AN OPERATIONAL MANAGEMENT MODEL FOR A COAL MINING PRODUCTION UNIT

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SUMMARY

Title: An operational management model for a coal mining production unit.
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It is expected from highly technical first line supervisors to manage an underground coal mining production unit and to reach stretched targets when they have very little operational management skills. A myriad of operational management philosophies are available that were not developed for a mining environment as such. These philosophies are focused on company level implementation and not on production unit level. To be used in the mining production unit is therefore necessary to adapt these philosophies. The first line supervisor needs an operational management business model that will assist and guide him/her in managing the production unit in order that production, cost and quality targets can be achieved. The first line supervisor must also be able to adapt quickly to changing requirements. The answer lies in the application of current world-class operational management philosophies to the management of the coal mining production unit. In the thesis an operational management model to assist the first line supervisor is derived from current operational management philosophies.

The research approach that was followed is:

- Current world-class operational management philosophies were investigated.
- The management philosophies to be analysed in detail were identified as Total Quality Management, Just-in-Time and Theory of Constraints.
- From these philosophies the key elements to be used in the development of an operational management model for an underground mining production unit were determined.
- These key elements were used as building blocks to develop the mining model.
- The developed model was illustrated utilising real data from a production section.

The developed mining model provides a framework for managing the production unit on a day-to day basis, but with a long-term vision. To achieve this a strategic and operational

level exist in the model, with different focus areas. The purpose of the strategic level is to focus the unit on the requirements of the customer, and to plan for a longer time horizon. The operational level assists the first line supervisor in managing the day-to-day operations of the production unit. The model also provides tools to continuously monitor and improve the performance of the unit. For any new initiative to be successful proper planning, training and an implementation plan are necessary. The planning phase includes change management and creating awareness of the mining model. Training consists of various training modules, presented over the implementation period. Each production unit that is introduced to the mining model follows a predetermined implementation plan with constant feedback on the progress made. The support from top management is actively demonstrated during the implementation period. A phased in rollout of the mining model is prescribed, i.e. not all production units will be introduced to the model at once.

The research highlighted the similarities that exist between the three operational management philosophies, leading to a cohesive set of building blocks for the mining model. Where differences between the three philosophies existed the most appropriate approach was selected, based on the evaluation of the elements. This highlights the impact that the evaluation process has on the design of the mining model, and forces one to scrutinise the process for ambiguity and partiality. This is one area where the research can be refined. It is suggested that a cross-functional team is used in the evaluation and design process.

To conclude, the mining model developed and illustrated provides the coal mining company with a tool that will assist a highly skilled technical first line supervisor with operational management practices based on world class operational management philosophies.

Key words: Just-in-Time; Theory of Constraints; Total Quality management; mining; operational; management; model; strategic; continuous; improvement

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1 INTRODUCTION

The research will be focused on the management practices and continuous improvement tools that a first line supervisor of a production unit in an underground coal mine needs, compared to what is available in the management scholarship environment.

1.1 RESEARCH ENVIRONMENT

An underground coal mine consists of support functions, such as financial, human resources and information management departments, and the technical functions. These technical functions include the production units, maintenance units and the environmental management department. A typical production unit has the following resources: approximately 15 team members per shift, one continuous miner (the equipment that cuts the coal from the coal face) and three shuttle cars that transport the coal from the continuous miner to the continuous feeder (which feeds the coal onto the network of conveyor belts). The production unit also includes electrical switchgear and various other smaller equipment used in the production process. The team members are a combination of engineering and production personnel. The first line supervisor for the section can be from either the engineering of production field: the shift boss or the foreman. Roving maintenance teams also exist: they would have the responsibility for scheduled maintenance activities as opposed to the section maintenance personnel who would be responsible for the first line maintenance duties. A small mine (approximately 3.5 - 4 million tons a year) will have 4-5 production sections.

1.2 CHALLENGES FACING THE FIRST LINE SUPERVISOR

In the competitive coal mining industry it is important for a mining company to be flexible, lean, and profit driven. Coal prices can vary quite substantially from year to year placing enormous pressure on the bottom line of coal mining companies. The coal mining company needs to adapt to fluctuations in demand for coal and the type of coal quality needed (i.e. the percentage fine coal allowed, or the heat value (for power stations), or the percentage contamination allowed (non-carbon elements in the coal) very quickly in order to stay profitable and to sustain profits over the long term. This creates pressure on the mine to continuously improve and stay lean, but still produce coal that is according to the quality and demand requirements.

To be able to adapt quickly, the coal mining company must be focused and business orientated with the end goal of the company in mind – to make profit now and in the future. This implies that all the employees of the mining company must be working towards this common goal and must be able to adapt quickly to the changing environment of the coal market. The top management team must set the strategic direction and the middle management team needs to implement specific actions to follow the strategy. This implies that middle management and the first line supervisors need to have the necessary skills to adapt quickly, make the necessary changes and then track progress continuously. The first line supervisors need to manage their production units on sound business principles using current world-class management tools and techniques in order to continuously improve the business.

The current reality is that most of the first line supervisors of production units are highly skilled in the technical and operational aspects of running a coal mining unit but lack in specialised operational management skills. They are therefore normally not adequately equipped to deal with the changing and stretched demands placed on them from middle management. The first line supervisor has a need for an operational management model that will assist him/her in running and continuously improving the production unit as a productive and profitable unit in the long term based on principles from accepted operational management philosophies.

There are many management philosophies that are used successfully in mainly manufacturing companies. These are for example lean manufacturing, quality management, constraint management, BPR (business process re-engineering) etc. These management philosophies all incorporate specific principles, operating rules and techniques and problem solving methods. For each philosophy many textbooks, articles, and case studies have been written on the subject matter. Therefore a detailed and very comprehensive information base is available for each management philosophy. Each philosophy has a different impact on how functional and operational activities must be carried out.

The management philosophies described are mostly developed for use in a manufacturing company. The principles, techniques, guidelines and tools refer to a factory environment with fixed workstations, the transformation of raw materials into final products and the distribution of these final products. The philosophies assume a company wide implementation and are more than just management tools – it is a total perspective of the way that business is done at the company.

