would ensure that there was sufficient rods ready for chroming during the test duration.

Two additional operators were given to the chrome section to eliminate the "social" problem as being part of the reason (according to the operators) for the bottleneck. Note that this addition, beside the additional motivation to prove their point (justifiably or not), would be the only known change that would be introduced to the system to be experimented with. The two extra operators would enable the system to deal with the variety introduced by absenteeism, operator preventative maintenance, the general work requirements in the section, etc. The argument is that if chrome has sufficient material ready for processing, and if no unusual downtime is experienced, if the two extra operators absorb more variety, more rods should be chromed. If this does happen then the chrome process is not a bottleneck and the hypothesis is true. Conversely, if this does not happen then the hypothesis is false.

Also, the validity of the action research had to be ensured:-

1. The schedule will not be changed to pass the "easy and quick" jobs through the chrome during the period of the test to boost the production figures. Rods had to be chromed in the sequence as required by the assembly cells. Having more WIP meant that they could plan their work to have more effective changeovers.
2. The shareholders of the system (operators, BUM, etc.) would be involved in the change decision.
3. The material build-up in the staging area before chroming would ensure no material shortage during the test period.
4. The test would be conducted for a minimum of four weeks.
5. If any unforeseen circumstances arise the test would be terminated.
6. There would be no additional time worked.

To ensure that the above occurred the process would be carefully monitored.

9.4 TEST RESULTS AND OBSERVATIONS

The test was conducted over four weeks within the above-mentioned parameters. During this period the following observations were made:-

1. The chrome rod output per day increased from an average of 10 386 (over 32 weeks) to an average of 12 249 (over 4 weeks, 4737 big and 7512 small rods). This constitutes a substantial average 18% increase in production. Refer to appendix C.1 for the values and appendix C.2 for the graphs of these comparative production

figures. Note that the graph only shows the 6 weeks prior to the test. The mean value shown is taken for week 5 to 36.

2. The cycle time on the big rod chrome line had reduced from 9 minutes per jig to 7 minutes per jig. This represents a 29% improvement in the cycle time.
3. The operators were working at a much higher efficiency. The assumption for their motivation can be attributed to the fact "that this was our idea", and maybe, to make the "political" point that they were overworked and did need an extra hand.
4. The daily production spread decreased from 4863 (over 32 weeks) to 336 (over 4 weeks).
5. On the big rod line the jigs were "loaded" at all times and the process did not have to wait on the operator loading. Only big rods were loaded on the big rod chrome line and small rods on the small rod chrome line respectively.
6. There has been no material shortage of "rods ready for chroming".
7. No unusual downtime was observed over the period that the test was conducted.
8. No unusual absenteeism occurred during the test period.

9.5 ANALYSIS AND DISCUSSION

1. The first point to make is whether four weeks was sufficient time to test whether chrome could be considered to be a bottleneck? The answer is a definite yes. Irrespective of the test duration, an improved throughput was possible under the test control parameters.
2. By using an additional operator per chrome line the production increased by 18%. The chrome section was therefore constrained by people and not by the equipment in the process. What would happen if more operators were used? At what point would the process become the constraint? What is the true "potential" output of the chroming process if some of the longer term improvements could be implemented?
3. To get a better understanding of the chroming process, each operation in the chroming process needs to be "timed" and the slowest process identified to establish the true throughput of the chroming lines.
4. The question should be raised as to how much longer the operators can sustain this remarkably improved production efficiency since they were working at close to 100% efficiency when the observations were made. Maybe even more operators are

needed to achieve the required production volumes. Irrespective, the point should be taken that they did improve the production figures, and substantially too.

5. To obtain the current volumes of big and small rods, one of the chrome lines was solely used for the chroming of big rods, and the other for the small rods. This self-organisation suggests that line 1 can be considered for big rods and line 2 for small rods under the current loading.

9.6 CONCLUSION

From the above discussions the conclusion is made that the hypothesis made in the previous chapter, namely that the chrome section does not have adequate regulatory capacity to control the variety that the system is subjected to, and as a result of this causes the system to become a bottleneck, is true. By increasing the regulatory capacity of the chrome section, the addition of more operators (a "soft" social aspect) and not by the improvement of the equipment (a "hard" aspect) in the process, it is shown that the chrome department is then able to deal with the variation that it is subjected to.

9.7 RECOMMENDATIONS

Based on the above discussions and conclusions the following recommendations are made:-

1. An additional operator must be allocated per line to achieve a target of 12000 units.
2. The jigs must be changed to a quick-change, loading and unloading situation and the number of rods per jig (80 in place of 48) must be maximised, where possible.
3. The chrome thickness must be reduced to a minimum requirement.
4. The possibility of Nitriding all the gas spring rods must be investigated.
5. Consideration must be given to standardisation of the piston rod ends.
6. Treat line 1 for big rods and line 2 for small rods. This could enable better focus on problems, less changeovers and standardisation. One condition is that the big-to-small ratio remains 4500 to 7500.
7. Since successful chroming is dependent on so many variables, it is strongly recommended that a monitoring system is linked to the chroming process.
8. A more detailed investigation must be conducted to establish a more accurate process/people constraint.

The next chapter uses a computer simulation to test the hypothesis made in chapter 8.

CHAPTER TEN: COMPUTER SIMULATION TO TEST THAT VARIETY AFFECTS MACHINE, HARDEN AND GRIND

In the discussion of the performance of the operational units (section 7.3.1.8 and appendix B8) it was shown that the Machine, Harden and Grind operational unit has the greatest downtime and consequently, the worst efficiency. It is also the first operational unit, on which both chrome and polish depend. The viable systems diagnosis suggested that the performance problems seemed to stem from the lack of control of variety within the operational units.

Therefore, the objective of the simulation's in this chapter attempts to test the hypothesis made in chapter ten, namely that the operational units of the Piston Rod Department does not have adequate regulatory capacity to effectively control the variety that the system is subjected to. Consequently this system cannot maintain the average daily requirements of 12000 piston rods per day. Throughput is used as the most critical essential variable since the Piston Rod Manufacturing Business Unit is measured against this performance measurement.

This chapter can basically be divided into two sections, namely section 10.2 and 10.3. Section 10.1 merely refers to the production figures for week 5 to 36 which can form a basis for comparison between the simulation and "reality".

Section 10.2 attempts to develop an understanding (model A) of the interaction of the four operational units. WIP is placed before each operational unit and an average hourly rate is calculated for each unit. First (section 10.2.1), the effects of an ideal "JIT-based" is considered where all the rates of the operational units are the same, namely 800 rods per hour.

The second simulation (section 10.2.2) introduces the actual hourly rates of the operational units, i.e. a more "real-life" situation is simulated. The importance and impact of WIP and an imbalance in the hourly production rates are clearly demonstrated.

Thirdly, section 10.2.3 shows how uncontrolled and irregular variety, in the form of downtime, reducers the ability of the operational units to meet their target even further. It is shown that the greater the amount of downtime, the more the efficiency of the other operational units decrease, and the greater the need for larger WIP between the processes. Since the four operational units are each dependent on the preceding operation, these inefficiencies have a "domino-effect" through the system.

Section 10.3 develops model B which considers the "Big Rod" Machine, Harden and Grind operational unit to investigate how "variety" actually affects the latter operational unit. The simulation demonstrates that the operational unit cannot deal with its unpredictable variety and that the hypothesis, therefore, holds true. The chapter concludes with recommendations to reduce this variety and to improve the operational units regulatory capacity.

10.1 HISTORICAL DATA

The historical production figures for week 5 to week 36 (shown in appendix B.10, 11 and 12) establishes a reference against which the simulation model can be checked. Note the minimum and maximum figures for the overall system obtained during this period was 5843 (on chrome) and 13512 (on machine, harden and grind) rods per day respectively, against the 12000 target. The average figure for the overall system was 9955 rods per day (which is for polish, the operational unit directly supplying the assembly cells;- the customer of the overall system).

For this same period, the big rod machine, harden and grind operational unit produced a maximum of 5463 rods, a minimum of 2671 rods and a average of 3895 rods per day. This is less than the required amount of 45 rods per day.

10.2 MODEL A: MODELLING THE SYSTEM-IN-FOCUS

The simulation in this section attempts to develop an understanding of the interaction of the four operational units.

During all the simulations WIP is placed between all the operational units. The big and small rod machine, harden and grind operational units were combined, since together, they are responsible for the 12000 units per day required. For all the simulations the model was run for the current extended day and night shift hours. Both these shifts have a total of 15 available hours (refer appendix B.14 for calculations). In the next sections the efficiency, production rates and WIP are varied.

10.2.1 THE "IDEAL" MODEL SIMULATION

In the calculation of the "ideal" JIT-based set-up the required rate was based on the average 12000 units and the available time of 15 hours per day. This translate to a minimum rate of 800 units per hour.

For this hypothetical simulation the assumption was made that all the operational units had the same hourly production rate of 800 rods per hour. Since the model was based on an hourly "run", the WIP required was 800 rods. A process efficiency of 100% was considered, i.e. no downtime due to equipment, process, absenteeism, machines, etc.

The simulation is shown in appendix D.1. Note that a minimum WIP of 800 rods is necessary at all times, and a constant rate is required to achieve 12000 rods per day. In this case the daily production of 12000 is achievable.

10.2.2 INTRODUCING ACTUAL RATES

For this simulation the actual measured rates for the operational units were introduced. These were taken from appendix B.13.

	BIG RODS	SMALL RODS	TOTAL RODS
M-H-G	474 rods/hr	758 rods/hr	1232 rods/hr
CHROME	320 rods/hr	516 rods/hr	836 rods/hr
POLISH	670 rods/hr	1083 rods/hr	1753 rods/hr

For the grinders the metres per hour rate was divided by the average piston rod length (refer appendix D5, D6 and D7). The 100% efficiency and the 15 available hours is maintained for this simulation. The effect of varying rates on the system are immediately visible. The WIP in the various staging areas are dependent on the hourly rate possible, as well as the WIP available from the preceding operation. The simulation is shown in appendix D.2. Note how, under the conditions of this simulation, the chrome section creates a bottleneck to the overall system.

The overall system can achieve 12540 units per day. This is based on the minimum chrome rate of 836 rods per hour and a 15-hour day. Supply was maximised at 1800 rods per hour.

An arbitrary figure in excess of the fastest operational unit rate, namely 1753 for polish, is considered. WIP was set at zero and the assembly cells were using rods at a rate of 800 rods per day. The faster operational units will basically build up WIP if the work is not managed, e.g. 9752 and 6776 for supply and machine, harden and grind respectively. Obviously, if supply is a problem, none of the operational units will be able to perform. If WIP is "build-up" after chrome, polish would be able to produce more rods.

10.2.3 INTRODUCING INEFFICIENCIES

The objective of introducing inefficiencies in this section is to simulate downtime for the operational units. The simulation is shown in appendix D.3

Since it was not possible to obtain accurate downtime information for all the operational units, randomly generated inefficiencies between 1,00 and 0,50 were used. These inefficiencies are used to illustrate the effect of downtime on the system as a whole. The next section will consider more accurate downtime information for the big rod machine, harden and grind. For this instance the rods department is only able to produce 9581 units per day due to the constraint in chrome (2654 units short to the assembly cells).

Appendix D.4 shows how increased WIP in the after-chrome and final kanban staging areas enable the rod manufacturing department to meet its customer "quantity" requirements, namely 12925 rods per day for polish. However, the simulation also show that the chrome area is still constrained by its "hourly rate" and still only producers 9581 units per day (in comparison with simulation in appendix D.3). The WIP before the harden, machine and grind and chrome sections is unaltered since there is sufficient material in these staging areas.

The above simulations highlight the major implications of having unequal rates due to process and downtime differences, namely the necessity to carry WIP in staging areas between the operational units to compensate for these different rates. This, however, poses a problem in that if the operational units within the overall system (machine, harden and grind and chrome) are already working almost 24 hours per day, namely 21,75 hours, how can WIP be accumulated.

The consequence of these operational units not producing this required WIP implies that these operational units, and hence the overall system, cannot meet its daily production target. The next section develops a model to show how the actual causes of downtime, the variety initiators, in one of these operational units prevent the operational unit from achieving its goal.

10.3 MODEL B: SIMULATING BIG RODS MACHINE, HARDEN AND GRIND

The objective of this simulation is to test the validity of the hypothesis as mentioned before. It will attempt to show that the uncontrolled variety which is caused by downtime affects the essential variable, throughput, to such an extend that the systems stability (equilibrium) is disturbed (i.e. its homeostasis is threatened) and the system cannot meet its objective.

In the previous section the effects of having unequal rates and the interaction (dependence) of the four operational units under discussion were seen. It was shown that changes in the efficiency of the respective units affected the overall efficiency of the rod manufacturing department and that downtime played a significant role in the reduction of this efficiency. The differences in these efficiencies can be overcome if WIP can be produced between the relevant operational units. This becomes a problem when this WIP cannot be produced. Since this operational unit is already working at 21,75 hours per day (of 24 possible hours per day), there is no significant time left for accumulating WIP. Also, the current overtime, especially Saturday and Sunday, is not economically feasible.

Also, in section 7.3.1.8 and appendix B8 it was shown that the machine, harden and grind operational unit has the greatest downtime and consequently, the worst efficiency. It is also the first operational unit, on which both chrome and polish depend. It is for these reasons that the big rod machine, harden and grind operational unit is used for this simulation. The operational unit is composed of 3 processes, viz. machining, induction hardening and grinding. (Section on 7.3.1.1.) The description of these processes will not be repeated here.

10.3.1 SETTING UP A TEST FOR BIG RODS MACHINE, HARDEN AND GRIND.

In order for the hypothesis to be true it must be shown that the causes of downtime (the "variety" initiators) prevent this operational unit to meet its daily production target of 4500 rods per day. (The requirement for the small rod section was 7500 units per day, which make up the total of 12000 rods per day.) At an average rod length this operational unit is capable of producing 7110 units per day. (Refer appendix B.13 and D.5)

The following steps are undertaken to test the hypothesis:-

1. The downtime for the operational unit must be monitored for 20 days.
2. This downtime will be used to develop a computer simulation to show how the various causes of downtime reducers the ability of the system to produce rods.
3. The simulation will be compared with the actual production figures obtained for week 5 to week 36 (appendix B.12) as well as the inherent capacity (appendix B.13) of the system.
4. If, from the above simulation, the big rod machine, harden and grind is able to produce its target the conclusion will be made that the hypothesis is false. Conversely, if it is shown that the big rod machine, harden and grind is not able to produce its target, then the conclusion will be made that the hypothesis is true.

The following assumptions were made for this simulation:

1. It was assumed that there is an unlimited amount of work (WIP) in the staging area in front of the hardener. The first reason for this was that machined rods can be sub-contracted at far in excess of what the operational unit requires, namely 4500 rods per day. Secondly, during observation and discussion of the process the CNC's were never "waiting on work", and as a result of this there was always WIP in the staging area before the induction hardener.
2. Since the induction hardener and the grinders are linked via a conveyor system these two processes will be considered as one. The rate measured was 3 metres per minute or 180 rods per hour. Refer appendix B.13.
3. The night and day shift are producing at the same operator efficiency levels, viz. 85%. Refer appendix B.14.
4. The rod lengths shown in appendices D.5, D.6 and D.7 are based on the 20% of part numbers which constitutes 80 - 90% of the total production (20 - 80% Rule).

10.3.2 MODEL B : SIMULATING "VARIETY"

Appendix D.8 shows the first computer simulation. In this simulation the average product length (379 mm) and consequently, the average production rate (474 rods per hour) is considered. The average downtime values (in hours) as recorded for 20 days are listed against the "cause" to introduce the daily occurring variety in the system. The major causes for the variety initiation or downtime were operator absenteeism and lateness, unplanned meetings, operators on training, quality problems, changing of measuring clocks, raw material quality problems, surface finish problems, grinding wheel changes, dressing and setting the grinding and regulating wheels, induction hardener setup, replacing of burnt-out induction coils, Vickers hardness first-off test, trucking of material, machine maintenance, rods straightening, waiting on work, waiting on tooling, etc. (refer appendix D.8).

The loss of production is calculated, and subtracted from the possible production of 7110 rods per day (474*15) to obtain the resultant (eventual) production figure. This exercise is completed for the 20 days and the average, maximum and minimum values are calculated.

The simulation shows that for the 20 days that the downtime was measured (and using a average rod length) the system producers an average daily figure of 4285 rods. This is less than the 4500 rods that it must produce. The average value for week 5 to 36 (appendix B.12) was 3895, with maximum of 5463 and a minimum of 2671. If the rod would be varied this would increase the production variation of the model.

10.3.3 SIMULATION WITH MAXIMUM THROUGHPUT

In this situation the maximum throughput was determined by considering the shortest rod (namely 250 mm, refer appendix D.5). At 180 rods per hour, this equates to a production rate of 720 units per day or 10800 units per day. The simulation is shown in appendix D.9.

Using the same downtime as measured in the above simulation the subsequent production figures are calculated for the 20 days. The average rods produced is 6510 rods per day. Under these conditions the operational unit is capable of achieving its target. This model simulates the best scenario.

10.3.4 SIMULATION WITH MINIMUM THROUGHPUT

The minimum throughput simulation is shown in appendix D.10. Again the same downtimes are considered. This time the longest rod (506 mm, refer D.5) is used. The resultant throughput is calculated to yield 355 rods per hour or 5325 rods per "15-hour" day.
The simulation shows that under the conditions of this simulation the big rod operational unit is only able to produce, on average over 20 days, 3210 rods per day.

10.4 CONCLUSION

This operational unit inherently has the capability of producing 7110 rods per day but when the system is subjected to the variety initiators (causes of downtime) the systems stability (equilibrium) is disturbed (i.e. its homeostasis is threatened) and the system cannot meet its objective.

From the above simulations the conclusion is made that hypothesis made in chapter ten, namely that the operational units of the Piston Rod Department does not have adequate regulatory capacity to control the variety that the system is subjected to, is true. Consequently this system cannot maintain its average daily target of 4500 units per day.

Due to the dependence of the subsequent operational units on the latter unit, if this section cannot achieve its target, neither can the next operations, viz. chrome, them polish and finally the customer, the assembly cells.

Although the simulation is simple, the average historical data (average, spread, maximum and minimum figures) of the simulation compares relatively well with that of the historical data. It emphasises the importance of having consistent, good quality material or product from the previous operation, i.e. the need for WIP between the processes.

10.5 RECOMMENDATIONS

Based on the above simulations, the causes of downtime and conclusions the following recommendations are made:-

1. All the causes of downtime be must be investigated and reduced or eliminated.

2. The efficiency of the equipment, machines, tooling, processes, etc. must be improved to reduce downtime.
3. The efficacy of the operations must be questioned.
4. Product standardisation must be looked at to reduce downtime which occur as a result of product variations. Examples are the elimination of 18, 15 and 13 mm diameter rods, the reduction of chrome thickness from 13 to 5 µm, eliminate the "grooved" rod, reduce piston and stud end types, etc.
5. Changeover times must be reduced, e.g. quick-change tooling, etc..
6. A planned maintenance programme must be established to reduce unplanned maintenance downtime.
7. All the required tooling must be available when and where required.
8. Develop suppliers to reduce material shortages and quality problems. Consider Electronic Date Interchange between all suppliers.
9. To improve product quality, work to general total quality management principles, e.g. visual control, layout and flow improvements, operator involvement, etc.
10. The control and accuracy of information must be improved, especially the true reasons for downtime and the system response time.

By implementing the recommendations listed above it is obvious that there would be more time available to produce more piston rods. The computer model shows how quickly production reducers (from a capable 7110 possible units to a average of 4285 rods per day with an average downtime of 5,96 hours per day) due to lost time.