It is important to note that there are physical, logistical and management differences between a coal mining production unit and a manufacturing company. For example in a mining unit the physical environment presents certain boundaries and increased safety risks that you would not normally find in a manufacturing plant. There are also many logistical challenges that face the maintenance team of a mining production unit that are not found in a manufacturing plant. These are for example the physical environment in which maintenance must be done, the distance from workshops and the physical bulkiness and size of the equipment to be maintained. The scale of operations of a mining production unit is also smaller in a mining production unit than in a manufacturing company, specifically if the number of personnel, the number of equipment and the product diversity are compared. It therefore implies that the implementation of one of the well known, widely used and accepted operational management philosophies in an underground coal mining production unit would need to be adapted to allow for the differences.

To summarise: there is a need in coal mining companies to have technical first line supervisors with excellent operational management skills as the current operational management skills that first line supervisors have are inadequate. Furthermore the current operational management philosophies that are available for use by first line supervisors are not developed for direct application in a mining environment and are also aimed at implementation for a whole company, not individual production units.

2 PROBLEM STATEMENT AND RESEARCH OBJECTIVES

The increased pressure on first line supervisors in the modern company is echoed by McManus (1995:18) who says that "a supervisor must become a trainer, facilitator, coach and leader...Such a change is dramatic and even frightening for a supervisor, especially one that has performed the traditional supervisory role for years." Lindbeck & Snower (2000:353) states that there have been fundamental changes in production technology and the ways in which to organize firms in the past decade. They argue that these changes have restructured the organization and method of how work is done. The changes also imply a different role to be played by the first line supervisor, as there is "an increased role for team work and job rotation, a reduction in the number of management levels, continuous learning and development of complementary skills, decentralisation of responsibility in firms and direct participation of employees in decision making on multiple fronts." They also refer to the traditional way of occupational barriers thinking: that is that employees need to have highly specialized skills appropriate for the standardized production process that they are involved in. Relating this to the environment of the coal mining production unit implies that the employees in a production unit must be highly skilled in the technical aspects of coal production. As the first line supervisors originates from this pool, it is clear that the first line supervisor will be well equipped with technical skills, but will have very little people and operations management experience or skills. In contrast to occupational barrier thinking Lindbeck & Snower (2000:354) discuss the modern thinking where a breakdown of occupational barriers is the norm in companies. In this environment the separation of roles tends to break down. Workers have responsibilities spanning more than one of the traditional occupational groupings. Multitask learning, all-round knowledge and skills transfer are some of the abilities that are expected from the worker, and therefore the first line supervisor.

The first line supervisor in the coal mining production unit is therefore required to perform on a high level of technical skill, but also requires more people and operational management abilities. The typical first line supervisor however has limited training in the field of operations management. "People skills" training is usually part of the required training for supervisors. The following is a list of typical non-technical training courses presented to first line supervisors:

- Models for leadership
- Seven habits of highly successful people
- Practical supervision
- Negotiating skills
- Situational leadership skills
- Business communication skills
- Customer care
- Emotional intelligence
- Making meetings work
- Personal insight
- Cross cultural diversity
- Psychology of personal success
- Assertiveness skills
- Root cause analysis
- Lateral thinking
- Creativity
- Change leadership / management

(Source: Sasol Mining organisational development & learning department)

It is clear from the list that it is focused on leadership skills and not as much on operational management.

It therefore follows from literature as well as from the current reality within a typical coal mine that the current capabilities of first line supervisors are mostly limited to technical excellence where-as the environment requires that the supervisor also manages the unit profitably – requiring people and operational management abilities. A solution to the problem could be to provide first line technical supervisors with an operational management model derived from the current management philosophies available that they can utilise in assisting them to guide and manage the mining production unit.

To determine which management philosophy to investigate is daunting. There are numerous philosophies currently in operation in the market, some very successful and some not. Even the academic fraternity battles to distinguish between "fads" and true solutions. Collins (2000: 26) refers to the "guru industry" as "….that hotchpotch of ideas and actors, which produces advice concerning the aims, processes and conduct of management". It is therefore necessary to clearly define the key criteria that a management philosophy must conform to in order for it to be included in this research.

To summarise: it is expected from highly technical first line supervisors to manage an underground coal mining production unit and to reach stretched targets when they have very little operational management skills. A myriad of operational management philosophies are available that were not developed for a mining environment as such. These philosophies are focused on company level implementation and not on production unit level. It is therefore necessary to adapt these philosophies for implementation in the mining production unit.

The first line supervisor needs an operational management business model that will assist and guide him/her in managing the production unit to such an extent that production, cost and quality targets can be achieved easily. Furthermore he/she must be able to adapt quickly to changing requirements. The answer lies in the application of current world-class operational management philosophies. A management model that could assist the first line supervisor needs to be derived from the available operational management philosophies.

Therefore the research objective for the thesis is:
The development of an operational management model for use in a coal mining production unit.

The research approach that will be followed is:
- Determine which management philosophies to analyse in detail, with the aim to:
- Determine the key elements from the chosen philosophies that could be used in an operational management model in an underground mining production unit.
- Use the key elements as building blocks to develop an operational management model for use in the production unit.
- Test the developed model utilising real data from a production section and simulating the use thereof.

The operational management model will be a framework of how to manage the production unit on a day-to day basis, but also with a long-term vision. It will therefore operate on both a strategic and operational level. The model will provide the first line supervisor with a management process, including problem solving techniques and operational management guidelines.

3 SELECTION OF MANAGEMENT PHILOSOPHIES

Key elements from current management philosophies will be used as building blocks for the development of the mining unit operational management model. To decide which management philosophies to consider it is necessary to define a set of criteria against which the philosophies can be measured.