Some of the results of implementing the above recommendations will have the effect of reducing the variety that the system is subjected to (e.g.., standardisation of the product, tooling and processes).

Other actions will result in increasing the regulatory capacity of the system (e.g., dedicated quick-change tooling, improving the efficacy and efficiency of the machines and equipment, etc.).

CHAPTER ELEVEN: SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

11.1 SUMMARY OF CONCLUSIONS

From the conclusions made in chapter 9 and 10 the hypothesis made in chapter 8, namely that the operational units (chrome and big rods machine, harden and grind) within the system-in-focus (piston rod department) do not have the sufficient control to acquire requisite variety to deal with the variety that they are subjected to, is proven to hold true.

Chapter 9 shows how the chrome section does not have adequate regulatory capacity to control the variety that the system is subjected to, and as a result of this causes the system to become a bottleneck.

The simulation exercise in chapter 10 shows how the machine, harden and grind operational unit cannot deal with variety when it is subjected with the various causes of downtime.

In both cases the consequence is that the operational unit is unable to meet its daily average production target. This irregular variety, which occurs without warning and is damaging to the system, need to be controlled more effectively.

Therefore, action must be taken to reduce this downtime. If this is not done and the system continually allows the essential variable, throughput, to go beyond its physiological limit, the system (the rods department) and in turn its higher recursive level (GSA) will battle to compete.

Lastly, the "variety" is not only contributed by the product variations, but by the variety attributed to human factors as well as the processes, machines and equipment;- all of which form a complex and dynamic socio-technical system which itself is continuously inter-acting with an ever-changing environment.

11.2 SUMMARY OF RECOMMENDATIONS

Based on the recommendations made in chapter 9 and 10 the following summarised recommendations are made:

1. Downtime (for all operational unit's) must be monitored so that its causes can be eliminated or reduced where possible, e.g. design quick change tooling, design dedicated tooling, reduce changeover times, etc.
2. Complete capability studies for machines to establish the true potential of all the processes. This will also highlight future bottlenecks. Ensure that all new machines bought are capable to produce product as per specifications.
3. Improve the efficiency of all equipment, e.g. consider alternative machines, equipment and processes.
4. Question efficacy, e.g. nitriding instead of chroming.
5. Establish a planned preventative maintenance program for all machines.
6. The product and process specifications must be reviewed in order to facilitate throughput improvements, i.e. design for manufacture. Components, materials, tooling and processes must be rationalised;- basically design to control variation.
7. The control and accuracy of information must be improved, especially the true reasons for downtime and the system response time.
8. To improve product quality, work to general total quality management principles, e.g. visual control, layout and flow improvements, operator involvement, a place for everything and everything in its place, etc.
9. Develop suppliers to reduce material shortages and quality problems. Consider Electronic Date Interchange between all suppliers.
10. To improve absenteeism problems and to facilitate flexibility pursue the cross training of operators, Employee Involvement improvements, ongoing training and operator development and have motivational production-related bonus.
11. Install monitoring systems for all critical processes.

In essence the results of implementing these recommendations will have the effect of reducing the variety the system has to deal with and will also increase the regulatory capacity of the system.

CHAPTER TWELVE: REFLECTIONS ON THE AUTHOR'S LEARNING

First and foremost, this thesis has taught me how to conduct a theoretical, rigorous and structured inquiry into a complex problematic socio-technical situation. Without doubt, this has left me with a valuable management "tool" to develop my mental model of similar situations and to take more effective action in the future. In the development of the framework various ideas were used and each has learned me a lesson.

Peirce's scientific method of inquiry demonstrated to be an effective pragmatic management approach. It allowed for both double-loop learning to occur. The other important aspect was the idea of fallibilism, allowing for continuous improvement. From the application of the framework a new belief was formed from which action will be taken.

Initially the problem was unclear, but through a sincere and in-depth immersion into the problem became clearer. This thesis supports Peirce's view that, "man has the natural ability to uncover the secrets of nature". From the initial immersion of the situation, management initially believed that product variety was one of the main causes for production non-conformance. Through further literature survey (immersion) this led to cybernetics, the Ashby-Conant theorem and Beer's VSM. From these "variety" was defined as the number of possible states that a system can have. This "variety" now not only constituted product variety but any variety which is introduced by the product, people, incapable processes and equipment, machine downtime, systems, etc. Although management were only partly correct, their initial intuition of "variety" was indeed one of the major causes for production non-conformance.

Being involved in the area where the research was conducted when I consider the recommendations against what is daily happening in the rods department, the value of these recommendations can be appreciated. The "truth" of the outcome of the research can mainly be attributed to the rigor applied during the stages of Peirces scientific method. By this very rigor the inquirer is compelled ("directed") to use the most appropriate methodologies, technique's, etc.;- leading to a more "truthful" solution.

Throughout the research the difficulty of dealing with social systems is highlighted and the need for a systems approach is realised. The complexity that human involvement introduces into a system cannot be ignored. In today's shopfloor environment the operators (worker) has become an important shareholder in the operations system. He/she is an important part of the system and if excluded the model of the system is incomplete. The operator is involved "every hour of the day" in the process and whenever any consideration is given to the system he/she must be given consideration. Some of the typical consequences of excluding human involvement are that:-

- you do not give them the opportunity to give critical information for the system development
- they can be uncooperative or even reject any solution which may be proposed without their involvement
- if they do not like your approach (or attitude to them) they will not divulge any crucial information or even give incorrect information which may be necessary for the development of the system model

Fortunately, due to the systems approach, I did not encounter the above problems.

During the VSM application the idea of business units, of hierarchy, of communication and control proved to a very useful model to gain an understanding of the overall system and of the inter-relationships between the various subsystems (operational units). Simultaneously a detailed insight of the processes, people, machines and the general running of the section were developed. Although SSM and Work Systems were not applied I have acquired the understanding of these methodologies. Their consideration in this thesis will lead to their future use in more applicable situations.

Lastly, what this thesis has demonstrated is that if a framework is theoretically developed and rigorously applied it will yield meaningful and realistic results. However, the outcome of this research did by no means give an absolute solution. This is a start into one aspect of a complex problem, namely how to deal with variety, there are many others.

GLOSSARY

adaptation: to maintain the essential variables within physiological limits (Clemson, 1984).

autonomy: "autonomy refers to a system that is able to act as an independent or free agent, without the constraint from a higher level system" (Clemson, 1984, page 227).

autopoiesis: the characteristics of all living systems (autopoietic)

bifurcation point: dividing into two branches.

black box: A 'black box' is a system whose internal workings are not open to inspection or study Clemson, 1984, page 228).

Clients, Actors and Owners: The above three role players are the major stakeholders of the process. Those who directly contribute to the realisation of the process are the actors. Those who benefit by the output of process are the clients. Those who can effectively decide to stop the process are assuming the owners role.

complex: having more relevant detail than the given observer can possibly cope with.

Contributions of People: "We call contributions those activities of people belonging to a work system which can be seen as helping to realise the defined output of a process. The process level defines the level of the contribution at the same time" (Hoebeke, 1994, page 13).

Environmental Constraints and Weltanschauung: When a work system is defined one needs to draw boundaries. These boundaries are referred to as environmental constraints. Weltanschauung refers to the stance or perspective various people take for defining a work system, i.e. the different value systems that people have when they are involved in joint activities based on the personal experiences, upbringing, culture, etc.

Essential Variables: variable which are closely related to survival and which are closely linked dynamically so that marked changes in any one leads sooner or later to the marked changes in the others (Clemson, 1984, page 233).

Framework: A structure composed of parts joined together.

'Hawthorne Effect': This phenomena refers to the way in which the novelty of experiencing a new situation, together with their sense of being a special group that has become the focus of attention, influenced the participants' response to their situation (Gill and Johnson, 1991, page 50).

Homeostasis: The constant conditions which are maintained in a system, e.g.., the body.

Methodology: The study of methods used in a particular subject.

Philosophy: The study of the principles of a particular subject, such as science or history. The pursuit of wisdom and knowledge.

Physiological Limits: The point at which the essential variables begins to make the system 'sick' is the physiological limit. (Clemson, 1984, page 244).

Process Level: "A process of a higher order is one whose output creates conditions for one of a lower order. Processes can be differentiated in hierarchy. To avoid confusion with what is seen in organisational terms as hierarchical levels we call this process level" (Hoebeke, 1994, page 11).

Symmetry of potential outcomes: A way of reducing the risk entailed in any project is to try to ensure that, whatever the findings from the work, the results will be equally valuable (Gill and Johnson, 1991, page 15).

System: A system is a set of inter-related elements. Thus, a system is an entity which is composed of at least two elements and a relation that holds between each of its elements and at least one other element in the set (Clemson, 1984, page 250).

The Management Process: "Management consists of those contributions which transform the transactions of a process with its environment into a coherent pattern so that all the parties involved with the process - actors, clients and owners - are enabled to identify the process, its purpose and the development of its purpose. Management is essential about meaning." (Page 18. Hoebeke L. (1994). *Making Work Systems Better*. Wiley. Chichester.)

Technique: The particular procedure for doing something.

teleological: the belief that events occur because they have a purpose.

The transformation Process: "A transformation process expresses a basic purpose behind the work system and transforms a specific input into a specific output. The output must contain the input which has been transformed during the process" (Hoebeke, 1994).

The work system: "A work system is a purposeful definition of the real world in which people spend effort in coherent activities for mutually influencing each other and their environment" (Hoebeke, 1994, page 9). It is the basic unit of Hoebeke's framework.

viable: able to maintain a separate existence.

variety: Variety is the total number of possible states of a system, or of an element of a system (Beer, 1981). It ca also be considered to be the measure of complexity and specifies directly the amount of regulation required for a given system.

REFERENCES & BIBLIOGRAPHY

REFERENCES

* Ackoff, R. (1974). Redesigning The Future. Wiley, Chichester.

* Argyris, C. (July-August 1994). "Good Communications That Block Learning." Harvard Business Review.

* Beer, S. (1966). Decision and Control. Wiley, Chichester.

* Beer, S. (1985). Diagnosing The System for Organisations. Wiley, Chichester.

* Checkland, P. B. (1981). Systems Thinking, Systems Practice. Wiley, Chichester.

* Clemson, B. (1984). Cybernetics: A New Management Tool. Abacus Press, Tunbridge Wells.

* Flood, R. L. and Jackson, M. C. (1991). Creative Problem Solving: Total Systems Interventions. Wiley, Chichester.

* Gill, J. and Johnson, P. (1991). Research Methods For Managers. Chapman, London.

* Goldratt, E. M. and Fox, R. (1986). The Race. North River Press, New York.

* Hoebeke, L. (1994). Making Work Systems Better: A Practitioner's Reflections. Wiley, Chichester.

* Jackson, M. C. (1990). Organisational Design and Behaviour. School of Management MBA, University of Hull.

* Reilly, F. E. (1970). Charles Peirce's Theory Of Scientific Method. Fordham University Press, New York.

* Ryan, T. (1995). Lecture Notes. UCT.

BIBLIOGRAPHY

Ashby, W. R. (1952). Design For A Brain. Wiley, New York.

Ashby, W. R. (1964). An Introdution To Cybernetics. Methuen, London.

Beer, S. (1959). Cybernetics and Management. English University Press, London.

Beer, S. (1974). Designing Freedom. Garden City Press, London.

Beer, S. (1979). The Heart of Enterprise. Wiley, Chichester.

Beer, S. (1981). Brain of the Firm, second edition. Wiley, Chichester.

Beishon, J. (1971). Systems. The Open University Press, Buckinghamshire.

Carter, R., Martin, J., Mayblin, B. and Munday, M. (1984). Systems, Management And Change: A Graphic Guide. Chapman, London.

Duck, J. D. (November-December 1993). "Managing Change: The Art Of Balancing". Harvard Business Review, page 109-118.

Drucker, P. F. (May- June 1963). "Managing for Business Effectiveness". Harvard Business Review, page 58-65.

Espejo, R. (1989). "P. M. Manufacturers: The VSM as a diagnostic tool". (Espejo, R. and Harnden, R. editors). The Viable System Model: Interpretations And Applications Of Beer's VSM. Wiley, Chichester.

Espejo, R. (1989). "The VSM Revisited". (Espejo, R. and Harnden, R. editors). The Viable System Model: Interpretations and Applications of Stafford Beer's VSM. Wiley, Chichester.

Flood, R. L. and Carson, E. R. (1988). Dealing with Complexity: An Introduction to the Theory and Application of Systems Science. Plenum Press, New York.

Goss, T., Pascale, R. and Athos, A. (November-December 1993). "The Reinvention Roller Coaster: Risking The Present For A Powerful Future". Harvard Business Review, page 97-108.

Hammersley, J. M. and Handscomb, D. C. (1964). Monte Carlo Methods. Meuthen.

Hayes, R. H. and Pisano, G. P. (January-February 1984). "Beyond World-Class: The New Manufacturing Strategy". Harvard Business Review, page 77 - 86.

Holmberg, B. A. (1989). "Developing Organisational Competence In A Business". (Espejo, R. and Harnden, R. editors). The Viable System Model: Interpretations and Applications of Stafford Beer's VSM. Wiley, Chichester.

Lockyer, K. G. (1974). Factory and Production Management. Pitman, New York.

Martin, R. (November-December 1993). "Changing The Mind Of The Corporation". Harvard Business Review, page 81 - 94.

Minto, B. (1982). The Pyramid Principle: Logic In Writing And Thinking. Minto International Inc., London.

Nohria, N and Berkley, J. D. (January-February 1994). "Whatever Happened To The Take-Charge Manager?". Harvard Business Review, page 128 - 137.

Rubinstein, R. Y. (1981). Simulation and the Monte Carlo Method. Wiley, Chichester.

Schonberger, R. J. (1982). Japanese Manufacturing Techniques: Nine Hidden Lessons In Simplicity. Macmillan, New York.

Senge, P. (1985). "Systems Principles for Leadership." (Adams, general editor) Transforming Leadership: From Vision to Results. Miles River Press, Virginia.

Senge, P. M. (1990). The Fifth Discipline: The Art and Practice of the Learning Organisation. Doubleday Currency, New York.

Semle, R. (January-February 1984). "Why My Former Employees Still Work For Me". Harvard Business Review, page 64 - 74.

Semle, R. (September-October 1989). "Managing Without Managers". Harvard Business Review.

Semle, R. (1994). Maverick. Warner Trade, New York.

Siegal, B. (December 1991). "Organising For A Successful Concurrent Engineering Process". Industrial Engineering, page 15 - 19.

Tones, G. T. (1972). Simulation and Business Decisions. The Chaucer Press, Suffolk.

Van Der Riet, D. (Autumn 1995). "Working Towards World Class Manufacturing: Profit Centres Hinder Competitive Advantage". Benchmark.

Whiteley, L., (November 1991). "New Roles For Manufacturing In Concurrent Engineering". Industrial Engineering, page 51-53.

APPENDIX A

(GSA - A BACKGROUND)

APPENDIX A.0 : SUMMARY OF CYBERNETIC LAWS, THEOREMS AND PRINCIPLES

3. EIGHTY-TWENTY PRINCIPLE:

In any large, complex system, eighty percent of the output will be produced by only twenty percent of the system.

7. ENTROPY: THE SECOND LAW OF THERMODYNAMICS

In any closed system the differences in energy can only stay the same or decrease over time; or, in any closed system, the amount of order (or organization) can never increase and must eventually decrease.

8. REDUNDANCY OF INFORMATION THEOREM:

Errors in information transmission can be protected against (to any level of confidence required) by increasing the redundancy in the messages.

9. REDUNDANCY OF RESOURCES PRINCIPLE:

Maintenance of stability under conditions of disturbance requires redundancy of critical resources.

10. REDUNDANCY OF POTENTIAL COMMAND PRINCIPLE:

In any complex decision network, the potential to act effectively is conferred by an adequate concatenation of information.

11. RELAXATION TIME PRINCIPLE:

System stability is possible only if the system's relaxation is shorter than the mean time between disturbances.

12. CIRCULAR CAUSALITY PRINCIPLE ONE:

Given positive feedback (i.e. a two-part system in which each stimulates any initial change in the other), radically different end states are possible from the same initial conditions.

13. CIRCULAR CAUSALITY PRINCIPLE TWO:
Given negative feedback (i.e. two-part system in which each part tends to offset any change in the other), the equilibrial state is invariant over a wide range of initial conditions.

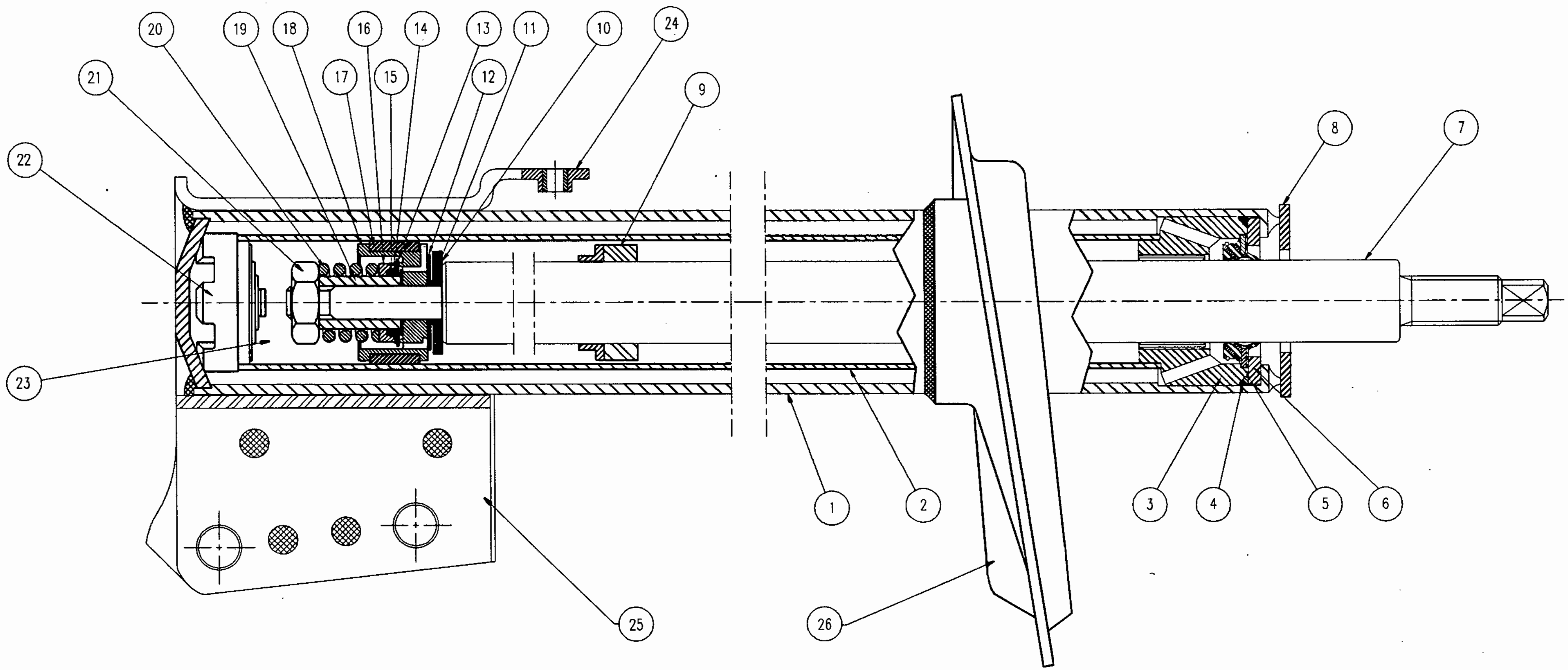
14. FEEDBACK DOMINANCE THEOREM:
For high gain amplifiers, the feedback dominates the output over wide variations in input.