The key criteria that the management philosophy has to comply to are that the management philosophy will:

- provide a solution that will facilitate continuous improvement and not necessarily quantum leap improvements
- be an original philosophy, not just a slight modification of an existing philosophy, or a combination of other philosophies
- be well documented in academic and business literature
- be well established (in other words no brand-new or non-proven philosophies)
- cover a wide application of the management of a company – therefore not only refer to one aspect such as for example maintenance management

The list of available management philosophies that could be included in this research are presented in table 1:

Table 1: List of available management philosophies

Lean manufacturing	The essence of lean thinking is the elimination of *muda* (waste) wherever it exists, within the individual firm but also along the whole supply chain.	The Antidote Issue (1997:11)
Total quality management	Total Quality Management is an interlocking arrangement of procedures and practices that ensures that all employees in every department are adequately trained and directed to continuously implement aligned improvements in quality, service and total cost such that customer expectations are met or exceeded	Bellefeuille (1993:47)

Just-in-Time	Just-in-Time is a philosophy that re-examines every production step with the aim to eliminate every step that is not absolutely necessary and does not directly add value	Walter (1986:28)
20 keys	20 Keys is the methodology for implementing PPORF (practical program of revolution in factories). PPORF is a simple improvement method with concrete and systematic steps for drastically reforming and strengthening every facet of the manufacturing organisation	Kobayashi (1995: i)
Business process re-engineering	BPR is the fundamental rethinking and radical design of business processes to achieve dramatic improvements in critical contemporary measures of performance such as cost, quality, service and speed	Zhang & Cao (2002: 146)
Management by Objectives	A system of management based on goal congruence as a means of improving performance	Dinesh & Palmer (1998: 363)
Total productive maintenance	TPM is a scientific company-wide approach in which every employee is concerned about the maintenance and the quality and efficiency of his or her equipment.	Cooke (2000: 1004)
Theory of Constraints	The Theory of Constraints is an overall management approach which enables management to focus on the identification and elimination of the organisation's constraints and to implement a process of ongoing improvement in order to achieve the organisation's goal	Geyser (1995:1)

Each management philosophy listed above is matched against the criteria and evaluated on a scale of one (no alignment with criteria), two (average alignment with criteria) or three (full alignment with criteria). The score given is based on the current knowledge of the researcher regarding the manufacturing philosophies. The result of the evaluation is shown in table 2.

Table 2: Result of evaluation of management philosophies

MANAGEMENT PHILOSOPHY	CRITERIA					TOTAL
	1	2	3	4	5	
Lean manufacturing	3	3	3	3	2	14
Total quality management	3	3	3	3	3	15
Just-in-time	3	3	3	3	3	15
20 keys	3	2	1	2	1	9
Business Process Re-engineering	1	3	3	3	3	13
Management by Objectives	2	2	1	2	1	8
Total Productive Maintenance	2	2	3	3	1	11
Theory of Constraints	3	3	3	3	3	15

Discussion

The management philosophies that are the most applicable to evaluate are in order of highest scores Total Quality Management, Just-in-Time, Theory of Constraints, Lean Manufacturing and Business Process Re-engineering. The concepts of Lean Manufacturing are included in Just-in-Time, therefore it will not be evaluated as a separate management philosophy. Business Process Re-engineering is more used when a radical change in the way business is done is needed – leading to a quantum leap improvement step. The main reasons for the lower scores of the remaining management philosophies are:

- Total Productive Maintenance: this philosophy focuses on the physical asset management side. Its principles are included in Total Quality Management and Just in Time.
- 20 Keys is not very well documented in the academic literature. It is a combination of best practices of other management philosophies presented visually and an organised method of achieving continuous improvement.
- Management by Objectives: This method focuses on the goals set and the evaluation of the results. It utilizes the concept of a balanced scorecard to continuously track performance. This method can be used in conjunction with any of the other mentioned management philosophies as a method of tracking progress.

The management philosophies Just-in-Time, Total Quality Management and
Theory of Constraints are therefore used as a basis for developing the operational management model.

4 DEFINING THE FUNCTIONALITY OF THE MINING OPERATIONAL MANAGEMENT MODEL

To be able to extract those elements from Total Quality Management, Just-in-Time and Theory of Constraints that will form the building blocks of the mining operational management model it is necessary to first define what the model should accomplish. It is therefore important to determine WHAT the model must accomplish, before the HOW is determined. This is accomplished by constructing an objective matrix that lists the specific functions that are required from the model. These functions are evaluated against each other to determine which aspects are the most applicable for use in the model and will add the most value to the first line supervisor of the mining production unit.

4.1 OBJECTIVE & PURPOSE OF THE OPERATIONAL MANAGEMENT MODEL

To develop an operational management model for an underground coal-mining environment that utilises the best and most applicable aspects from the selected management philosophies Total Quality Management, Just-in-Time and Theory of Constraints.

The operational management model needs to provide a first line supervisor with a proactive management tool that will assist him/her in quickly and easily adjusting the operations of the unit as well as to plan for the future in order to achieve the short and long term goals of the unit.

4.2 OBJECTIVE MATRIX

To define the functions of the operational management model an objective matrix (VM Services, 1992(v2): 8) is constructed. The objective matrix classifies different elements of the development of the operational management model in four quadrants:

- Results to achieve: the best possible results one would hope to achieve from the operational management model.
- Available resources: a list of all relevant resources that is available for the development of the operational management model.
- Results to prevent: all negative results that could be the result of the operational management model being used, and what needs to be out-designed from the start of the development.
- Constraints: all factors that could possibly hamper the achievement of the objective, i.e. those factors that could prevent the operational management model from being successfully used.

The objective matrix for the proposed operational management model is listed in table 3.

Table 3: Objective matrix

RESULTS TO ACHIEVE	RESULTS TO PREVENT
• Identifying problems • Improve problem solving activities • Breakdown silo's between functions • Assist unit leaders to become business orientated • Reduce downtime • Reduce cost • Streamline processes • Manage bottlenecks	• Complicated calculations • More paperwork • Capital expenditure • Saving cost to the detriment of total production output • Time consuming activities • Un-flexible in use • Short term focus only
AVAILABLE RESOURCES	**CONSTRAINTS**
• JIT, TQM, TOC information • Extensive maintenance & production information (downtimes, rates etc) • Financial information	• Resistance to change • Employees of production unit not trusting "another theoretical model" • Attitudes and perceptions of supervisors regarding "academic" sources

To confirm the content of the objective matrix the input of knowledgeable people in Sasol Mining was obtained. The people approached were a mine manager, the manager of the Work Study and Design department and one or two Industrial Engineers working on the mines. Their input and comments were used to complete the objective matrix, determine the functions and also determine the priorities of the functions.

4.3 FUNCTIONS

From the objective matrix the core functions of the operational management model are derived. A function is a description of the characteristics of the operational management model that will fulfill the user requirements as set out in the objective matrix.

The functions as derived from the objective matrix are:

- Identify root causes
    - Provide a tool or process to highlight the problem areas within the unit and then identify the root causes. The first line supervisor is so busy with the day-to-day operations that he/she may find it difficult to obtain a bird's eye view of the operations in the production unit and identify where, and why, problem areas exist. The operational management model must provide the means or method to achieve this overview of the unit but with the ability to identify the problem areas (i.e. causing high downtime or high operational cost expenditure) as well as providing tools and techniques to identify the root causes.
- Provide solution frameworks
    - The first line supervisor should be able to refer to a set of generic core principles regarding specific operational and managerial problems, i.e. how to reduce lead times.
- Manage cost expenditure
    - The operational management model must assist the first line supervisor in managing the capital and operational cost of the production unit without it harming the production output or safety of the employees.

- Increase throughput
    - The production target of the production unit can be achieved by mining more coal (i.e. increasing the number of shifts or mining equipment) or by increasing the mining rate (i.e. more coal from the same number of equipment and shifts). The operational management model needs to assist the first line supervisor in determining what strategy to follow when, and also on how to achieve this.
- Improve business orientation
    - With the increased demands placed on the first line supervisor it is imperative that the production unit is run as a mini-business, using all the techniques, tools and practices that would be utilized in a business. The operational management model must assist the first line supervisor in long and short term planning and in decision-making based on sound business principles.
- Integrate sections
    - Traditionally the first line supervisor only looked at the production of the unit and the maintenance was the responsibility of the engineering team (roving maintenance team). For the production unit to be productive it must be managed as a whole, integrating all functions of the production unit. The first line supervisor needs a model to assist him/her in combining all activities of the unit and also convey this method of thinking to the employees of the production unit.
- Streamline processes
    - The operational management model need to provide a method for the first line supervisor to identify and eliminating unproductive actions in the operations of the unit that lead to long cycle times, high cost, duplicated and non-aligned efforts.
- Manage bottlenecks
    - The first line supervisor needs to identify and manage those processes or equipment that are limiting the output from the unit preventing it from achieving and exceeding the goals. The operational management model needs to provide a method for him / her to identify and manage these bottlenecks.

4.4 FUNCTION EVALUATION

In the previous paragraph eight functions were listed as being required from the mining operational management model. It would be difficult to use all eight functions in evaluating the different aspects of Total Quality Management, Just-in-Time and Theory of Constraints. Therefore an evaluation matrix (VM Services, 1992(v2): 24) is developed to determine which functions are the most important for the first line supervisor. The evaluation and subsequent ranking of the functions are done based on the researcher's understanding of and experience in the mining environment as well as discussions with various managers in the mining environment (refer to paragraph 4.2).

The evaluation matrix is shown in figure 1.

EVALUATION								ID	FUNCTION	SCORE	RANKING
A	A2	A3	A3	E1	A1	G2	H2	**A**	ID root causes	9	3
	B	B2	B2	E1	B1	G3	H2	**B**	Provide solution frameworks	5	4
		C	D1	E2	C1	G2	H2	**C**	Manage cost expenditure	1	6
			D	D1	F1	G2	H2	**D**	Increase throughput	2	5
				E	E1	G1	H1	**E**	Improve business orientation	5	4
					F	G2	H1	**F**	Integrate sections	1	6
						G	G1	**G**	Streamline processes	13	1
							H	**H**	Manage bottlenecks	10	2

Rating

1 - minor difference in importance

2 - medium difference in importance

3 - large difference in importance

Figure 1: Evaluation matrix

Explanation of the evaluation matrix

- All the functions as identified are listed in the column named **Function**.
- Starting with function A, it is evaluated against function B in terms of importance. If function A is more important for application in the model than function B, "A" is written in the relevant block in the columns named **Evaluation**.
- Using the rating provided, the level of difference in importance is determined. The rating is written next to the function letter.
- Moving systematically through the evaluation matrix all the functions are evaluated against each other in the described manner.
- Each function's score is calculated by counting the ratings where that function was the important one in relation to others. For example, when determining the score for function G, all the G1's, G2's and G3's are counted together, leading to a score of 13 for function G.
- Next the functions are ranked according to the scores they received. From the evaluation matrix it can be seen that function G has a ranking of 1 due to the highest score of 13. This result is shown graphically in figure 2.

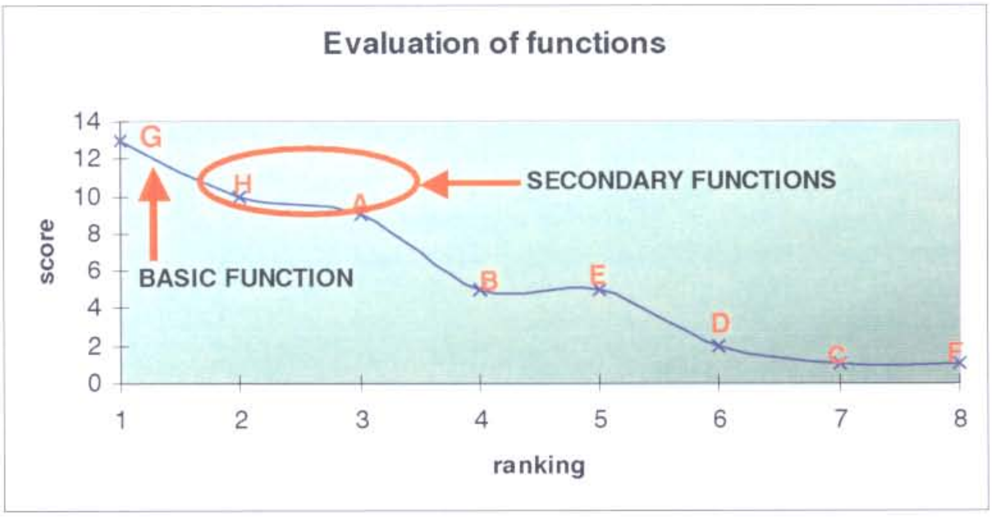


Figure 2: Evaluation of functions

In the graph two sets of functions clearly stand out from the rest. The one is the basic function, which represents the core function the model must fulfill (function G). The two functions called secondary functions (H & A) support the basic function in satisfying the specification and requirements of the operational management model. Functions B, E, D, C and E are lower priority functions of the operational management model and will possibly still realise if the basic and secondary functions are attained in the model (VM Services, 1992(v2), p 26).