16. STEADY STATE PRINCIPLE:
If a system is in a state of equilibrium (a steady state), then all sub-systems must be in equilibrium. If all sub-systems are in a state of equilibrium, then the system must be in equilibrium.

19. SELF ORGANIZING SYSTEMS PRINCIPLE:
Complex systems organize themselves; the characteristic structural and behavioral patterns in a complex system are primarily a result of the interactions among the system parts.

20. BASINS OF STABILITY PRINCIPLE:
Complex systems have basins of stability separated by thresholds of instability. A system "parked" on a ridge will "roll downhill".

APPENDIX A.1 : COMPONENTS OF A TYPICAL STRUT



ITEM	DESCRIPTION
1	INTER-CYLINDER ASSY
2	INNER CYLINDER
3	ROD GUIDE ASSY
4	PACKING HEAD (O-RING)
5	ROD SEAL
6	SEAL RETAINER
7	PISTON ROD ASSY
8	STRIKER PLATE
9	REBOUND STOP
10	PISTON STOP
11	PIVOT WASHER

ITEM	DESCRIPTION
12	BYPASS VALVE
13	ORIFICE DISC
14	SEALING DISC
15	O-RING
16	RECOIL VALVE
17	PISTON BAND
18	PISTON
19	RECOIL VALVE GUIDE
20	RECOIL SPRING
21	PISTON NUT
22	COMP HEAD ASSY

ITEM	DESCRIPTION
23	SHOCK ABSORBER OIL
24	BRAKE PIPE BRACKET
25	MOUNTING BRACKET ASSY
26	SPRING SEAT

SCALE 1:1,5625	DESCRIPTION 27/20 DESIGN
DRAWN B.MORAR	DESIGN OF A TYPICAL STRUT
DATE 20.06.95	

Gabriel S.A. (Pty) Ltd

APPENDIX A.2 : THE OPERATION OF A SHOCK ABSORBER

How does a Gabriel shock absorber work?

Functions:

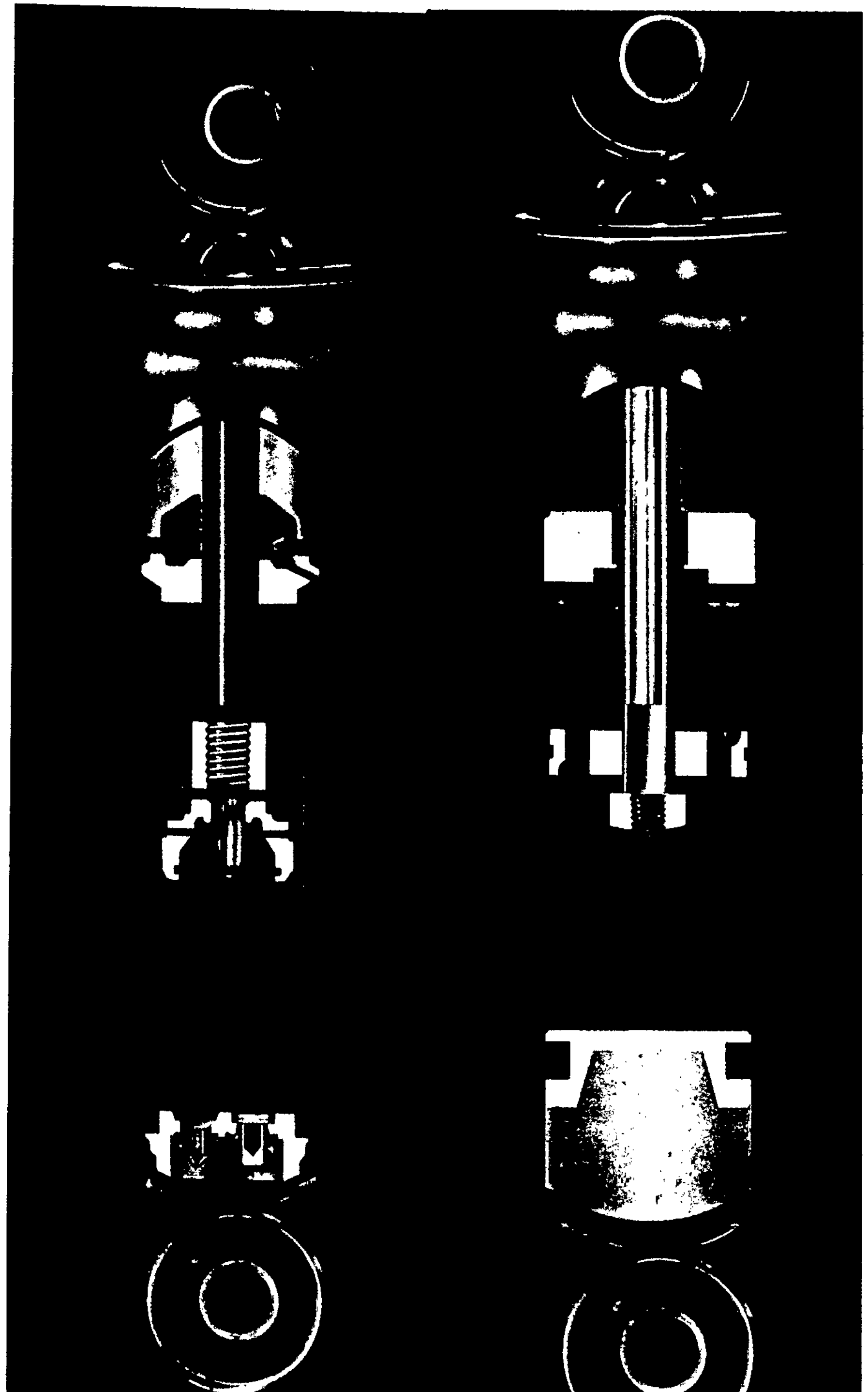
a) The primary function is to keep the wheel in contact with the road for the maximum possible period of time. Consider that your tyres are your final road contact. No matter how good your brakes are or how powerful your engine, if your tyres do not grip the road, your brakes will not stop your car nor will your engine make it go.

b) The secondary function is to control body pitch and roll of the car. Shock absorbers therefore influence the speed of roll and the violence of any pitching action during cornering, braking and acceleration. Apart from passenger comfort, if the driver is being moved about violently then he or she will have poor control over the motorcar.

c) A third function is phasing. This means the front and rear of your car will rise and fall simultaneously when for example you drive fast over long bumps. The fine tuning of the suspension to correct phasing is done by the shock absorbers. If the phasing is not correct the vehicle will develop a pitching motion with the effective roll, force and gravity centres constantly changing. This means that the reaction of your vehicle to steering, braking, etc. is constantly changing with the inevitable higher risks of skidding.

Conventional Gabriel shock absorbers

Conventional shock absorbers consist essentially of two cylinders, one inside the other. The outer cylinder is an oil reservoir and the inner (with a piston rod) the working cylinder. The piston which is attached to the body of the car moves up and down in the working cylinder each time the wheels follow



the road irregularities. Each piston movement forces a specially blended Gabriel oil either through spring loaded valves or through small holes (or a combination of both) from one section of the cylinder to the other. The design and combination of these valves and holes give each shock absorber its specific levels of damping which makes the shock absorber harder or softer, depending on the road condition.

Put this to the test yourself. If you pull gently on one of your shock absorbers the resistance will be just as gentle. But, when you tug hard, you'll feel the tremendous increase in resistance.

This is how your shock absorbers "read" the road and keep things rolling along smoothly.

Pressurised Gabriel shock absorbers

These come in two basic types. There is the twin cylinder which is almost identical to the conventional shock absorber. The difference is that the air space in the oil reservoir is pressurised with Nitrogen gas.

The other type is the monotube. These consist of a single cylinder with a piston operating in oil similar to the conventional shock absorber. The difference is that all the control valving is contained in the piston assembly instead of part in the piston and part in the base of the cylinder. Below the working piston is a second piston. This device, known as the "floating piston" has no piston rod attached to it and is free to move up and down in the cylinder. Between this floating piston and the bottom of the cylinder is a chamber filled with Nitrogen at high pressure. The gas pressure keeps the floating piston pushed hard against the oil at all times and the working piston operating in the oil provides the damping characteristics.

APPENDIX A.3 : ANSWERS TO "VARIETY" QUESTIONS

Question 1:- "In your opinion, how does the current variety of designs, components and processes affect GSA's operations system?"

Question 2:- "What action would you take to overcome the above "problem" ?"

MANAGER 1

Answer 1: Variation in design, "componentry" and process has a significant effect on GSA's operations.

a. Design: The relatively large number of designs being processed through a plant has had the positive effect on GSA in being able to supply a wide customer base. However, the addition of complexity has also limited throughout and increased inventory levels and is in the process of being reduced.

b. Components: The proliferation of components has caused many problems. These problems range from a wide base of suppliers to a loss of production due to stock outs. The only positive aspect is potentially a barrier to entry but this is not significant.

c. Process: The number of different processes involved has led to a "spaghetti junction" effect that is not compatible with synchronous manufacturing. It has also made internal scheduling very complex.

These variations have in turn made the design and maintenance of GSA's operations systems more complex, less accurate and more prone to failure.

Answer 2: Rationalise, re-engineer, introduce GTQMS principles (e.g., one piece flow, pull system, visual control, etc.), design and implement a system that everybody understands and adheres to.

MANAGER 2

Answer 1: GSA cannot negotiate lower prices due to uneconomical batches;- low volumes spread over many parts.

a. No flexibility to use parts as replacement;- when shortages occur on one part other parts cannot be used.

b. More variety to control;- many different suppliers,
- many different kanban locations, and
- more people to handle.

c. Causes many obsolete part numbers and consequently, scrap.

d. Causes over stock because it is not easy to balance different parts;- over requirement on some parts and under requirement of others.

e. Tight tolerances;- waste time on inspection,
- waste time on production line, and
- more expensive from suppliers because they have to build in additional processes.

f. Waste space because of variety.

Answer 2: Reduce the variety of designs, components and processes.

MANAGER 3

Answer 1: It has both negative and positive effects on the operations system.

Negative affects:-

a. Additional complexity.

b. Increase part numbers that require managing.

c. Complicates assembly process / skills required.

d. Increased inventory and cost.

e. Engineering changes are harder to control.

f. Extra capital equipment is required.

g. Smaller quantities of individual parts increases piece price cost.

h. More frequent and longer changeovers (GSA and suppliers).

i. Additional tooling required.

j. Amortisation on tooling longer.

k. Complicates scheduling.

l. Increases space requirements.

m. Have to compromise ideal stock holding with required batch size and frequency.

Positive affects:-

Has allowed us the ability to use an alternate part under deviation when the correct part was unavailable.

Answer 2: Identify what designs are required from a business or strategic reason and eliminate or reduce the affect of the others.

MANAGER 4

Answer 1: Forces more set-ups and smaller batch quantities to be able to produce each part number.

Increase the number of processes required e.g. spin riveter, crimp, staking machines and associated labour, space etc.

Extra costs and labour for additional tooling

Extra costs and labour for gauging and test equipment

Larger supplier base and increased incoming inspection

Too many parts which dimensionally and visually are almost alike, this leads to errors on assembly, machining and storage.

Answer 2: Rationalisation of parts and materials to reduce variation.

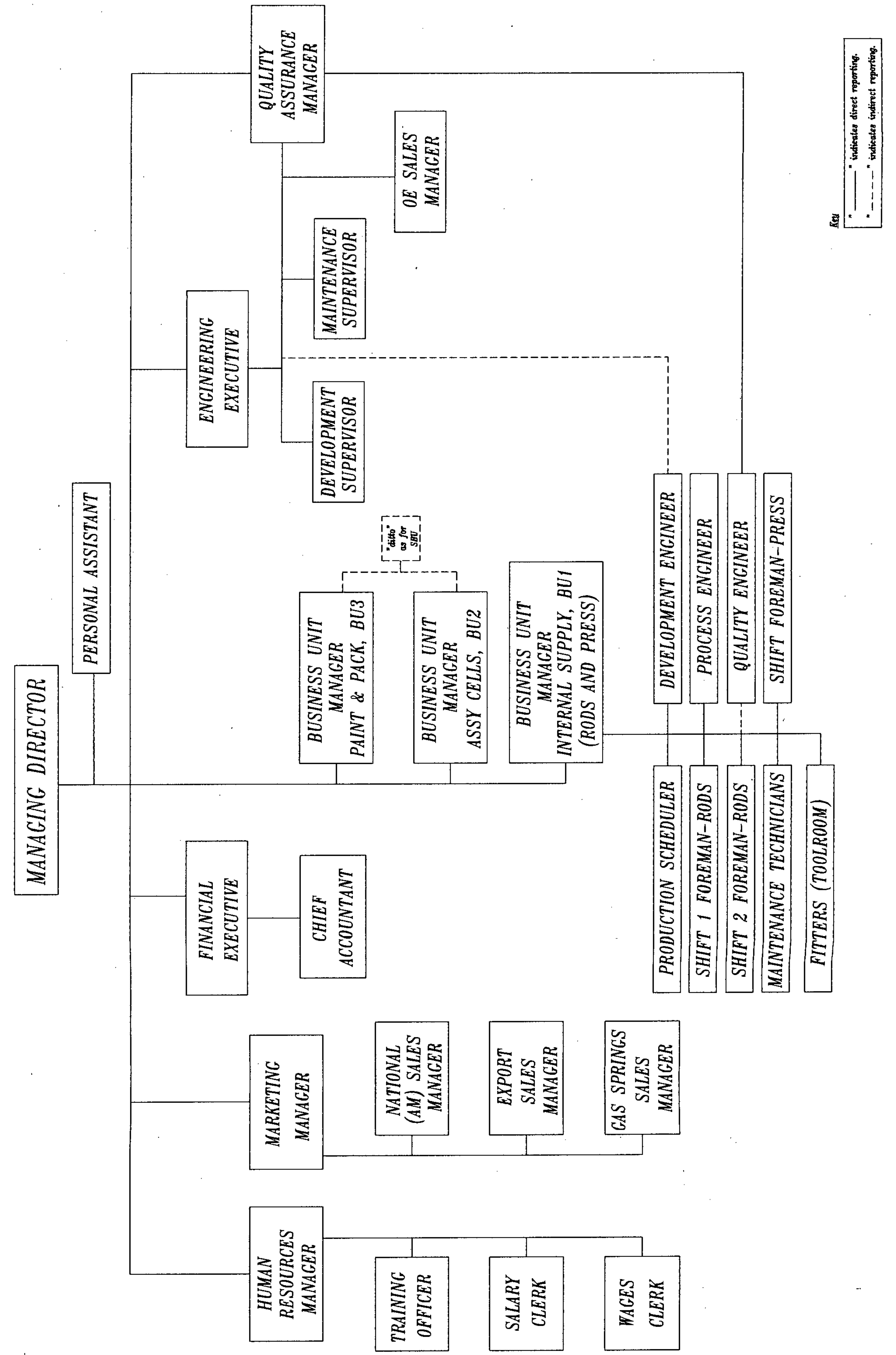
Review of designs, e.g. are adjustable shocks needed?

Review if we should be trying to make every part for every vehicle every built?

APPENDIX B

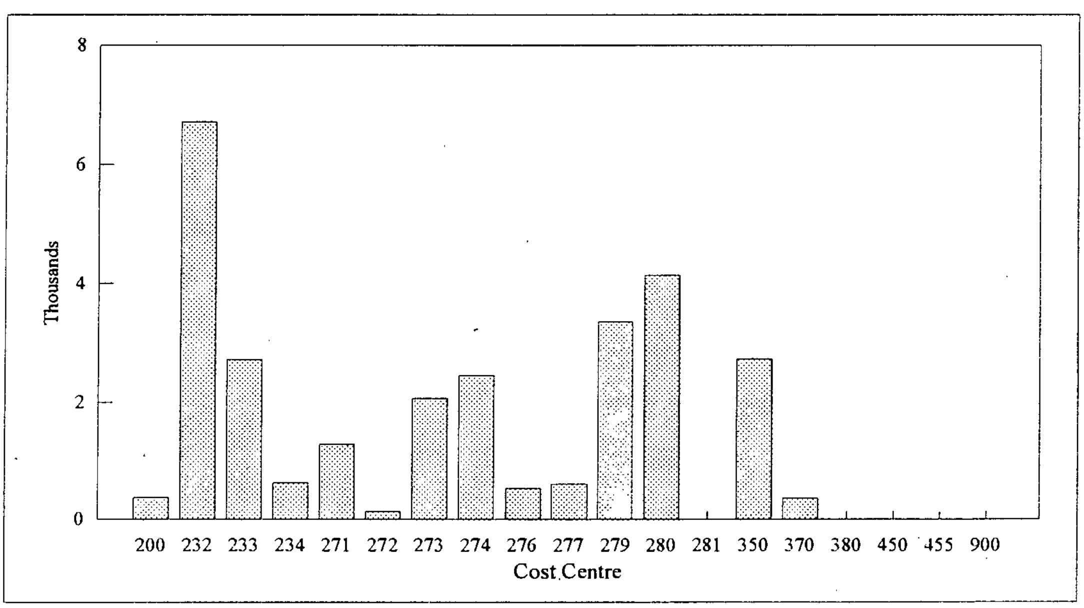
(VSM)