From the above analysis it is deducted that the functions to be used when investigating and evaluating the three management philosophies Theory of Constraints, Just-in-Time and Total Quality Management are:

Streamline processes

Manage bottlenecks

Identify root causes

5 TOTAL QUALITY MANAGEMENT

5.1 INTRODUCTION

Total Quality Management is based on a collection of quality control principles first taught to the Japanese after the Second World War by Dr W Edwards Deming and other quality guru's like J.M. Juran. It has since grown to an all-encompassing business philosophy with scientifically founded principals and techniques.

This chapter explores the different aspects of Total Quality Management and will be used in a later chapter to evaluate it, together with the two other management philosophies, Just-in-Time and Theory of Constraints, against the defined functions. The chapter starts by discussing the overall management philosophy – a general description of what Total Quality Management is. The core principles are listed and discussed and the impact of Total Quality Management on a company is deliberated. The specific problem solving and measurement tools and techniques are described as well as the prerequisites for implementing Total Quality Management.

5.2 OVERALL MANAGEMENT PHILOSOPHY

It is difficult to define Total Quality Management in a few words. In the literature on Total Quality Management the absence of any uniform definition thereof is striking (Lau & Anderson, 1997: 86). This has led to the situation that many Total Quality Management initiatives are ill-defined which makes it difficult for companies to design and implement effective quality programs. Bellefeuille (1993: 47) tries to capture the essence of Total Quality Management in the following definition: "Total Quality Management is an interlocking arrangement of procedures and practices that ensures that all employees in every department are adequately trained and directed to continuously implement aligned improvements in quality, service and total cost such that customer expectations are met or exceeded." Hellsten & Klefsjö (2000: 242) echoes the customer focus when referring to Total Quality Management as an "…evolving system of practices, tools and training methods for managing companies to provide customer satisfaction in a rapidly changing world." Vuppalapati, Ahire & Gupta (1994:86) re-enforces the integrated approach of Total Quality Management and the focus on continuous improvement as a method to improve the quality of products and processes with the distinct aim of achieving customer satisfaction.

It is clear that there are certain underlying principles that stand out in all the different definitions. The first principal is that of an integrated, strategic approach that involves everyone in the company with the sole aim of satisfying the customer's expectations. But what are customer expectations? Determining the perceptions on quality from a large number of customers is very difficult (Lau & Anderson, 1997:94) yet a company needs to measure and act on all these perceptions. In general terms customers expect quality in the product as well as quality in service. Quality according to customers is that their need for a product or service must be met on time, every time and within an acceptable price range (Bloch, 1992:25). Therefore Total Quality Management integrates the philosophy, strategy, guiding principles, management and technical tools and quantitative methods of a company (Simmons, 1994:36) in order to meet the need of customers as and when it arises.

The second principle is that the impact of Total Quality Management is not only seen in the strategic processes of a company. The direct results of a Total Quality Management approach are seen on the shop floor. It improves the quality of products and services, placing a very specific technical focus on the processes that create the outputs, instead of just the outputs themselves (Trahant & Campbell, 1995:37). Deming emphasized that quality is the outcome of a method, not the method itself (Hellsten and Klefsjö, 2000:238) This implies that the focus is on the process of manufacturing the product according to quality standards, and not on applying quality assurance processes on finished products.

Thirdly, to turn the strategic plan into actions Total Quality Management uses the inherent capabilities of the workers to their fullest extent to control the processes to prevent defects and serve the customer best – to meet or exceed the expectations.

Therefore Total Quality Management can be described as an operational management philosophy that aims to deliver a product that equals or exceeds the customer's expectations. This is achieved by designing quality in from the product development stage right through to the after sales service processes utilizing and involving everyone in the company.

5.3 THE KEY VALUES OF THE PHILOSOPHY

Total Quality Management consists of core values, tools and techniques. The core values of Total Quality Management as expressed by various quality awards are summarised in table 4.

Table 4: Core values of awards (Hellsten & Klefsjö, 2000:240)

Malcolm Baldridge National Quality Award	European Quality Award	Swedish Quality Award
Customer driven quality	Results orientation	Customer orientation
Leadership	Customer focus	Committed leadership
Continuous improvement & learning	Leadership and consistency of purpose	Participation by everyone
Valuing employees	Management by processes and facts	Competence development
Fast response	People development and involvement	Long range perspective
Design quality and prevention	Partnership development	Public responsibility
Long range view of the future	Public responsibility	Process orientation
Management by fact		Prevention
Partnership development		Continuous improvement
Public responsibility and citizenship		Learning from others
Results focus		Faster response
		Management by facts
		Partnership

According to Hellsten & Klefsjö (2000:240) six core values can be identified when studying literature on Total Quality Management. These are "focus on customers", "management commitment", "everybody's commitment", "focus on processes", "continuous improvement" and "fact-based decisions". The following paragraphs discuss these values in more detail.