APPENDIX B.1 : GSA's ORGANISATIONAL STRUCTURE

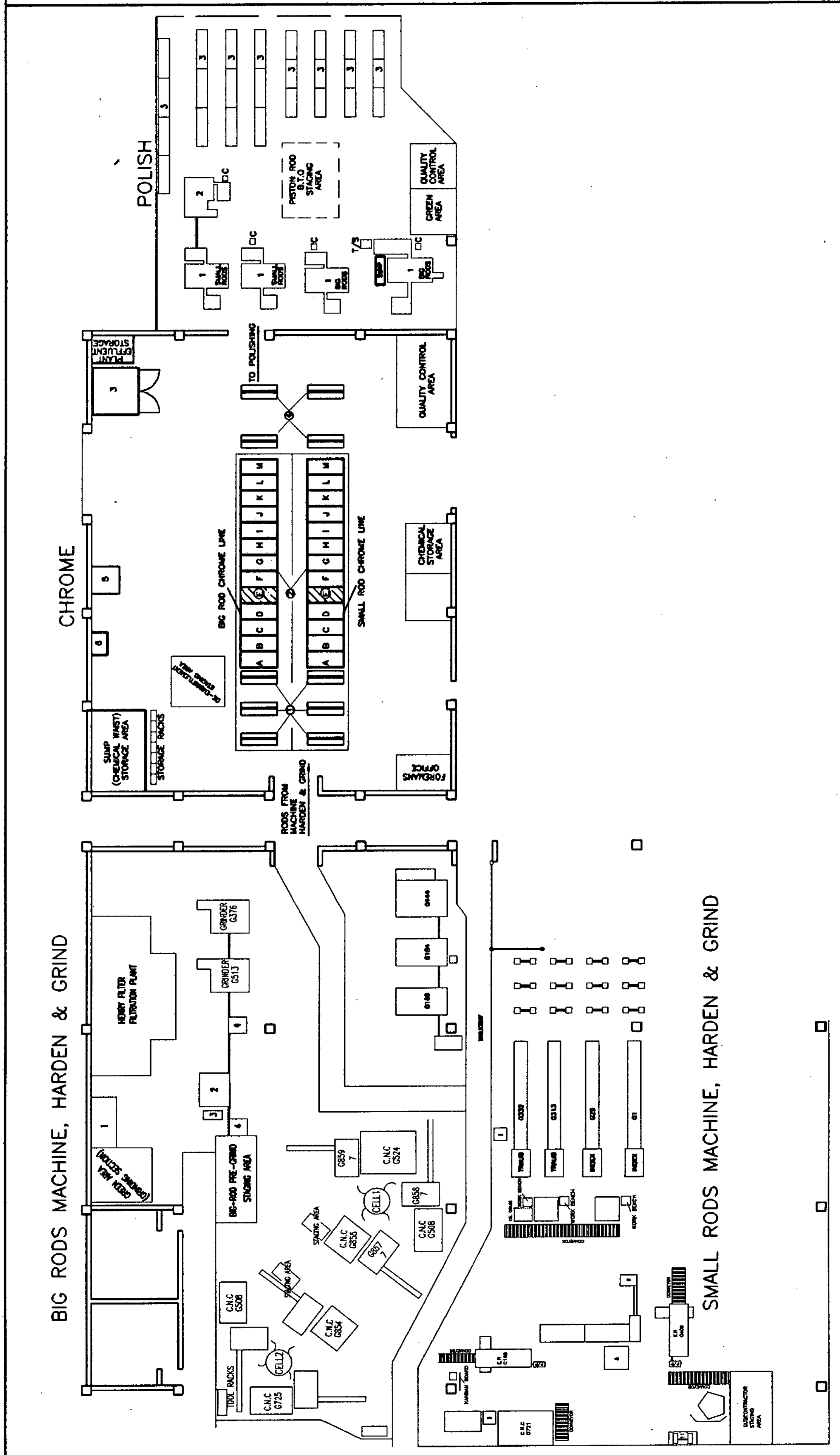


APPENDIX B.2 : SCRAP ANALYSIS BY COST CENTRE

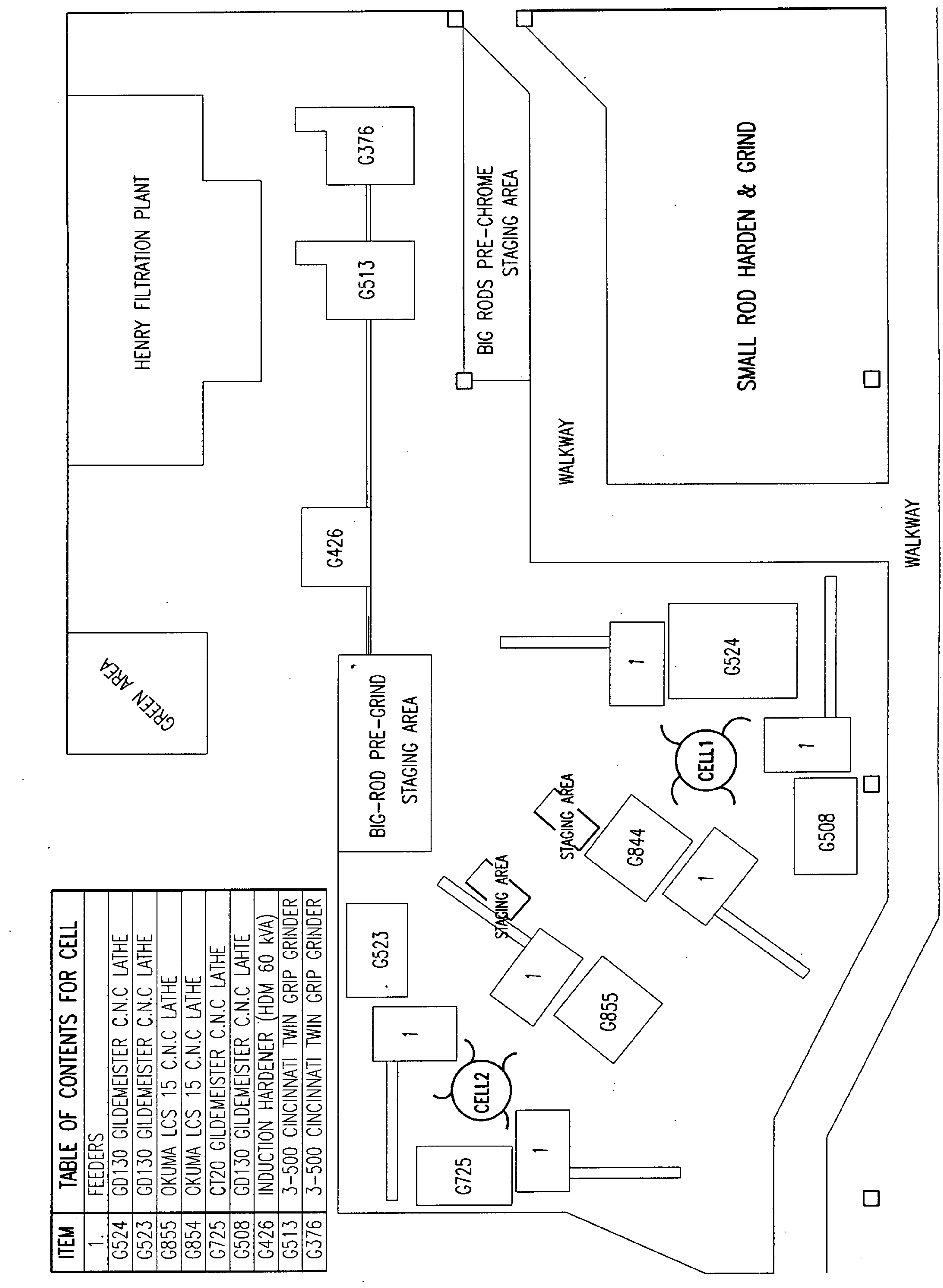
SECTION	COST CENTRE	SCRAP VALUE
Press Shop	200	373
Rods - Cut and Gring	232	6706
Chrome and Polish	233	2718
Projection Weld	234	618
Struts	271	1275
Cartridge	272	131
Gas Springs	273	2055
AM Shocks	274	2445
OE Shocks	276	521
Paint and Pack	277	602
Sub - Assembly	279	3349
Tubing	280	4137
Dustbin	281	0
Goods Inwards	350	2726
Bulk Store	370	361
Warehouse	380	0
Development	450	0
Quality Control	455	0
Stores	900	0



APPENDIX B.3 : PISTON ROD MANUFACTURING DEPARTMENT LAYOUT

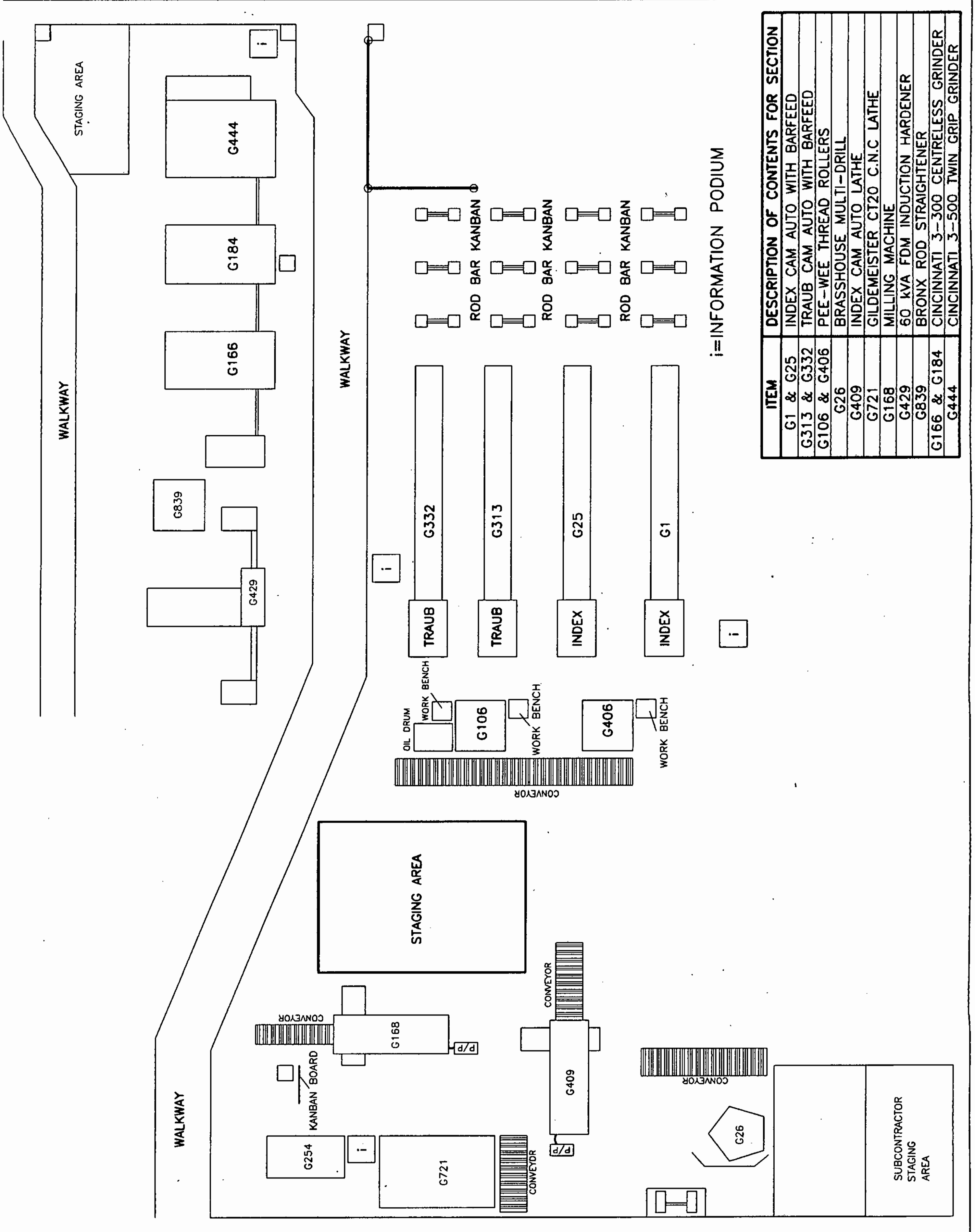


APPENDIX B.4 : BIG ROD MACHINE, HARDEN & GRIND LAYOUT



ITEM	TABLE OF CONTENTS FOR CELL
1.	FEEDERS
G524	GD130 GILDEMEISTER C.N.C LATHE
G523	GD130 GILDEMEISTER C.N.C LATHE
G855	OKUMA LCS 15 C.N.C LATHE
G854	OKUMA LCS 15 C.N.C LATHE
G725	CT20 GILDEMEISTER C.N.C LATHE
G508	GD130 GILDEMEISTER C.N.C LAHTE
G426	INDUCTION HARDENER (HDM 60 kVA)
G513	3-500 CINCINNATI TWIN GRIP GRINDER
G376	3-500 CINCINNATI TWIN GRIP GRINDER

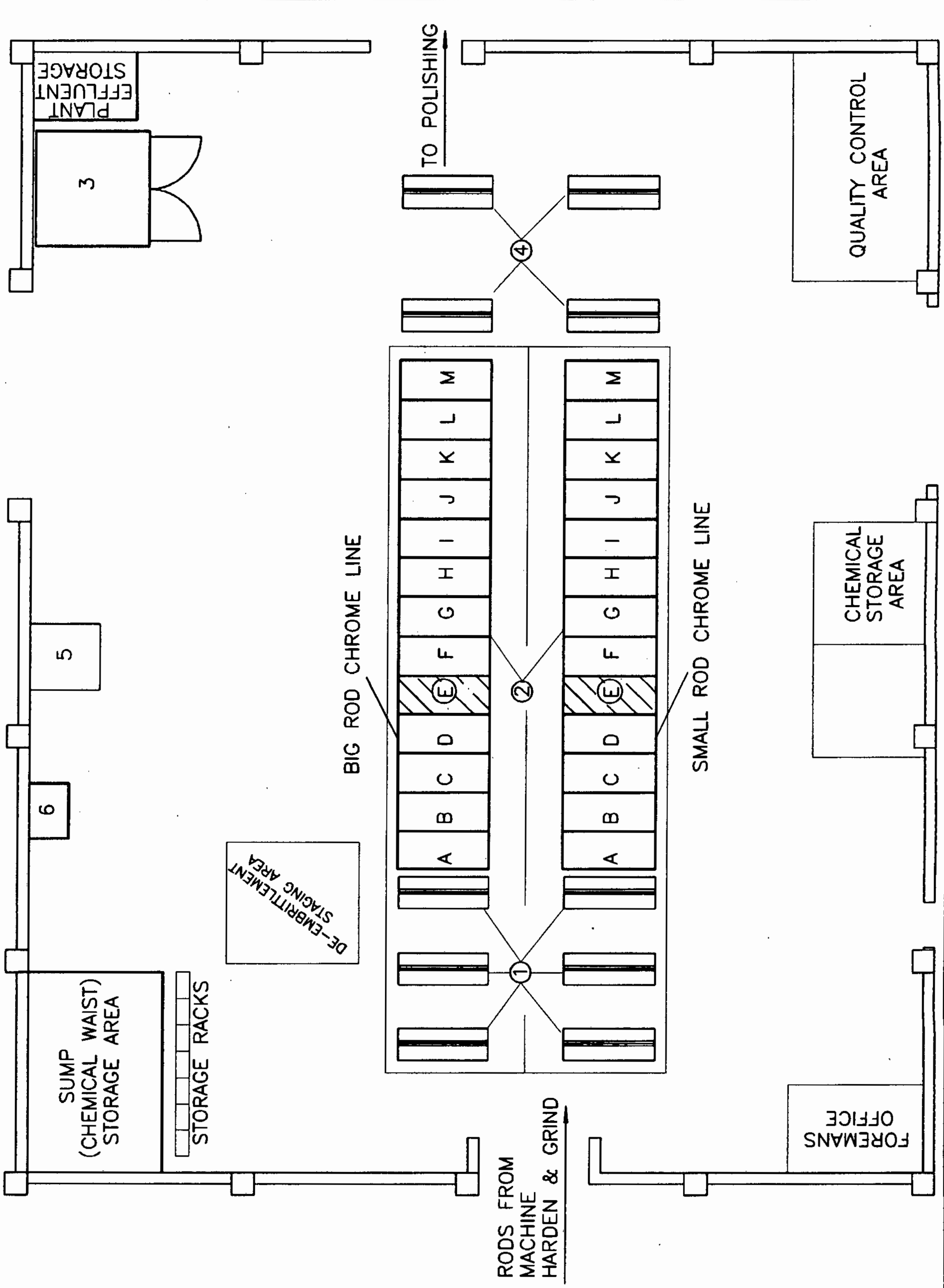
APPENDIX B.5 : SMALL ROD MACHINE, HARDEN & GRIND LAYOUT



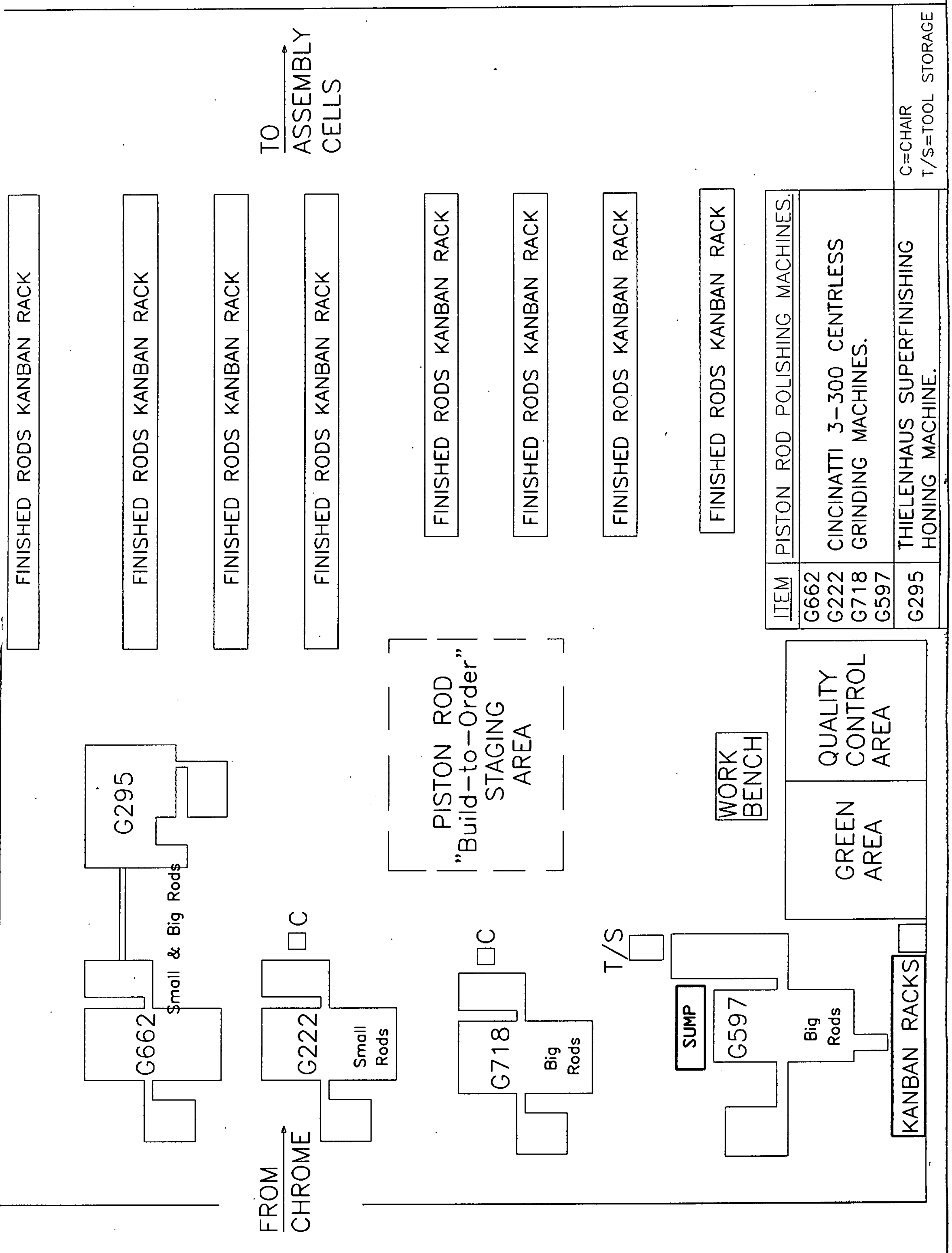
ITEM	DESCRIPTION OF CONTENTS FOR SECTION
G1 & G25	INDEX CAM AUTO WITH BARFEED
G313 & G332	TRAUB CAM AUTO WITH BARFEED
G106 & G406	PEE-WEE THREAD ROLLERS
G26	BRASSHOUSE MULTI-DRILL
G409	INDEX CAM AUTO LATHE
G721	GILDEMEISTER CT20 C.N.C LATHE
G168	MILLING MACHINE
G429	60 kVA FDM INDUCTION HARDENER
G839	BRONX ROD STRAIGHTENER
G166 & G184	CINCINNATI 3-300 CENTRELESS GRINDER
G444	CINCINNATI 3-500 TWIN GRIP GRINDER

APPENDIX B.6 : CHROME LAYOUT

ITEM	DESCRIPTION OF CONTENTS OF SECTION
1.	LOADING & OFF-LOADING AREA
2.	CHROMING PROCESS TANKS A to M:-
	A. SOAK CLEANER
	B. ELECTROLYTIC - CLEANER
	C. RINSE
	D. RINSE
	E. **TRANSFER STATION**
	F. ETCH TANK
	G. PLATING TANK
	H. PLATING TANK
	I. PLATING TANK
	J. DRAGOUT
	K. RINSE 3
	L. RINSE 4
	M. HOT RINSE
3.	DE-EMBRITTLEMENT OVEN
4.	JIG STORAGE AREA
5.	PHOSPHATING TANK
6.	SHOWER



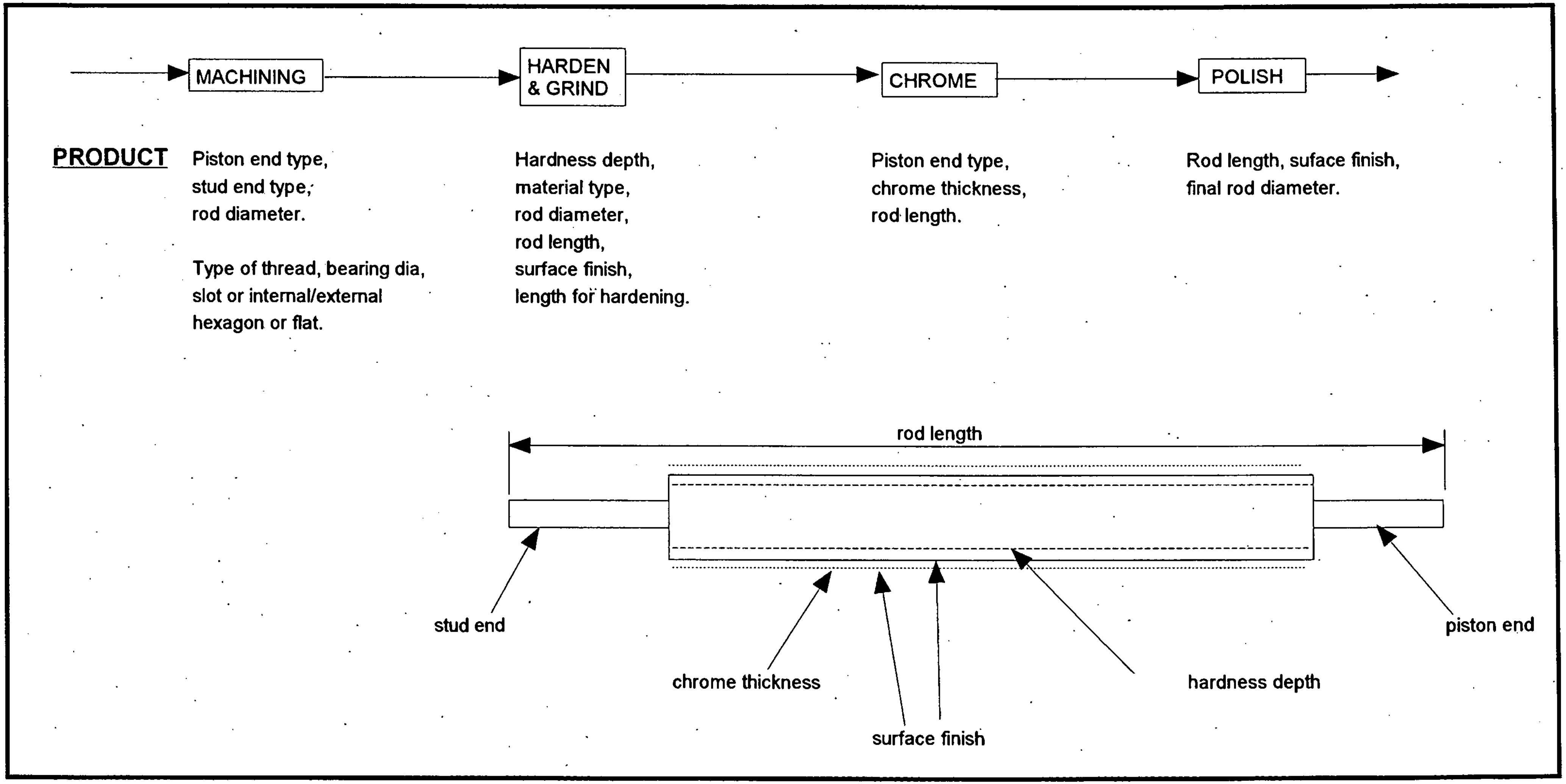
APPENDIX B.7 : POLISH LAYOUT



ITEM	PISTON ROD POLISHING MACHINES.
G662 G222 G718 G597	CINCINATTI 3-300 CENTRLESS GRINDING MACHINES.
G295	THIELENHAUS SUPERFINISHING HONING MACHINE.

		MACHINING	HARDENING	GRINDING	CHROMING	POLISHING
PRODUCT	BIG	Dia change (28,5; 25; 22 & 20 mm) Note: 17mm is machined as "small rod". Only 2300 rods/day are made in house. Remaining 2200 rods are subcontracted:- - All 28,5; 25 and 22mm diameters.	Dia change (28,5; 25; 22, 20 &17mm). Length change. Hardness depth change.	Dia change (28,5; 25; 22; 20 & 17mm)	Dia change (28,5; 25; 22 & 20 mm) - change jigs & set jig heigght. - change inserts. - change chrome plating parameters -thickness and length.	Dia change (28,5; 25; 22 & 20 mm) - grinder setup. - conveyor setup.
	SMALL	Have 8, 10, 11, 12.7, 13, 14, 15, & 17 mm. Variety large and difficult to manage. All different designs leads to "messy" flow. All 8, 10, 13, 15 and 17mm rods are subcontracted.	7 diameters, excludes 17mm. Length change. Hardness depth change.	7 diameters, excludes 17mm.	7 diameters, excludes 17mm.	7 diameters, excludes 17mm.
DOWNTIME CHANGEOVER'S	BIG	Variety dealt with by tooling changeovers - change program. - change threadbox. - change length of feeders. - takes approx. 15 to 5 minutes.	Changeover to relevant rod:- - change rollers. - change coil. - change power (voltage/current). - check coolant flow. - change feed-motor speed. Hardener and grinder c/over take approximately 0,75 to 2,75 hours. Limit to 2 per week.	Changeover of grinders for correct rod:- - change conveyor guides. - change measuring gauges (clocks). - set grinder's to achieve diameter & surface finish. - check coolant flow. Limit to 2 per week.	Changeover of rod holders - 0,5 to 2,75 hrs . (loading of jig takes 5 to 15 minutes)	Grinder and conveyor setup:- - 5 to 15 minutes.
	SMALL	Added to the above is "threading" and "drilling" cell tooling changes. takes approx. 0,5 to 1 hour.	As for big rods. Hardener and grinder c/over take approximately 0,75 to 3,15 hours. Limit to 7 per week.	As for big rods. Limit to 7 per week.		
OTHER	BIG	Cycle time is 50 sec's in place of 40 sec's. (Only 2300 rods in place of 3000/day. Still need to subcontract remaining 2200.) Bad quality material.	Replace burned coil - 1 hr. Straighten - up to 3 hrs. Maintenance - 0,5 to 3 hrs. El meeting - 1 hr. Bad quality material.	Dress wheels - 5 times/day for 1,5 to 3,15 hours in total (to achieve surface finish required). Mintenance - 0,5 to 3 hrs. El meeting - 1 hr. Grinding wheel change:- every 8 to 10 weeks per grinder (2 off) takes 2 to 3,5 hours. Bad quality material.	Carrier trip - 0,75 hrs. (1 to 4 times per day). Maintenance - 1 to 3 hrs. Rectifier trip - 1,5 hrs. Bad quality material.	Not as much downtime as other areas. Grinding wheel change:- every 4 - 6 weeks takes 30 to 45 minutes. Bad quality material.
	SMALL	Machines and process quite old. Alot of cross-flow of process. Maintenance - 1 to 10 hours. Bad quality material.	Replace burned coil - 1 hr. Straighten - 4 to 10 hrs. Maintenance - 0,5 to 3 hours. El meeting - 1 hr. Bad quality material.	Dress wheels - 5 times/day for 1,5 to 4 hours in total (to achieve surface finish required). Mintenance - 0,5 to 3,5 hrs. El meeting - 1 hr. Grinding wheel change:- every 8 to 10 weeks per grinder type A (1 off) takes 2 to 3,5 hours. Grinding wheel change:- every 3 to 4weeks per grinder type B (2 off) takes 30 to 45 min's. Bad quality material.	As for big rods. Bad quality material.	As for big rods. Bad quality material.
OPERATOR (Human Factors)		Efficiency level / training. Absenteeism. Attitude, motivation Fitness level	Efficiency level / training. Absenteeism. Attitude, motivation Fitness level	Efficiency level / training. Absenteeism. Attitude, motivation Fitness level	Efficiency level / training. Absenteeism. Attitude, motivation Fitness level	Efficincy level / training. Absenteeism. Attitude, motivation Fitness level

APPENDIX B.8 : THE VARIETY INITIATORS FOR BIG & SMALL RODS



APPENDIX B. 9 : VARIETY WHICH ARE INTRODUCED BY THE PRODUCT

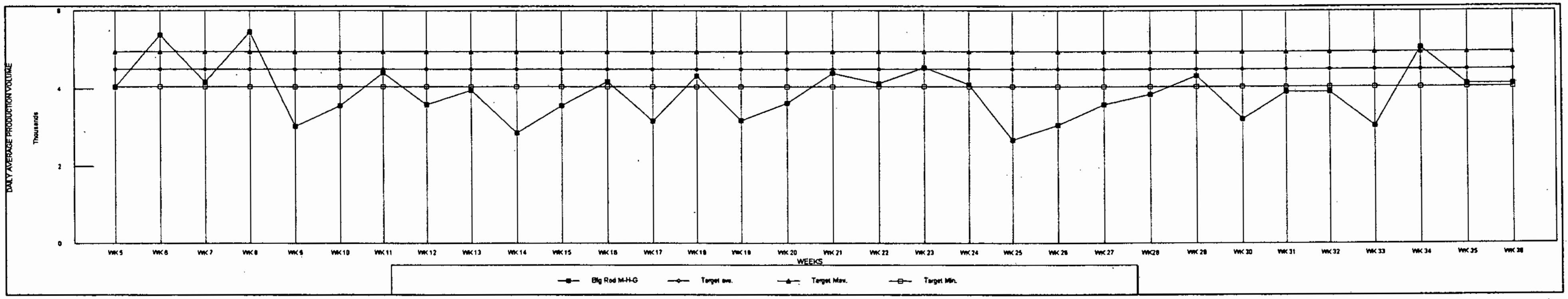
BIG ROD MACHINE, HARDEN & GRIND

DAILY AVERAGE PER WEEK **1995**

	WK 5	WK 6	WK 7	WK 8	WK 9	WK 10	WK 11	WK 12	WK 13	WK 14	WK 15	WK 16	WK 17	WK 18	WK 19	WK 20
Target ave.	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500
Target Max.	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950
Target Min.	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050
Big Rod M-H-G	4034	5378	4177	5463	3034	3560	4410	3583	3961	2862	3566	4191	3171	4325	3184	3623

	WK 21	WK 22	WK 23	WK 24	WK 25	WK 26	WK 27	WK28	WK 29	WK 30	WK 31	WK 32	WK 33	WK 34	WK 35	WK 36
Target ave.	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500
Target Max.	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950
Target Min.	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050
Big Rod M-H-G	4391	4136	4547	4101	2671	3053	3590	3850	4337	3225	3915	3927	3051	5061	4128	4132

	MEAN	MAX	MIN	STD DEV	MAX-MIN
Target	4500	4950	4050	450	900
Big M-H-G	3895	5463	2671	672	2792



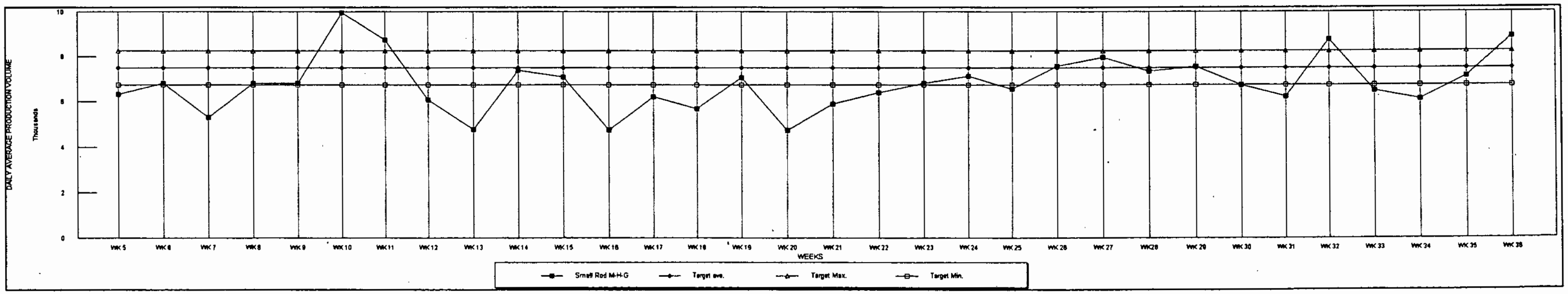
SMALL ROD MACHINE, HARDEN & GRIND

DAILY AVERAGE PER WEEK

	WK 5	WK 6	WK 7	WK 8	WK 9	WK 10	WK 11	WK 12	WK 13	WK 14	WK 15	WK 16	WK 17	WK 18	WK 19	WK 20
Target ave.	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
Target Max.	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250
Target Min.	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750
Small Rod M-H-G	6329	6802	5300	6812	6805	9952	8728	6076	4754	7378	7092	4746	6218	5690	7069	4729

	WK 21	WK 22	WK 23	WK 24	WK 25	WK 26	WK 27	WK28	WK 29	WK 30	WK 31	WK 32	WK 33	WK 34	WK 35	WK 36
Target ave.	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
Target Max.	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250
Target Min.	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750
Small Rod M-H-G	5896	6397	6804	7136	6565	7574	7949	7343	7546	6715	6224	8768	6481	6117	7132	8892

	MEAN	MAX	MIN	STD DEV	MAX-MIN
Target	7500	8250	6750	750	1500
Small M-H-G	6813	9952	4729	1189	5223



APPENDIX B.10 : PERFORMANCE GRAPH OF THE BIG & SMALL RODS MACHINE, HARDEN & GRIND

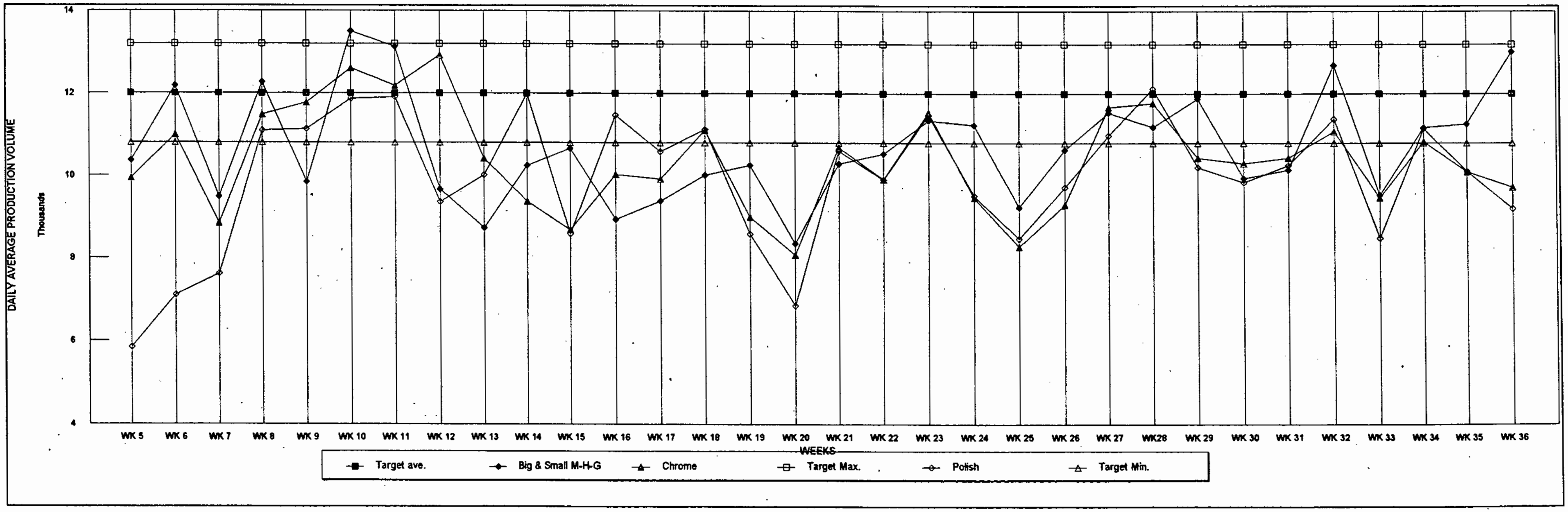
PISTON ROD MANUFACTURE

DAILY AVERAGE PER WEEK 1995

	WK 5	WK 6	WK 7	WK 8	WK 9	WK 10	WK 11	WK 12	WK 13	WK 14	WK 15	WK 16	WK 17	WK 18	WK 19	WK 20
Target ave.	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000
Target Max.	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200
Target Min.	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800
Big & Small M-H-G	10363	12180	9477	12274	9839	13512	13138	9659	8725	10240	10658	8937	9388	10015	10253	8351
Chrome	9942	11001	8838	11487	11773	12613	12180	12929	10411	9370	8681	10019	9920	11102	8991	8066
Polish	5843	7098	7607	11088	11132	11872	11911	9351	10010	11992	8577	11464	10581	11134	8579	6846

	WK 21	WK 22	WK 23	WK 24	WK 25	WK 26	WK 27	WK28	WK 29	WK 30	WK 31	WK 32	WK 33	WK 34	WK 35	WK 36
Target ave.	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000
Target Max.	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200
Target Min.	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800
Big & Small M-H-G	10287	10533	11352	11237	9236	10627	11539	11193	11883	9940	10139	12695	9532	11178	11260	13023
Chrome	10691	9919	11542	9467	8284	9298	11677	11776	10435	10299	10433	11079	9470	10834	10094	9722
Polish	10613	9904	11488	9519	8468	9721	10983	12129	10202	9846	10257	11386	8483	11157	10113	9196

	MEAN	MAX	MIN	STD DEV	MAX-MIN
Target:	*12000*	*13200*	*10800*	*1200*	*2400*
Big & Small M-H-G	*10708*	*13512*	*8351*	*1307*	*5161*
Chrome	*10386*	*12929*	*8066*	*1207*	*4863*
Polish	*9955*	*12129*	*5843*	*1583*	*6286*



APPENDIX B.11 : PERFORMANCE GRAPH OF "TOTAL" MACHINE, HARDEN & GRIND, CHROME and POLISH

	BIG RODS			SMALL RODS			TOTAL ROD PRODUCTION		
	MACHINE, HARDEN & GRIND	CHROME	POLISH	MACHINE, HARDEN & GRIND	CHROME	POLISH	MACHINE, HARDEN & GRIND	CHROME	POLISH
WK5	4034	4019	3138	6329	5923	2706	10363	9942	5843
WK6	5378	4661	3604	6802	6340	3495	12180	11001	7098
WK7	4177	3715	3263	5300	5123	4344	9477	8838	7607
WK8	5463	4460	4314	6812	7028	6774	12274	11487	11088
WK9	3034	4550	4413	6805	7223	6718	9839	11773	11132
WK10	3560	3877	4231	9952	8736	7641	13512	12613	11872
WK11	4410	3995	3980	8728	8185	7931	13138	12180	11911
WK12	3583	4593	3138	6076	8336	6213	9659	12929	9351
WK13	3961	4001	4087	4764	6410	5923	8725	10411	10010
WK14	2862	2438	3400	7378	6932	8592	10240	9370	11992
WK15	3566	2091	2477	7092	6590	6100	10658	8681	8577
WK16	4191	4321	4422	4746	5698	7042	8937	10019	11464
WK17	3171	3603	4032	6218	6317	6548	9388	9920	10581
WK18	4325	4206	4478	5690	6896	6656	10015	11102	11134
WK19	3184	2892	2875	7069	6099	5705	10253	8991	8579
WK20	3623	2850	2655	4729	5216	4191	8351	8066	6846
WK21	4391	4525	4203	5896	6166	6410	10287	10691	10613
WK22	4136	3825	4090	6397	6094	5814	10533	9919	9904
WK23	4547	4585	3912	6804	6957	7575	11352	11542	11488
WK24	4101	3786	4171	7136	5681	5348	11237	9467	9519
WK25	2671	2568	2384	6565	5716	6084	9236	8284	8468
WK26	3053	3507	3287	7574	5791	6433	10627	9298	9721
WK27	3590	4684	3070	7949	6993	7913	11539	11677	10983
WK28	3850	2614	2685	7343	9162	9444	11193	11776	12129
WK29	4337	4135	4165	7546	6300	6037	11883	10435	10202
WK30	3225	3327	2938	6715	6972	6907	9940	10299	9846
WK31	3915	4006	3797	6224	6427	6460	10139	10433	10257
WK32	3927	4393	4808	8768	6686	6578	12695	11079	11386
WK33	3051	3078	2677	6481	6392	5806	9532	9470	8483
WK34	5061	4224	4222	6117	6610	6935	11179	10834	11157
WK35	4128	3857	4019	7132	6237	6094	11260	10094	10113
WK36	4132	3571	3746	8892	6151	5450	13023	9722	9196
average	*3895*	*3780*	*3646*	*6813*	*6606*	*6308*	*10708*	*10386*	*9955*
max	*5463*	*4684*	*4808*	*9952*	*9162*	*9444*	*13512*	*12929*	*12129*
min	*2671*	*2091*	*2384*	*4729*	*5123*	*2706*	*8351*	*8066*	*5843*
spread	*2792*	*2593*	*2424*	*5223*	*4039*	*6739*	*5161*	*4863*	*6286*
std dev	*682*	*716*	*677*	*1199*	*931*	*1365*	*1328*	*1226*	*1609*

APPENDIX B.12 : TABULATION OF PRODUCTION FIGURES FOR THE OPERATIONAL UNITS

APPENDIX B.13 : CAPABILITY CALCULATIONS

For all the calculations below, the available time for work of 15 hours per day was used. Refer to appendix B.14 for the calculation of paid hours to actual used time. No material shortage or downtime is assumed.

a) **BIG ROD M-H-G**

Machining (Refer appendix B.4 for layout)

In plant

2 Cells of 3 CNC's/cell.
Each cell was designed to have a cycle time of 40 seconds/rod.
Over 2 shifts of total 15 hours/day = 1350 rods.
The two cells produce 2 x 1350 = 2700 rods/day.