5.3.1 Total customer satisfaction

Total Quality Management demands that all efforts must be directed towards fulfilling customer expectations. Customer expectations can be divided in two groups: order qualifiers and order winners. For a specific product/service to be accepted in the market it must have certain qualifiers. Qualifiers are attributes of the product that are perceived as being standard. Without them the product/service will not sell at all. For a product/service to be better than the competition it needs attributes that will excite the customer. The customer must feel that he/she wins when buying the specific product/service, as the attributes are more than in other similar products, and that it provides value for money. These attributes are the order winners – winning orders for the company! (Pretorius: 2001). Zultner (1993:81) also explored this concept and states that customers are satisfied on three levels:

Table 5: Customer satisfaction levels (Zultner, 1993:81)

TYPE OF REQUIREMENT IN PRODUCT / SERVICE	IMPACT ON CUSTOMER
Normal requirements (one dimensional quality)	Just asking what they want
Expected requirements (expected quality)	So basic the customer does not know about it until it is left out
Exciting requirements (attractive quality)	Unexpected and highly satisfying attributes

The company therefore needs to know what the customer wants in terms of quality attributes, and which attributes are order qualifiers or order winners. Tools used in the process of determining customer expectations are customer surveys, focus groups and complaints analysis (Bellefeuille, 1993:47). The expectation of customers must be met consistently in order to improve bottom-line performance of the company and not fall into the stagnation trap. As the market gets used to what are perceived as order winners, those specific attributes become order qualifiers! Thus for the company to continuously improve, emphasis must be placed on well-designed processes and procedures that are improved continuously.

But who is the customer? It is not just the final end user of the product or the client. The next process in the production flow is also a customer. Therefore each workstation throughout the value adding chain must know what its customer's needs are. By concentrating on meeting the requirements of the next workstation, it is ensured that the final product will meet the customer's demand. This concept of "the next process is the customer" was first coined by Kaoru Ishikawa, a Japanese business consultant and writer (Imai, 1986: 52). Lau & Anderson (1997:88) states "...management must also recognize that internal customers are as important in assuring quality as external customers who purchase and use the product."

Quality in a product is also defined by the quality of the after-sales service process. The modern day customer wants more than just a good final product. He/ she wants a package that includes good service during, as well as after, the transaction. World-class service is still in most cases an order winner. Cox & Wyndrum (1994:42) states that the customer's willingness to return to a supplier can be directly traced to the customer's perception of the quality of service of the supplier.

5.3.2 Continuous Improvement

The Total Quality Management philosophy requires that a company continuously improves its business processes. A very specific method of enabling continuous improvement in a Total Quality Management environment is found in the Japanese Kaizen system. According to Imai (1986: xx) Kaizen means "...continuing improvement involving everyone – managers and workers alike".

Kaizen is a process oriented way of thinking, in contrast with a results orientated way of thinking. Imai (1986:7) refers to the difference between maintenance, Kaizen and innovation. Maintenance is the activities that are directed toward maintaining the status quo, making sure the standards are followed. Kaizen aims to improve the standards, continuously seeking better ways of doing things. With these improvements one will not find drastic changes, or breakthrough technology. Small changes in layouts, operating processes, standards etc. are the driving force. Innovation refers to the major changes, the new technology, the breakthrough thinking. Zultner (1993: 79) also refers to these principles, but he calls it standardisation, improvement and innovation. He defines *standardisation* as the drawing up of a standard set of instructions, guidelines, templates, checklists, drawings etc. The goal is to reduce variability in processes and therefore achieve consistency. *Improvement* in processes is accomplished by using the plan-do-check-act cycle as discussed later in this paragraph. *Innovation* is accomplished by breaking bottlenecks and making quantum leap improvements.

Total Quality Management values a focus on processes rather than activities. Cox & Wyndrum (1994:44) presents a structured procedure that can be used when investigating processes for improvement (refer to table 6):

Table 6: Improvement process

STEP	ACTION	COMMENT
1	Define the process (map it out to understand it completely)	
2	Develop ownership of the process	Clear accountabilities – define who is currently responsible for what
3	Develop process management rules	○ Identify customer requirements ○ Establish measures / key performance indicators ○ Assess the as-is process to determine if it conforms to customer requirements
4	Improvement of the process	○ Quality improvement teams identify opportunities ○ Prioritise opportunities ○ Schedule tasks ○ Revise process
5	Start again at step 1	

A very specific method of achieving Kaizen (continuous improvement) can be found in the Deming cycle (Hall, 1987:61) that consists of four basic steps:

- Plan for the improvement
- Follow the plan
- Check the results
- Take the necessary action for addressing any deviations

It may be a very simple cycle but it ensures that a process does not stagnate. It is this continuous attention to detail that reduces the cost, effort and time used in the efficient running of operations. See figure 3 for a graphic representation of the cycle.

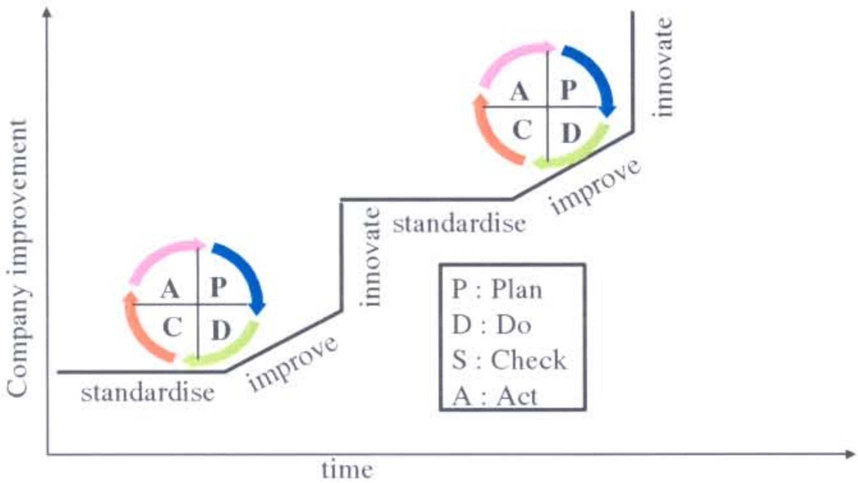


Figure 3: Continuous improvement cycle (Zultner, 1993: 81)

The PDCA cycle is usually used within quality circles. A Quality circle is defined as "..a small group that voluntarily performs quality-control activities..." (Imai, 1986:11).

5.3.3 Fact based decision making

Relevant information on customers, suppliers, competitors, products and/or services and processes is critical to decision making regarding quality improvement (Lau & Anderson, 1997:91). Designing and implementing a valid measuring system for Total Quality Management is a central focus of an effective Total Quality Management program. The aim of the measurement system is to communicate meaningfully on what quality means, to allow specific quality goals to be established and results to be forecasted and thirdly to provide a basis for employee reward and motivational programs. Statistical process measurement is not only executed by a team of experts, but all workers are trained to understand and use these measurements. All the measurements are structured to focus the employees on what is needed to reach the goal of total customer satisfaction.

Total Quality Management concentrates strongly on the use of quantitative methods for detail measurement. Simmons (1994:36) goes so far as to state that "...numbers, measurement and statistics are at the heart of total quality management." Statistical process control was the first method used to measure if processes are under control. Not only production processes are measured, but also people, schedule, reliability and performance processes. Customer satisfaction and employee satisfaction are also measured.

5.3.4 Total employee involvement & commitment

Teamwork and partnerships are an essential part of a successful Total Quality Management program. These partnerships are not just internally focused, but must be extended to the suppliers. With divisional barriers existing within an organisation, and between an organisation and its suppliers, the sharing of ideas and knowledge creation cannot ensue. Therefore the involvement of the workers as well as the suppliers is essential in improving the processes within the company. Management needs to be totally committed towards involving all employees at all levels in the decision-making process, solving problems and sharing ideas.

Nadkarni (1995: 93) lists a few methods for advancing total employee involvement:

- Employees are empowered to make decisions.
- Quality policies are thoroughly explained.
- Success stories are celebrated.
- Diversity in ideas, attitudes and work habits are valued.
- Improvement suggestions are encouraged and followed up immediately.

Quality Circles is an excellent empowerment tool, as the groups need to present their ideas to the whole workforce (including management) and are rewarded not only for the impact on the bottom line, but also for the process followed – the effort put in to develop the proposals.

5.4 IMPACT ON FUNCTIONS

Total Quality Management has an impact far wider than just the production line. Quality becomes part of the culture of an organization. This section examines some of the other functional areas within an organisation that Total Quality Management has an impact on.

5.4.1 Safety

Safety in any industry is of cardinal importance. Trahant & Campbell (1995:36) refers to the use of Total Quality Management techniques in preventing shortcuts in operations by improving the process instead. Total Quality Management helps management to understand the production processes and therefore to be able to define risk areas. Using the plan-do-check-act cycle constant improvements can be made to the production processes to lower the safety risks identified.

5.4.2 Marketing

Marketing's function in a Total Quality Management environment is not just to generate sales, but also to determine the quality specifications from customers for the company's products and services. As customer satisfaction is the ultimate goal of Total Quality Management, paying inadequate attention to internal and external customers will be disastrous. Making assumptions about the customer's needs will result in misdirected efforts and investments (Masters, 1996:55). The marketing function needs to understand the customer in depth. Customer requirements are deployed to the design function, manufacturing and other services. A company needs to create and enhance long-term customer relationships that are not only based on advertising and promotions. Zineldin (1999:720) emphasizes that the company needs to "..understand the market structure and develop long-term relationships with suppliers, distributors, investors, end users and other companies and people in the market."

Another important role of the marketing function is to gain knowledge of the quality performance of the company's competitors. The difference between order qualifiers and order winners are to some extent determined by what competitors offer.

The functions listed above are pro-active actions that the marketing function needs to take. A more re-active role to be played is that of determining what went wrong with products and providing the information to the design function. Analysis of complaints, product returns, warranty claims etc. plays a major role in the re-shaping of processes and/or the redesigning of products. (Oakland, 1989: 32)

5.4.3 Product design

In a Total Quality Management environment quality is built–in from the design phase of a product. The original design of a product is influenced by its proposed use. A cafeteria chair will not have the same characteristics or quality specifications as a dining room chair. Quality of design therefore is "... a measure of how well the product or service is designed to achieve its stated purpose"(Oakland, 1989:6).

A design of high quality plays an important role in the prevention of defects in the product, but also in the logistics surrounding the manufacturing, maintenance and service of it. Utilising Total Quality Management principles the designers determine what will be the easiest, most economic method to manufacture the product, how to test the quality of the final product as well as how to maintain /service the final product afterwards. These operational specifications are then included into the design of the product. The detail specifications and standards for production and maintenance are developed using a technique called Quality Function Deployment (QFD) defined as "a system for translating consumer requirements into appropriate company requirements at each stage from research and product development to engineering and manufacturing to marketing/sales and distribution" (Hellsten & Klefsjö, 2000:241). Operating and maintenance manuals as well as quick and easy repair facilities are part of the total design package.

5.4.4 Procurement

The role of the procurement function needs to change to fit into the total quality focus of the company. When doing vendor ratings and supplier approvals, the critical factor must not only be price, but the ability of the supplier to meet the quality requirements set by the company.

Bloch (1992:25) mentions 3 different types of suppliers:
Quality suppliers - they meet basic requirements.
Preferred suppliers - they are better able to understand customers' needs.
Partner suppliers - they have quality and continuous improvement programs in place.

The procurement function needs to determine what type of supplier is needed for the different products produced by the company. The supplier strategy should be structured around that information – deciding which suppliers will be strategic partners, which will receive contracts, etc.

5.4.5 In-bound and out-bound logistics

It will not suffice if the manufacturing processes within a company are designed and operated according to Total Quality Management principles but the in-bound and out-bound logistical processes not. During the design phase of a new product in-bound and out-bound logistical processes are also looked at to ensure that the logistical process and facilities will sustain, if not enhance, the quality of the product. The receiving and issuing of raw materials can play a major role in the final quality of the product and needs close scrutiny to ensure everything is done in such a manner that product quality is not negatively affected. The whole inbound and out-bound logistical process must be statistically measured and controlled, and any deviations from target acted upon immediately. (Oakland, 1989:34)

5.4.6 Quality assurance (QA)

In a Total Quality Management company the focus of quality assurance shifts from detection of defects in the product to the prevention of product defects (Oakland, 1989:34). Inspections to remove defects are reduced and inspectors are used to improve processes and to determine errors beforehand. Quality assurance staff is responsible for advising on and providing of expertise on the quality management of manufacturing processes. They need to maintain the quality systems and train the workforce in the quality philosophy, management and techniques used in the company.