Subcontractor

If the daily requirement is 4500 rods/day, then 1800 rods/day are supplied by the subcontractor. Based on discussions held with the scheduler and the current subcontractors, and considering the fact that their are other available subcontractors it is assumed that piston rod machining has an unlimited capacity.

Hardening and Grinding

Due the times measured this was the constraining processes of this operational unit.

The throughput rate (linked hardener and grinder) was measured ("timed") and the average value of 3 metres/min is considered.

- 3 metres/min = 180 metre/hr.
- Using a weighted average length of 379 mm (refer appendix D.4) this translates to 474 rods/hr.
- The average possible daily production is then
  475 rods/hr x 15 hr's = 7110 rods/day

b) **SMALL RODS M-H-G** (Refer appendix B.5. for layout drawing)

Machining

As for big rods, since machined rods can be subcontracted, machining does not form a bottleneck (constraint).

Hardening and Grinding

Again this process was considered as one since the process is linked. The rate of various rods through the grinder was measured and an average taken.
Considering this rate of 3,5 metres/min and an average weighted length of 277 mm the average daily capability of the process (refer appendix D.5 and D.6) is 758 x 15 rods/day = 11 371 rods/day.

For the big and small rod M-H-G the total capability is then
7110 + 11 371 = **18 481 rods/day.** (Reminder: This does not consider any downtime, it is based on actual measured rates and 15 hour non-stop working machine and operator.)

APPENDIX B.13 : CAPABILITY CALCULATIONS

c) **CHROME** (Refer Appendix B.6 for layout drawing)

Big Rod Line

Calculations are based on approximately 1 min/μm chrome deposition. For big rods chrome thickness is 13μm. Hence, based on this, the cycle would be 13 minutes minimum. But during time measurements taken a jig took 9 minutes. One of the reasons for this is that their are 3 chroming tanks per line. This value 9 min's/jig was used instead.
All the big rod jigs can take 48 rods.
Consequently the 1-hour rate is 60/9 * 48 = 320 rods/hr.
Taken for 15 hours, the big rod line capability is 4800 rods/day.

Small Rod Line

The calculations for this line is based on:-

- 20% of rods with 13μm on 48-rod jig:- All OE and all strut rods.
- 20% of rods with 13μm on 80-rod jig:- gas spring rods.
- 60% of rods with 5μm on 48-rod jig:- AM shock rods.
- During time measurements on the small rod line the time for the 13μm rods and the 5μm rods were 9 min's and 5 min's respectively. The values (obtained in practice) are used in the calculations below.

0,2 * (60 x 48/9) + 0,2 * (60x80/9) + 0,6 * (60 x 48 /5)
= 0,2 x 320 rods/hr = 0,2 x 533 rods/hr + 0,6 x 576 rods/hour.
= 516 rods/hour.
For 15-hour day, small rod capacity is 7743 rods/day
Total chrome capacity is 4800 + 7743 = **12 543 rods/day.**

d) **POLISH** (Refer Appendix B.7 for layout drawing)

Small rods

Polishing rate = 2,5 metres/minute. For 2 grinders = 300 metres/hour.
For an average rod length of 277 mm, production is 300/0,277
= 1083 rods/hour.
For a 15-hour day, production capacity is 16 245 rods/day.

Big rods

Polisher rate = 2,12 metres/minute.
For 2 grinders, rate = 254 metres/hour.
For an average rod length of 379 mm, hourly production is 670 rods/hr.
For 15-hour day, capacity is 10 052 rods/day

Total polish capacity is then **26 297 rods/day.**

	MONDAY to THURSDAY		FRIDAY		SATURDAY		SUNDAY		
DAY SHIFT	7.30 am to 6 pm	10.50	7.30 am to 3.20 pm	7.83	6am to 11 am	5.00	6am to 10 pm	4.00	
	1/2 hr lunch	-0.50	1/2 hr lunch	-0.50					
	2x15 min's teabreak	-0.50	+ 1x15 min's	-0.25	+ 1x15 min's	-0.25	+ 1x15 min's	-0.25	
	Green Area meetings : 15 min's	-0.25	Green Area meetings : 15 min's	-0.25					
	Housekeeping : 30 min's	-0.50	Housekeeping : 30 min's	-0.50					
	O.P.M : 15 min's	-0.25	O.P.M : 15 min's	-0.25					
	EI meeting : 30 min's/wk	-0.10	EI meeting : 30 min's/wk	-0.10		-0.25		-0.25	
	Available time	8.40	Available time	5.98	Available time	4.50	Available time	3.50	
	Actual hours worked (85% Eff)	7.14	Actual hours worked (85% Eff)	5.08	Actual hours worked (80% Eff)	3.60	Actual hours worked (80% Eff)	2.80	
NIGHT SHIFT	8 pm to 7.15 am	11.25	3 pm to 9.30 pm	6.50					
	1/2 hr lunch	-0.50	1/2 hr lunch	-0.50					
	2x15 min's teabreak	-0.50	+ 1x15 min's	-0.25					
	Green Area meetings : 15 min's	-0.25	Green Area meetings : 15 min's	-0.25					
	Housekeeping : 30 min's	-0.50	Housekeeping : 30 min's	-0.50					
	O.P.M : 15 min's	-0.25	O.P.M : 15 min's	-0.25					
	EI meeting : 30 min's/wk	-0.10	EI meeting : 30 min's/wk	-0.10					
	Available time	9.15	Available time	4.65					
	Actual hours worked (85% Eff)	7.78	Actual hours worked (85% Eff)	3.95					
	TOTAL paid hours	21.75		14.33		5.00		4.00	TOTAL WEEKLY TIME 110.3 (paid)
	TOTAL daily available time (includes lunch, tea & Green Area's, H/k'g, OPM, EI)	17.55		10.63		4.50		3.50	TOTAL WEEKLY 88.83 (81%) (available time)
	Actual remaining time (Eff of 80-85% considered)	14.92		9.04		3.60		2.80	TOTAL WEEKLY 75.11 (68%) (actual time)

NOTE:- For Monday to Friday an operator efficiency of 85% is used.
For Saturday and Sunday an operator efficiency of 80% is used.
SATURDAY AND SUNDAY'S TIME WERE ADDED TO FRIDAYS TIME (9,04 + 3,6 + 2,8 = 15,44 hours),
THEREFORE, A FIVE-DAY WEEK WAS IS USED IN ALL CALCULATIONS.

APPENDIX B.14 : CALCULATION OF AVAILABLE HOURS

APPENDIX C

(ACTION RESEARCH)

APPENDIX C.1 : IMPACT OF ACTION RESEARCH INTERVENTION - TABULATION

BEFORE INTERVENTION

	BIG CHROME	SMALL CHROME	TOTAL CHROME
WK5	4019	5923	9942
WK6	4661	6340	11001
WK7	3715	5123	8838
WK8	4460	7028	11487
WK9	4550	7223	11773
WK10	3877	8736	12613
WK11	3995	8185	12180
WK12	4593	8336	12929
WK13	4001	6410	10411
WK14	2438	6932	9370
WK15	2091	6590	8681
WK16	4321	5698	10019
WK17	3603	6317	9920
WK18	4206	6896	11102
WK19	2892	6099	8991
WK20	2850	5216	8066
WK21	4525	6166	10691
WK22	3825	6094	9919
WK23	4585	6957	11542
WK24	3786	5681	9467
WK25	2568	5716	8284
WK26	3507	5791	9298
WK27	4684	6993	11677
WK28	2614	9162	11776
WK29	4135	6300	10435
WK30	3327	6972	10299
WK31	4006	6427	10433
WK32	4393	6686	11079
WK33	3078	6392	9470
WK34	4224	6610	10834
WK35	3857	6237	10094
WK36	3571	6151	9722

average	*3780*	*6606*	*10386*
max	*4684*	*9162*	*12929*
min	*2091*	*5123*	*8066*
spread	*2593*	*4039*	*4863*
std dev	*716*	*931*	*1226*

AFTER INTERVENTION

	BIG CHROME	SMALL CHROME	TOTAL CHROME	TARGET
WK 37*	4505	7607	12112	12000
WK38*	5083	7365	12448	12000
WK39*	4560	7577	12137	12000
WK40*	4800	7500	12300	12000

average	*4737*	*7512*	*12249*
max	*5083*	*7607*	*12448*
min	*4505*	*7365*	*12112*
spread	*578*	*242*	*336*
std dev	*228*	*94*	*136*

IMPROVEMENT	25%	14%	18%

APPENDIX C.2 : IMPACT OF ACTION RESEARCH INTERVENTION - GRAPH

PISTON ROD MANUFACTURE
DAILY AVERAGE PER WEEK

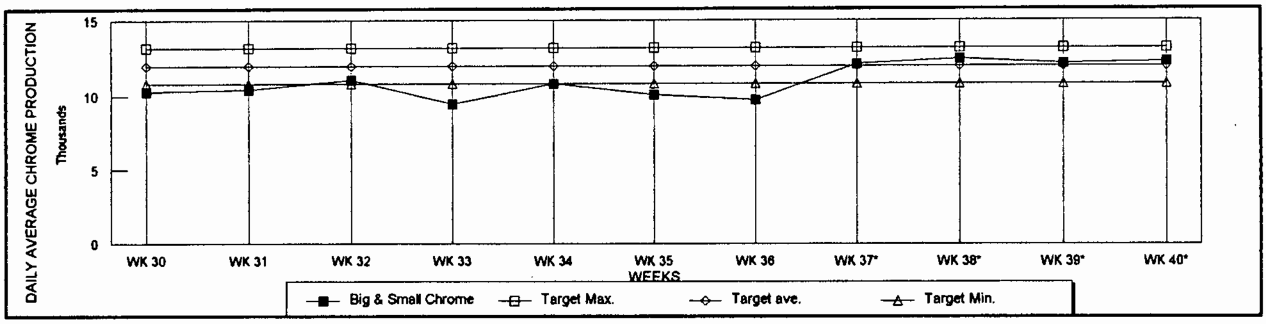
1995

NOTE: The "mean before" is taken for weeks 5 to 36.
The "mean after" is taken for weeks 30 to 40.

Big & Small Chrome

	WK 30	WK 31	WK 32	WK 33	WK 34	WK 35	WK 36	WK 37*	WK 38*	WK 39*	WK 40*
Target ave.	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000
Target Max.	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200	13200
Target Min.	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800
Big & Small Chrome	10299	10433	11079	9470	10834	10094	9722	12112	12448	12137	12300

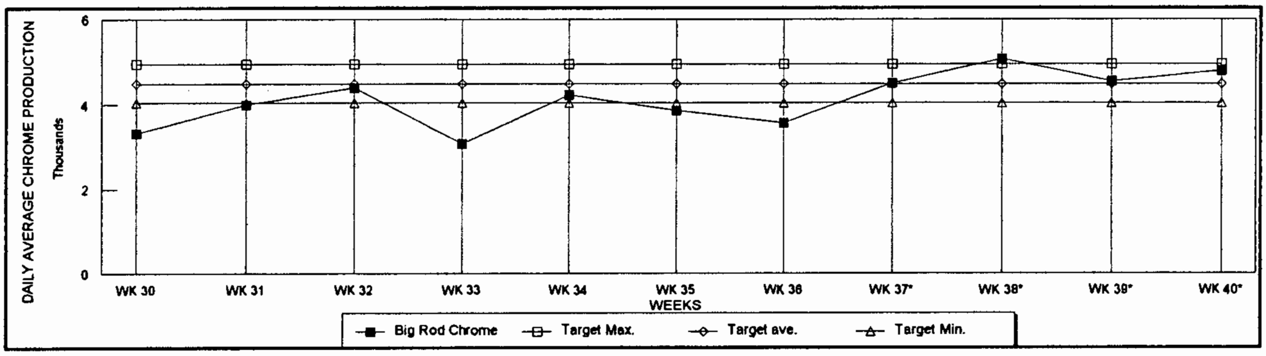
	MEAN BEFORE	MEAN AFTER
Target:	*12000*	*12000*
Big & Small Chrome	*10386*	*12249*



Big Rod Chrome

	WK 30	WK 31	WK 32	WK 33	WK 34	WK 35	WK 36	WK 37*	WK 38*	WK 39*	WK 40*
Target ave.	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500	4500
Target Max.	4950	4950	4950	4950	4950	4950	4950	4950	4950	4950	.4950
Target Min.	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050	4050
Big Rod Chrome	3327	4006	4393	3078	4224	3857	3571	4505	5083	4560	4800

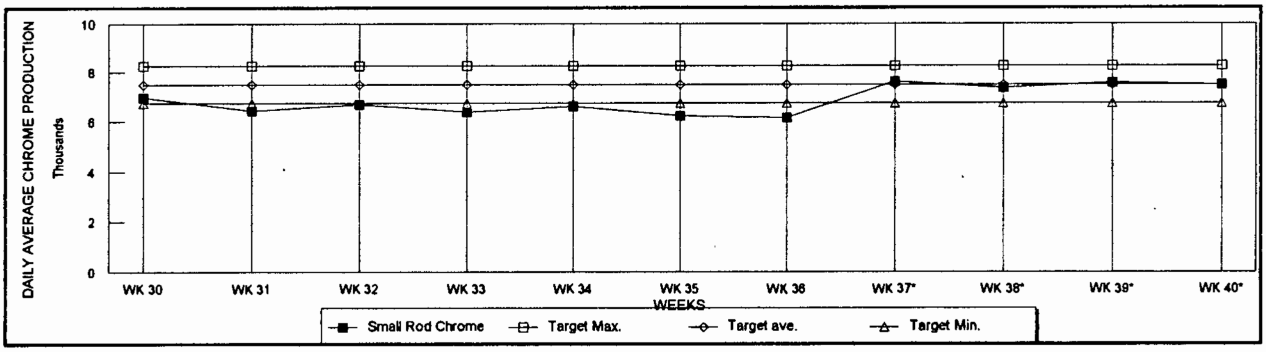
	MEAN BEFORE	MEAN AFTER
Target:	*4500*	*4500*
Big Rod Chrome	*3780*	*4737*



Small Rod Chrome

	WK 30	WK 31	WK 32	WK 33	WK 34	WK 35	WK 36	WK 37*	WK 38*	WK 39*	WK 40*
Target ave.	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
Target Max.	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250	8250
Target Min.	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750	6750
Small Rod Chrome	6972	6427	6686	6392	6610	6237	6151	7607	7365	7577	7500

	MEAN BEFORE	MEAN AFTER
Target:	*7500*	*7500*
Small Rod Chrome	*6606*	*7512*



APPENDIX D

(SIMULATION)

PISTON ROD MANUFACTURE

A

	SUPPLY				H-M-G				CHROMING				POLISHING				
OPERATION (units)	SUPPLY RATE (rods/hr)	Supply Eff'y (%)	Actual Supply (rods/hr)	Supply WIP (Rods)	H-M-G (rods/hr)	H-M-G Eff'y (%)	Actual H-M-G (rods/hr)	H-M-G WIP (Rods)	CHROMING (rods/hr)	C'g Eff'y (%)	Actual C'g (rods/hr)	Chrome WIP (Rods)	POLISHING (rods/hr)	P'g Eff'y (%)	Actual P'g (rods/hr)	KANBAN (Rods)	ASSY CELL USE
INITIAL WIP →			→	0			→	0		→		0		→	0		0
1st hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
2nd hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
3rd hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
4th hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
5th hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
6th hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
7th hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
8th hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
9th hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
10th hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
11th hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
12th hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
13th hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
14th hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
15th hr	800	1	800	800	800	1	800	800	800	1	800	800	800	1	800	800	800
END OF DAY TOTAL:			12000	800			12000	800			12000	800			12000	800	12000
			PRODUCED	CUM WIP			PRODUCED	CUM WIP			PRODUCED	CUM WIP			PRODUCED	CUM WIP	ASSY USE

NOTE:-

1. EFficiency = 100%.
2. Available Time = 15 hours.
3. All Operational Unit Rates = 800 rods/hour.
4. Initial WIP in all the staging areas is taken as zero.

APPENDIX D.1 : SIMULATION OF "IDEAL" MODEL

B

PISTON ROD MANUFACTURE

OPERATION (units)	SUPPLY: SUPPLY RATE (rods/hr)	SUPPLY: Supply Eff'y (%)	SUPPLY: Actual Supply (rods/hr)	SUPPLY: Supply WIP (Rods)	H-M-G: H-M-G (rods/hr)	H-M-G: H-M-G Eff'y (%)	H-M-G: Actual H-M-G (rods/hr)	H-M-G: H-M-G WIP (Rods)	CHROMING: CHROMING (rods/hr)	CHROMING: C'g Eff'y (%)	CHROMING: Actual C'g (rods/hr)	CHROMING: Chrome WIP (Rods)	POLISHING: POLISHING (rods/hr)	POLISHING: P'g Eff'y (%)	POLISHING: Actual P'g (rods/hr)	KANBAN (Rods)	ASSY CELL USE
INITIAL WIP				0				0				0			0		0
1st hr	1800	1	1800	1800	1232	1	1232	1232	836	1	836	836	1753	1	836	836	800
2nd hr	1800	1	1800	2368	1232	1	1232	1628	836	1	836	836	1753	1	836	872	800
3rd hr	1800	1	1800	2936	1232	1	1232	2024	836	1	836	836	1753	1	836	908	800
4th hr	1800	1	1800	3504	1232	1	1232	2420	836	1	836	836	1753	1	836	944	800
5th hr	1800	1	1800	4072	1232	1	1232	2816	836	1	838	838	1753	1	836	980	800
6th hr	1800	1	1800	4640	1232	1	1232	3212	836	1	836	836	1753	1	836	1016	800
7th hr	1800	1	1800	5208	1232	1	1232	3608	836	1	836	836	1753	1	836	1052	800
8th hr	1800	1	1800	5776	1232	1	1232	4004	836	1	836	836	1753	1	836	1088	800
9th hr	1800	1	1800	6344	1232	1	1232	4400	836	1	836	836	1753	1	836	1124	800
10th hr	1800	1	1800	6912	1232	1	1232	4796	836	1	836	836	1753	1	836	1160	800
11th hr	1800	1	1800	7480	1232	1	1232	5192	836	1	836	836	1753	1	836	1196	800
12th hr	1800	1	1800	8048	1232	1	1232	5588	836	1	836	836	1753	1	836	1232	800
13th hr	1800	1	1800	8616	1232	1	1232	5984	836	1	838	836	1753	1	836	1268	800
14th hr	1800	1	1800	9184	1232	1	1232	6380	836	1	838	836	1753	1	836	1304	800
15th hr	1800	1	1800	9752	1232	1	1232	6776	836	1	836	836	1753	1	836	1340	800
END OF DAY TOTAL:			27000	9752			18480	6776			12540	836			12540	1340	12000
			PRODUCED	CUM. WIP			PRODUCED	CUM. WIP			PRODUCED	CUM. WIP			PRODUCED	CUM. WIP	ASSY USE

NOTE:-

1. EFficiency = 100%.
2. Available Time = 15 hours.
3. Operational Unit Rates are:-
   - M-H-G = 1232 rods/hour
   - CHROME = 836 rods/hour
   - POLISH = 1753 rods/hour
4. Initial WIP in all the staging areas is taken as zero.

APPENDIX D.2 : SIMULATION OF ACTUAL RATES

C

PISTON ROD MANUFACTURE

OPERATION (units)	SUPPLY: SUPPLY RATE (rods/hr)	Supply Eff'y (%)	Actual Supply (rods/hr)	Supply WIP (Rods)	H-M-G: H-M-G (rods/hr)	H-M-G Eff'y (%)	Actual H-M-G (rods/hr)	H-M-G WIP (Rods)	CHROMING: CHROMING (rods/hr)	C'g Eff'y (%)	Actual C'g (rods/hr)	Chrome WIP (Rods)	POLISHING: POLISHING (rods/hr)	P'g Eff'y (%)	Actual P'g (rods/hr)	KANBAN (Rods)	ASSY CELL USE
INITIAL WIP				0				0				0			0		0
1st hr	1800	0.90	1620	1620	1232	0.57	702	702	836	0.55	460	460	1753	0.71	460	460	800
2nd hr	1800	0.60	1440	2358	1232	0.75	924	1166	836	0.81	677	677	1753	0.55	677	337	800
3rd hr	1800	0.75	1350	2784	1232	0.89	1096	1586	836	0.51	426	426	1753	0.92	426	-37	800
4th hr	1800	0.60	1080	2767	1232	0.91	1121	2281	836	0.85	711	711	1753	0.89	711	-126	800
5th hr	1800	0.70	1260	2906	1232	0.90	1109	2679	836	0.78	652	652	1753	0.79	652	-274	800
6th hr	1800	0.80	1440	3237	1232	0.83	1023	3049	836	0.83	694	694	1753	0.61	694	-380	800
7th hr	1800	0.67	1206	3421	1232	0.81	998	3353	836	0.76	635	635	1753	0.50	635	-545	800
8th hr	1800	0.85	1530	3953	1232	0.77	949	3667	836	0.78	652	652	1753	0.55	652	-693	800
9th hr	1800	0.90	1620	4624	1232	0.73	899	3914	836	0.95	794	794	1753	0.88	794	-698	800
10th hr	1800	0.50	900	4625	1232	0.50	616	3736	836	0.72	602	602	1753	0.73	602	-897	800
11th hr	1800	0.64	1152	5161	1232	0.74	912	4045	836	0.98	819	819	1753	0.50	819	-877	800
12th hr	1800	0.83	1494	5743	1232	0.52	641	3867	836	0.69	577	577	1753	0.84	577	-1100	800
13th hr	1800	0.75	1350	6453	1232	0.60	739	4029	836	0.86	719	719	1753	0.50	719	-1181	800
14th hr	1800	0.68	1224	6937	1232	0.75	924	4234	836	0.72	602	602	1753	0.77	602	-1380	800
15th hr	1800	0.81	1458	7471	1232	0.82	1010	4642	836	0.67	560	560	1753	0.56	560	-1619	800
END OF DAY TOTAL:			20124	7471			13663	4642			9581	560			9581	-1619	12000
			PRODUCED	CUM. WIP			PRODUCED	CUM. WIP			PRODUCED	CUM. WIP			PRODUCED	CUM. WIP	ASSY USE

NOTE:-

1. EFficiency = 100 to 50%.
2. Available Time = 15 hours.
3. Operational Unit Rates are:-
   - M-H-G = 1232 rods/hour
   - CHROME = 836 rods/hour
   - POLISH = 1753 rods/hour
4. Initial WIP in all the staging areas is taken as zero.

APPENDIX D.3 : SIMULATION WITH INEFFICIENCIES : ZERO W.I.P

D

PISTON ROD MANUFACTURE

OPERATION (units)	SUPPLY: SUPPLY RATE (rods/hr)	Supply Eff'y (%)	Actual Supply (rods/hr)	Supply WIP (Rods)	H-M-G: H-M-G (rods/hr)	H-M-G Eff'y (%)	Actual H-M-G (rods/hr)	H-M-G WIP (Rods)	CHROMING: CHROMING (rods/hr)	C'g Eff'y (%)	Actual C'g (rods/hr)	Chrome WIP (Rods)	POLISHING: POLISHING (rods/hr)	P'g Eff'y (%)	Actual P'g (rods/hr)	KANBAN (Rods)	ASSY CELL USE
INITIAL WIP				0				0				3344				2400	0
1st hr	1800	0.90	1620	1620	1232	0.57	702	702	836	0.55	460	3804	1753	0.71	1245	3645	800
2nd hr	1800	0.80	1440	2358	1232	0.75	924	1166	636	0.81	677	3236	1753	0.55	964	3809	800
3rd hr	1800	0.75	1350	2784	1232	0.89	1096	1586	836	0.51	426	2699	1753	0.92	1613	4622	800
4th hr	1800	0.60	1080	2767	1232	0.91	1121	2281	836	0.85	711	1796	1753	0.89	1560	5382	800
5th hr	1800	0.70	1260	2906	1232	0.90	1109	2679	836	0.78	652	888	1753	0.79	888	5470	800
6th hr	1800	0.80	1440	3237	1232	0.83	1023	3049	836	0.83	694	694	1753	0.61	694	5364	800
7th hr	1800	0.67	1206	3421	1232	0.81	998	3353	836	0.76	635	635	1753	0.50	635	5199	800
8th hr	1800	0.85	1530	3953	1232	0.77	949	3667	836	0.78	652	652	1753	0.55	652	5051	800
9th hr	1800	0.90	1620	4624	1232	0.73	899	3914	836	0.95	794	794	1753	0.88	794	5046	800
10th hr	1800	0.50	900	4625	1232	0.50	616	3736	836	0.72	602	602	1753	0.73	602	4847	800
11th hr	1800	0.64	1152	5161	1232	0.74	912	4045	836	0.98	819	819	1753	0.50	819	4867	800
12th hr	1800	0.83	1494	5743	1232	0.52	641	3867	836	0.69	577	577	1753	0.84	577	4644	800
13th hr	1800	0.75	1350	6453	1232	0.60	739	4029	836	0.86	719	719	1753	0.50	719	4563	800
14th hr	1800	0.68	1224	6937	1232	0.75	924	4234	836	0.72	602	602	1753	0.77	602	4364	800
15th hr	1800	0.81	1458	7471	1232	0.82	1010	4642	836	0.67	560	560	1753	0.56	560	4125	800
END OF DAY TOTAL:			20124	7471			13663	4642			9581	560			12925	4125	12000
			PRODUCED	CUM. WIP			PRODUCED	CUM. WIP			PRODUCED	CUM. WIP			PRODUCED	CUM. WIP	ASSY USE

NOTE:-

1. EFficiency = 100 to 50%.
2. Available Time = 15 hours.
3. Operational Unit Rates are:-
   M-H-G = 1232 rods/hour
   CHROME = 836 rods/hour
   POLISH = 1753 rods/hour
4. Increased WIP

APPENDIX D.4 : SIMULATION WITH INEFFICIENCIES : INCREASED W.I.P

APPENDIX D.5 : 17, 20, 22, 25 & 28,5 mm PISTON ROD DATA

17mm	ROD	QTY	LENGTH	TOTAL LTH
	324025-11	250	250	62500
	324025-16	200	275	55000
	TOTALS	**450**	**525**	**117500**
	COUNT	**2**	**Max. Length:**	**275**
	Ave. length	**261**	**Min. Length:**	**250**

20mm	ROD	QTY	LENGTH	TOTAL LTH
	304025	1000	431	431000
	314268	1200	364	436800
	314330	1500	353	529500
	314538	500	350	175000
	314560	400	404	161600
	314570	1500	359	538500
	314571	400	457	182800
	314636	600	401	240600
	314672	1300	501	651300
	314680	800	370	296000
	314702	300	348	104400
	314703	300	381	114300
	314704	200	375	75000
	314705	500	396	198000
	314707	500	429	214500
	314711	1000	340	340000
	314713	200	394	78800
	314714	1800	404	727200
	314729	1200	389	466800
	314730	1100	411	452100
	314745	600	469	281400
	344610	400	374	149600
	344666	1200	421	505200
	383147	200	467	93400
	TOTALS	**18700**	**9588**	**7443800**
	COUNT	**24**	**Max. Length:**	**501**
	Ave. length	**398**	**Min. Length:**	**340**

22mm	ROD	QTY	LENGTH	TOTAL LTH
	314102	2400	408	979200
	314246	300	489	146700
	314248	200	421	84200
	314258	200	423	84600
	314329	1500	367	550500
	314614	300	370	111000
	348087	450	400	180000
	348180	1200	400	480000
	348186	150	400	60000
	383018	200	377	75400
	383022	300	461	138300
	383139	200	423	84600
	383189	1300	385	500500
	383233	1400	406	568400
	383238	1400	370	518000
	383249	800	366	292800
	383271	200	506	101200
	383281	200	479	95800
	TOTAL	**12700**	**7451**	**5051200**
	COUNT	**18**	**Max. Length:**	**506**
	AVERAGE	**398**	**Min. Length:**	**366**

25 mm	ROD	QTY	LENGTH	TOTAL LTH
	364041	300	373	111900
	348141	10	402	4020
	TOTAL	**310**	**775**	**115920**
	COUNT	**2**	**Max. Length:**	**402**
	AVERAGE	**374**	**Min. Length:**	**373**

28,5 mm	ROD	QTY	LENGTH	TOTAL LTH
	348512	10	464	4640
	TOTAL	**10**	**464**	**4640**
	COUNT	**1**	**Max. Length:**	**464**
	AVERAGE	**464**	**Min. Length:**	**464**

THE AVERAGE LENGTH FOR SMALL RODS IS: **379**

THE TOTAL WEEKLY PRODUCTION REQUIREMENT IS : approx. 32170 small rods.

DIAMETER	AVE. LENGTH	WEEKS PROD. QTY.
DIA 17	261	450
DIA. 20	398	18700
DIA. 22	398	12700
DIA. 25	374	310
DIA. 28,5	464	10
OVERALL:	**379**	**32170**

MAX. LENGTH: **506**
MIN. LENGTH: **250**

	DIA 17	DIA. 20	DIA. 22	DIA. 25	DIA. 28,5
Max. Length:	**275**	**501**	**506**	**402**	**464**
Min. Length:	**250**	**340**	**366**	**373**	**464**

APPENDIX D.6 : 12,7 & 14 mm PISTON ROD DATA

12,7mm	ROD	QUANTITY	LENGTH	TOTAL LENGTH
	304106	200	331	66200
	314099-21	250	150	37500
	314099-22	1000	153	153000
	314099-24	1700	159	270300
	314099-25	400	163	65200
	314099-27	2900	169	490100
	314099-29	1500	175	262500
	314099-30	1000	178	178000
	314099-31	200	182	36400
	314099-38	600	204	122400
	314099-43	1500	220	330000
	314099-45	300	226	67800
	314099-51	2000	245	490000
	314099-54	600	255	153000
	314099-57	1500	264	396000
	314099-58	600	267	160200
	314099-60	500	274	137000
	314099-61	800	277	221600
	314099-62	400	280	112000
	314099-66	800	293	234400
	314099-71	800	309	247200
	314099-73	600	315	189000
	314099-74	900	318	286200
	314099-48	500	235	117500
	TOTALS	**21550**	**5642**	**4823500**
	COUNT	**24**	**Max. Length:**	**331**
	Ave. length	**224**	**Min. Length:**	**150**

14mm	ROD	QUANTITY	LENGTH	TOTAL LENGTH
	364014-05	200	206	41200
	364014-07	300	209	62700
	364014-16	250	238	59500
	364014-18	200	254	50800
	364014-19	1000	260	260000
	364014-21	200	263	52600
	364014-23	200	279	55800
	364014-34	200	266	53200
	364014-35	200	257	51400
	364014-38	300	247	74100
	364022-2	300	158	47400
	364022-4	300	149	44700
	364116	200	241	48200
	364142	200	275	55000
	364163-1	100	329	32900
	TOTALS	**4150**	**3631**	**989500**
	COUNT	**15**	**Max. Length:**	**329**
	Ave. length	**238**	**Min. Length:**	**149**

APPENDIX D.7 : 11, 8, 10, 13 & 15 mm PISTON ROD DATA

11mm	ROD	QUANTITY	LENGTH	TOTAL LENGTH
	304050-31	800	180	144000
	304094	1600	363	580800
	304104	2100	448	940800
	304140-01	200	85	17000
	344569	1300	390	507000
	344573	400	355	142000
	344609-1	1200	293	351600
	344637	1000	370	370000
	344649-1	200	249	49800
	344665	1200	326	391200
	348016-53	500	228	114000
	348288-45	500	208	104000
	TOTALS	11000	3495	3712200
	COUNT	12	Max. Length:	448
	Ave. length	337	Min. Length:	85

8mm	ROD	QUANTITY	LENGTH	TOTAL LENGTH
	358066-05	600	242	145200
	358066-09	750	125	93750
	358101-03	500	173	86500
	358101-04	1000	198	198000
	358101-05	250	223	55750
	358101-06	2000	251	502000
	358101-07	450	266	119700
	358101-08	250	275	68750
	358101-17	900	136	122400
	TOTALS	6700	1889	1392050
	COUNT	9	Max. Length:	275
	Ave. length	208	Min. Length:	125

10mm	ROD	QUANTITY	LENGTH	TOTAL LENGTH
	358254-61	250	499	124750
	358278-02	200	350	70000
	358278-11	600	167	100200
	358278-12	1500	250	375000
	TOTALS	2550	1266	669950
	COUNT	4	Max. Length:	499
	Ave. length	263	Min. Length:	167

13mm	ROD	QUANTITY	LENGTH	TOTAL LENGTH
	383125	150	394	59100
	TOTALS	150	394	59100
	COUNT	1	Max. Length:	394
	Ave. length	394	Min. Length:	394

15mm	ROD	QUANTITY	LENGTH	TOTAL LENGTH
	383091	300	275	82500
	383290	300	273	81900
	TOTALS	600	548	164400
	COUNT	2	Max. Length:	275
	Ave. length	274	Min. Length:	273

THE AVERAGE LENGTH FOR SMALL RODS IS: 277mm.

THE TOTAL WEEKLY PRODUCTION REQUIREMENT IS : approx. 46700 small rods.

DIAMETER	AVE. LENGTH	WEEKS PROD. QTY.
DIA 12,7	Min. Length:	21550
DIA. 14	Min. Length:	4150
DIA. 11	Min. Length:	11000
DIA. 8	Min. Length:	6700
DIA. 10	Min. Length:	2550
DIA. 13	Min. Length:	150
DIA. 15	Min. Length:	600
OVERALL:	0	46700

MAX. LENGTH: 499
MIN. LENGTH: 85

	DIA 12,7	DIA. 14	DIA. 11	DIA. 8	DIA. 10	DIA. 13	DIA. 15
Max. Length:	331	329	448	275	499	394	275
Min. Length:	150	149	85	125	167	394	273

MACHINING-HARDEN-GRIND

	VARIETY FACTORS (DOWNTIME):	RATE (rods/hr)	DOWNTIME (hrs) DAY 1	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 2	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 3	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 4	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 5	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 6	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 7	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 8	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 9	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 10	PROD. LOSS (Rods/day)
1	CHANGEOVERS	474	1.00	474	1.50	711		0	2.25	1066.5		0		0	1.75	829.5		0	1.25	592.5		0
2	DRESS & SET (REG'G & GRIND WHEEL)	474	1.00	474	2.25	1066.5	3.75	1777.5	1.25	592.5	1.75	829.5	1.25	592.5	1.50	711	1.75	829.5	1.25	592.5	1.50	711
3	HARDENER-COIL BURN	474		0		0		0		0		0		0	1.00	474	1.50	711	0.75	355.5		0
4	STRAIGHTENING	474		0		0		0		0		0		0		0		0		0		0
5	VICKERS FIRST-OFF	474	0.50	237		0		0	0.25	118.5	0.33	156.42		0	0.50	237	0.33	156.42	0.50	237		0
6	TRUCKING	474		0		0		0	0.25	118.5	0.35	165.9		0		0	0.25	118.5		0		0
7	MAINTENANCE	474	0.75	355.5	0.50	237	1.00	474	0.15	71.1	0.40	189.6	1.25	592.5		0	1.75	829.5	0.25	118.5	0.25	118.5
8	CHANGE GRINDING WHEEL	474		0		0		0		0		0		0		0		0		0	5.15	2441.1
9	UNPLANNED MEETING	474		0		0		0	1	474		0		0		0	0.5	237		0		0
10	SLOW OP : DEPTH	474	1.25	592.5	0.67	317.58		0		0		0		0		0		0		0		0
11	CHANGE CLOCKS	474		0		0		0		0		0	0.25	118.5		0		0	1.25	592.5		0
12	WAIT ON TOOLING	474		0		0		0		0		0	0.15	71.1		0		0	0.5	237		0
13	REWORK	474	1.25	592.5		0	0.5	237		0	1	474		0		0		0	0.75	355.5	0.5	237
14	CLEAN QUENCH RING	474		0	0.5	237		0		0		0		0		0		0		0		0
15	OPERATOR LATE	474	0.25	118.5		0		0	0.15	71.1		0		0		0		0		0	0.75	355.5
16	OPERATOR ABSENT	474		0		0		0		0		0		0		0		0		0		0
17	FINISH PROBLEM	474	1	474	0.3	142.2	1	474	0.25	118.5	0.5	237	0.75	355.5	1.25	592.5	1.25	592.5	0.5	237	0.5	237
18	SET HARDENER	474		0		0		0	0.5	237		0		0	0.75	355.5		0		0		0
19	REPAIR COILS	474		0		0		0		0	0.75	355.5		0	1	474		0		0		0
20	OTHER	474		0		0		0		0		0		0		0		0		0		0
	POSSIBLE PRODUCTION (UNITS/DAY):	474	15	7110	15	7110	15	7110	15	7110	15	7110	15	7110	15	7110	15	7110	15	7110	15	7110
	TOTAL DOWNTIME (HOURS):		7		6		6		6		5		4		8		7		7		9	
	TOTAL PRODUCTION LOSS (UNITS/DAY):			3318		2711		2963		2868		2408		1730		3674		3474		3318		4100
	ACTUAL PRODUCTION FOR DAY (UNITS/DAY):			3792		4399		4148		4242		4702		5380		3437		3636		3792		3010

	VARIETY FACTORS (DOWNTIME):	RATE (rods/hr)	DOWNTIME (hrs) DAY 11	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 12	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 13	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 14	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 15	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 16	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 17	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 18	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 19	PROD. LOSS (Rods/day)	DOWNTIME (hrs) DAY 20	PROD. LOSS (Rods/day)
1	CHANGEOVERS	474		0	1.75	829.5	1.50	711		0		0	1.50	711		0	0.75	355.5		0		0
2	DRESS & SET	474	0.75	355.5	1.50	711	2.00	948	2.50	1185	3.00	1422	1.25	592.5	1.00	474	1.25	592.5	1.25	592.5	1.25	592.5
3	HARDENER-COIL BURN	474		0		0		0	0.33	156.42		0		0		0		0		0		0
4	STRAIGHTENING	474	0.75	355.5		0	0.50	237		0	1.50	711		0		0		0		0		0
5	VICKERS FIRST-OFF	474		0	0.25	118.5	0.50	237		0		0	0.25	118.5		0		0		0		0
6	TRUCKING	474		0		0		0		0		0	0.33	156.42		0		0		0	0.25	118.5
7	MAINTENANCE	474	0.75	355.5	0.50	237	1.25	592.5	1.75	829.5		0	1.25	592.5	0.75	355.5	2.00	948	1.00	474	1.50	711
8	CHANGE GRINDING WHEEL	474		0		0		0		0		0		0		0		0		0		0
9	UNPLANNED MEETING	474		0		0		0	0.5	237		0		0		0	0.5	237	2	948	0.25	118.5
10	SLOW OP : DEPTH	474		0		0		0		0		0		0		0		0		0	0.75	355.5
11	CHANGE CLOCKS	474		0		0		0		0		0		0		0		0		0		0
12	WAIT ON TOOLING	474		0	0.3	142.2		0		0		0		0		0		0		0		0
13	REWORK	474		0		0		0		0		0		0	4.25	2014.5		0		0		0
14	CLEAN QUENCH RING	474	1.5	711		0		0		0		0		0		0		0		0		0
15	OPERATOR LATE	474		0		0		0		0		0		0		0	0.33	156.42		0		0
16	OPERATOR ABSENT	474		0		0		0		0		0		0		0		0		0		0
17	FINISH PROBLEM	474	0.5	237	0.33	156.42	0.25	118.5	0.5	237	1.33	630.42	0.5	237	1	474	1.25	592.5	0.25	118.5	1.75	829.5
18	SET HARDENER	474		0		0		0		0		0		0		0		0		0		0
19	REPAIR COILS	474		0		0		0		0		0		0		0		0		0		0
20	OTHER	474		0		0		0		0		0		0		0		0		0		0
	POSSIBLE PRODUCTION (UNITS/DAY):	474	15	7110	15	7110	15	7110	15	7110	15	7110	15	7110	15	7110	15	7110	15	7110	15	7110
	TOTAL DOWNTIME (HOURS):		4		5		6		6		6		5		7		6		5		6	
	TOTAL PRODUCTION LOSS (UNITS/DAY):			2015		2195		2844		2645		2763		2408		3318		2882		2133		2726
	ACTUAL PRODUCTION FOR DAY (UNITS/DAY):			5096		4915		4266		4465		4347		4702		3792		4228		4977		4385

AVE DOWNTIME:	5.96	MAX DOWNTIME:	9	MIN DOWNTIME:	4
AVE PROD LOSS:	2825	MAX PROD LOSS:	4100	MIN PROD LOSS:	1730
AVE ACTUAL PROD	4285	MAX ACTUAL PROD:	5380	MIN ACTUAL PROD:	3010

APPENDIX D.8 : MODEL B - SIMULATION OF VARIETY IN BIG RODS M-H-G

MACHINING-HARDEN-GRIND

	VARIETY FACTORS (DOWNTIME):	RATE (rods/hr)	DAY 1 DOWNTIME (hrs)	DAY 1 PROD. LOSS (Rods/day)	DAY 2 DOWNTIME (hrs)	DAY 2 PROD. LOSS (Rods/day)	DAY 3 DOWNTIME (hrs)	DAY 3 PROD. LOSS (Rods/day)	DAY 4 DOWNTIME (hrs)	DAY 4 PROD. LOSS (Rods/day)	DAY 5 DOWNTIME (hrs)	DAY 5 PROD. LOSS (Rods/day)	DAY 6 DOWNTIME (hrs)	DAY 6 PROD. LOSS (Rods/day)	DAY 7 DOWNTIME (hrs)	DAY 7 PROD. LOSS (Rods/day)	DAY 8 DOWNTIME (hrs)	DAY 8 PROD. LOSS (Rods/day)	DAY 9 DOWNTIME (hrs)	DAY 9 PROD. LOSS (Rods/day)	DAY 10 DOWNTIME (hrs)	DAY 10 PROD. LOSS (Rods/day)
1	CHANGEOVERS	720	1.00	720	1.50	1080		0	2.25	1620		0		0	1.75	1260		0	1.25	900		0
2	DRESS & SET (REG'G & GRIND WHEEL)	720	1.00	720	2.25	1620	3.75	2700	1.25	900	1.75	1260	1.25	900	1.50	1080	1.75	1260	1.25	900	1.50	1080
3	HARDENER-COIL BURN	720		0		0		0		0		0		0	1.00	720	1.50	1080	0.75	540		0
4	STRAIGHTENING	720		0		0		0		0		0		0		0		0		0		0
5	VICKERS FIRST-OFF	720	0.50	360		0		0	0.25	180	0.33	237.6		0	0.50	360	0.33	237.6	0.50	360		0
6	TRUCKING	720		0		0		0	0.25	180	0.35	252		0		0	0.25	180		0		0
7	MAINTENANCE	720	0.75	540	0.50	360	1.00	720	0.15	108	0.40	288	1.25	900		0	1.75	1260	0.25	180	0.25	180
8	CHANGE GRINDING WHEEL	720		0		0		0		0		0		0		0		0		0	5.15	3708
9	UNPLANNED MEETING	720		0		0		0	1	720		0		0		0	0.5	360		0		0
10	SLOW OP : DEPTH	720	1.25	900	0.67	482.4		0		0		0		0		0		0		0		0
11	CHANGE CLOCKS	720		0		0		0		0		0	0.25	180		0		0	1.25	900		0
12	WAIT ON TOOLING	720		0		0		0		0		0	0.15	108		0		0	0.5	360		0
13	REWORK	720	1.25	900		0	0.5	360		0	1	720		0		0		0	0.75	540	0.5	360
14	CLEAN QUENCH RING	720		0	0.5	360		0		0		0		0		0		0		0		0
15	OPERATOR LATE	720	0.25	180		0		0	0.15	108		0		0		0		0		0	0.75	540
16	OPERATOR ABSENT	720		0		0		0		0		0		0		0		0		0		0
17	FINISH PROBLEM	720	1	720	0.3	216	1	720	0.25	180	0.5	360	0.75	540	1.25	900	1.25	900	0.5	360	0.5	360
18	SET HARDENER	720		0		0		0	0.5	360		0		0	0.75	540		0		0		0
19	REPAIR COILS	720		0		0		0		0	0.75	540		0	1	720		0		0		0
20	OTHER	720		0		0		0		0		0		0		0		0		0		0
	POSSIBLE PRODUCTION (UNITS/DAY):	720	15	10800	15	10800	15	10800	15	10800	15	10800	15	10800	15	10800	15	10800	15	10800	15	10800
	TOTAL DOWNTIME (HOURS):		7		6		6		6		5		4		8		7		7		9	
	TOTAL PRODUCTION LOSS (UNITS/DAY):			5040		4118		4500		4356		3658		2628		5580		5278		5040		6228
	ACTUAL PRODUCTION FOR DAY (UNITS/DAY):			5760		6682		6300		6444		7142		8172		5220		5522		5760		4572

	VARIETY FACTORS (DOWNTIME):	RATE (rods/hr)	DAY 11 DOWNTIME (hrs)	DAY 11 PROD. LOSS (Rods/day)	DAY 12 DOWNTIME (hrs)	DAY 12 PROD. LOSS (Rods/day)	DAY 13 DOWNTIME (hrs)	DAY 13 PROD. LOSS (Rods/day)	DAY 14 DOWNTIME (hrs)	DAY 14 PROD. LOSS (Rods/day)	DAY 15 DOWNTIME (hrs)	DAY 15 PROD. LOSS (Rods/day)	DAY 16 DOWNTIME (hrs)	DAY 16 PROD. LOSS (Rods/day)	DAY 17 DOWNTIME (hrs)	DAY 17 PROD. LOSS (Rods/day)	DAY 18 DOWNTIME (hrs)	DAY 18 PROD. LOSS (Rods/day)	DAY 19 DOWNTIME (hrs)	DAY 19 PROD. LOSS (Rods/day)	DAY 20 DOWNTIME (hrs)	DAY 20 PROD. LOSS (Rods/day)
1	CHANGEOVERS	720		0	1.75	1260	1.50	1080		0		0	1.50	1080		0	0.75	540		0		0
2	DRESS & SET	720	0.75	540	1.50	1080	2.00	1440	2.50	1800	3.00	2160	1.25	900	1.00	720	1.25	900	1.25	900	1.25	900
3	HARDENER-COIL BURN	720		0		0		0	0.33	237.6		0		0		0		0		0		0
4	STRAIGHTENING	720	0.75	540		0	0.50	360		0	1.50	1080		0		0		0		0		0
5	VICKERS FIRST-OFF	720		0	0.25	180	0.50	360		0		0	0.25	180		0		0		0		0
6	TRUCKING	720		0		0		0		0		0	0.33	237.6		0		0		0	0.25	180
7	MAINTENANCE	720	0.75	540	0.50	360	1.25	900	1.75	1260		0	1.25	900	0.75	540	2.00	1440	1.00	720	1.50	1080
8	CHANGE GRINDING WHEEL	720		0		0		0		0		0		0		0		0		0		0
9	UNPLANNED MEETING	720		0		0		0	0.5	360		0		0		0	0.5	360	2	1440	0.25	180
10	SLOW OP : DEPTH	720		0		0		0		0		0		0		0		0		0	0.75	540
11	CHANGE CLOCKS	720		0		0		0		0		0		0		0		0		0		0
12	WAIT ON TOOLING	720		0	0.3	216		0		0		0		0		0		0		0		0
13	REWORK	720		0		0		0		0		0		0	4.25	3060		0		0		0
14	CLEAN QUENCH RING	720	1.5	1080		0		0		0		0		0		0		0		0		0
15	OPERATOR LATE	720		0		0		0		0		0		0		0	0.33	237.6		0		0
16	OPERATOR ABSENT	720		0		0		0		0		0		0		0		0		0		0
17	FINISH PROBLEM	720	0.5	360	0.33	237.6	0.25	180	0.5	360	1.33	957.6	0.5	360	1	720	1.25	900	0.25	180	1.75	1260
18	SET HARDENER	720		0		0		0		0		0		0		0		0		0		0
19	REPAIR COILS	720		0		0		0		0		0		0		0		0		0		0
20	OTHER	720		0		0		0		0		0		0		0		0		0		0
	POSSIBLE PRODUCTION (UNITS/DAY):	720	15	10800	15	10800	15	10800	15	10800	15	10800	15	10800	15	10800	15	10800	15	10800	15	10800
	TOTAL DOWNTIME (HOURS):		4		5		6		6		6		5		7		6		5		6	
	TOTAL PRODUCTION LOSS (UNITS/DAY):			3060		3334		4320		4018		4198		3658		5040		4378		3240		4140
	ACTUAL PRODUCTION FOR DAY (UNITS/DAY):			7740		7466		6480		6782		6602		7142		5760		6422		7560		6660

AVE DOWNTIME:	5.96	MAX DOWNTIME:	9	MIN DOWNTIME:	4
AVE PROD LOSS:	4290	MAX PROD LOSS:	6228	MIN PROD LOSS:	2628
AVE ACTUAL PROD	6510	MAX ACTUAL PROD:	8172	MIN ACTUAL PROD:	4572

APPENDIX D.9 : SIMULATION OF VARIETY WITH SHORTEST ROD

MACHINING-HARDEN-GRIND

		RATE (rods/hr)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)
	VARIETY FACTORS (DOWNTIME):		DAY 1		DAY 2		DAY 3		DAY 4		DAY 5		DAY 6		DAY 7		DAY 8		DAY 9		DAY 10	
1	CHANGEOVERS	355	1.00	355	1.50	532.5		0	2.25	798.75		0		0	1.75	621.25		0	1.25	443.75		0
2	DRESS & SET (REG'G & GRIND WHEEL)	355	1.00	355	2.25	798.75	3.75	1331.25	1.25	443.75	1.75	621.25	1.25	443.75	1.50	532.5	1.75	621.25	1.25	443.75	1.50	532.5
3	HARDENER-COIL BURN	355		0		0		0		0		0		0	1.00	355	1.50	532.5	0.75	266.25		0
4	STRAIGHTENING	355		0		0		0		0		0		0		0		0		0		0
5	VICKERS FIRST-OFF	355	0.50	177.5		0		0	0.25	88.75	0.33	117.15		0	0.50	177.5	0.33	117.15	0.50	177.5		0
6	TRUCKING	355		0		0		0	0.25	88.75	0.35	124.25		0		0	0.25	88.75		0		0
7	MAINTENANCE	355	0.75	266.25	0.50	177.5	1.00	355	0.15	53.25	0.40	142	1.25	443.75		0	1.75	621.25	0.25	88.75	0.25	88.75
8	CHANGE GRINDING WHEEL	355		0		0		0		0		0		0		0		0		0	5.15	1828.25
9	UNPLANNED MEETING	355		0		0		0	1	355		0		0		0	0.5	177.5		0		0
10	SLOW OP : DEPTH	355	1.25	443.75	0.67	237.85		0		0		0		0		0		0		0		0
11	CHANGE CLOCKS	355		0		0		0		0		0	0.25	88.75		0		0	1.25	443.75		0
12	WAIT ON TOOLING	355		0		0		0		0		0	0.15	53.25		0		0	0.5	177.5		0
13	REWORK	355	1.25	443.75		0	0.5	177.5		0	1	355		0		0		0	0.75	266.25	0.5	177.5
14	CLEAN QUENCH RING	355		0	0.5	177.5		0		0		0		0		0		0		0		0
15	OPERATOR LATE	355	0.25	88.75		0		0	0.15	53.25		0		0		0		0		0	0.75	266.25
16	OPERATOR ABSENT	355		0		0		0		0		0		0		0		0		0		0
17	FINISH PROBLEM	355	1	355	0.3	106.5	1	355	0.25	88.75	0.5	177.5	0.75	266.25	1.25	443.75	1.25	443.75	0.5	177.5	0.5	177.5
18	SET HARDENER	355		0		0		0	0.5	177.5		0		0	0.75	266.25		0		0		0
19	REPAIR COILS	355		0		0		0		0	0.75	266.25		0	1	355		0		0		0
20	OTHER	355		0		0		0		0		0		0		0		0		0		0
	POSSIBLE PRODUCTION (UNITS/DAY):	355	15	5325	15	5325	15	5325	15	5325	15	5325	15	5325	15	5325	15	5325	15	5325	15	5325
	TOTAL DOWNTIME (HOURS):		7		6		6		6		5		4		8		7		7		9	
	TOTAL PRODUCTION LOSS (UNITS/DAY):			2485		2031		2219		2148		1803		1296		2751		2602		2485		3071
	ACTUAL PRODUCTION FOR DAY (UNITS/DAY):			2840		3294		3106		3177		3522		4029		2574		2723		2840		2254

		RATE (rods/hr)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)	DOWNTIME (hrs)	PROD. LOSS (Rods/day)
	VARIETY FACTORS (DOWNTIME):		DAY 11		DAY 12		DAY 13		DAY 14		DAY 15		DAY 16		DAY 17		DAY 18		DAY 19		DAY 20	
1	CHANGEOVERS	355		0	1.75	621.25	1.50	532.5		0		0	1.50	532.5		0	0.75	266.25		0		0
2	DRESS & SET	355	0.75	266.25	1.50	532.5	2.00	710	2.50	887.5	3.00	1065	1.25	443.75	1.00	355	1.25	443.75	1.25	443.75	1.25	443.75
3	HARDENER-COIL BURN	355		0		0		0	0.33	117.15		0		0		0		0		0		0
4	STRAIGHTENING	355	0.75	266.25		0	0.50	177.5		0	1.50	532.5		0		0		0		0		0
5	VICKERS FIRST-OFF	355		0	0.25	88.75	0.50	177.5		0		0	0.25	88.75		0		0		0		0
6	TRUCKING	355		0		0		0		0		0	0.33	117.15		0		0		0	0.25	88.75
7	MAINTENANCE	355	0.75	266.25	0.50	177.5	1.25	443.75	1.75	621.25		0	1.25	443.75	0.75	266.25	2.00	710	1.00	355	1.50	532.5
8	CHANGE GRINDING WHEEL	355		0		0		0		0		0		0		0		0		0		0
9	UNPLANNED MEETING	355		0		0		0	0.5	177.5		0		0		0	0.5	177.5	2	710	0.25	88.75
10	SLOW OP : DEPTH	355		0		0		0		0		0		0		0		0		0	0.75	266.25
11	CHANGE CLOCKS	355		0		0		0		0		0		0		0		0		0		0
12	WAIT ON TOOLING	355		0	0.3	106.5		0		0		0		0		0		0		0		0
13	REWORK	355		0		0		0		0		0		0	4.25	1508.75		0		0		0
14	CLEAN QUENCH RING	355	1.5	532.5		0		0		0		0		0		0		0		0		0
15	OPERATOR LATE	355		0		0		0		0		0		0		0	0.33	117.15		0		0
16	OPERATOR ABSENT	355		0		0		0		0		0		0		0		0		0		0
17	FINISH PROBLEM	355	0.5	177.5	0.33	117.15	0.25	88.75	0.5	177.5	1.33	472.15	0.5	177.5	1	355	1.25	443.75	0.25	88.75	1.75	621.25
18	SET HARDENER	355		0		0		0		0		0		0		0		0		0		0
19	REPAIR COILS	355		0		0		0		0		0		0		0		0		0		0
20	OTHER	355		0		0		0		0		0		0		0		0		0		0
	POSSIBLE PRODUCTION (UNITS/DAY):	355	15	5325	15	5325	15	5325	15	5325	15	5325	15	5325	15	5325	15	5325	15	5325	15	5325
	TOTAL DOWNTIME (HOURS):		4		5		6		6		6		5		7		6		5		6	
	TOTAL PRODUCTION LOSS (UNITS/DAY):			1509		1644		2130		1981		2070		1803		2485		2158		1598		2041
	ACTUAL PRODUCTION FOR DAY (UNITS/DAY):			3816		3681		3195		3344		3255		3522		2840		3167		3728		3284

AVE DOWNTIME:	5.96	MAX DOWNTIME:	9	MIN DOWNTIME:	4
AVE PROD LOSS:	2115	MAX PROD LOSS:	3071	MIN PROD LOSS:	1296
AVE ACTUAL PROD	3210	MAX ACTUAL PROD:	4029	MIN ACTUAL PROD:	2254

APPENDIX D.10 : SIMULATION OF VARIETY WITH LONGEST ROD