5.4.7 Organisational structure

Total Quality Management cannot succeed in an organisation with functional barriers, autocratic structures and restricting policies. Isolation of individuals and departments are detrimental to teamwork. Therefore a company that implements Total Quality Management will need to change its organisational structure to a more team driven structure. Masters (1996:54) lists some tools that can be used to identify the problems in the structure and policies of a company. These are brainstorming, fishbone diagrams and workflow diagrams. By using these tools companies can determine where in the organisational structure to focus the improvement effort.

The internal structure and functioning of teams will be affected. Teams in a Total Quality Management environment need to be empowered and efficient. To enable the transition from the traditional autocratic structure of teams to a more flexible, efficient set-up, Masters (1996:55) recommends the use of a trained facilitator. The facilitator will assist the new team to determine their purpose for existence. The team should have specific goals to achieve within a set time frame. The team must consist of cross-functional team members. It is very important is to ensure that the team accepts responsibility and accountability for reaching the set goals.

5.5 PROBLEM SOLVING & MEASUREMENT TOOLS AND TECHNIQUES

Measurement is the starting point for problem solving. Measurement focuses everyone on the important, critical issues that need to be addressed in a continuous improvement program.

Total Quality Management distinguishes between two types of measures (Perry & Wichert, 1995:52):

- measures of how the **process** is progressing
- measures of **results** from initiatives using the process.

The focus of the two types of measures is therefore on the process (operational, maintenance, design, etc) and the product (quality, quantity etc). The Total Quality Management measurement focus has a balanced viewpoint of what to measure and how to analyse the results. Bhote (1997:29) and Zultner (1993:85) summarise the problem solving and measurement tools into 3 distinct tool kits that are depicted in table 7.

Table 7: The 3 tool kits of TQM (Adapted from Bhote (1997: 29) & Zultner (1993:85))

QUALITY CONTROL TOOLS	QUALITY MANAGEMENT TOOLS	21st CENTURY QUALITY TOOLS
Pareto charts	Affinity diagrams	Design of experiments
Cause and effect diagrams	Inter-relationship diagrams	Multiple environment over stress test
Control charts (SPC)	Matrix data analysis charts	Quality function deployment
Frequency distributions	Tree diagram	Total productive maintenance
Brainstorming	Matrix diagram	Benchmarking
PDCA cycle	Process decision program chart	Poka yoke
Scatter plots	Precedence diagrams	Next operation as customer

The quality control and management tools presented in table 7 (columns 1 and 2) are well known, and will not be discussed, except for control charts (SPC). Figure 4 is a graphical representation of these 14 tools.

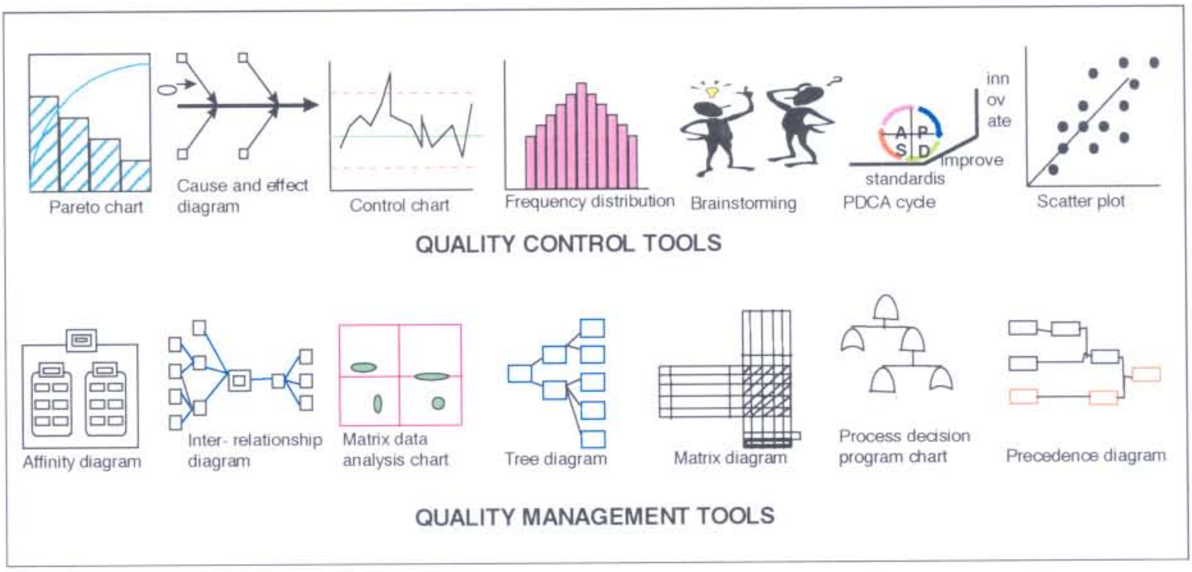


Figure 4: The 14 quality control and management tools

5.5.1 Control charts

Gitlow et.al. (1989:162) define control charts as "..statistical tools used to analyse and understand process variables, to determine a process's capability to perform with respect to those variables and to monitor the effect of those variables on the difference between customer (either internal and /or external) needs and process performance". By implication the role of control charts are firstly to determine if a process is statistically under control, stable and predictable. Secondly they are used to enable management to improve the process by manipulating the variable factors.

A control chart has a basic structure consisting of a centerline and control limits. Control charts are constructed by drawing samples, and these samples are grouped together. The centerline is the average of the sampling distribution, and the control limits are based on the mean plus/minus three times the standard error (upper and lower control limits). The standard error is based on the variation that occurs within the sampled subgroups. An example of a typical control chart is shown in figure 5.

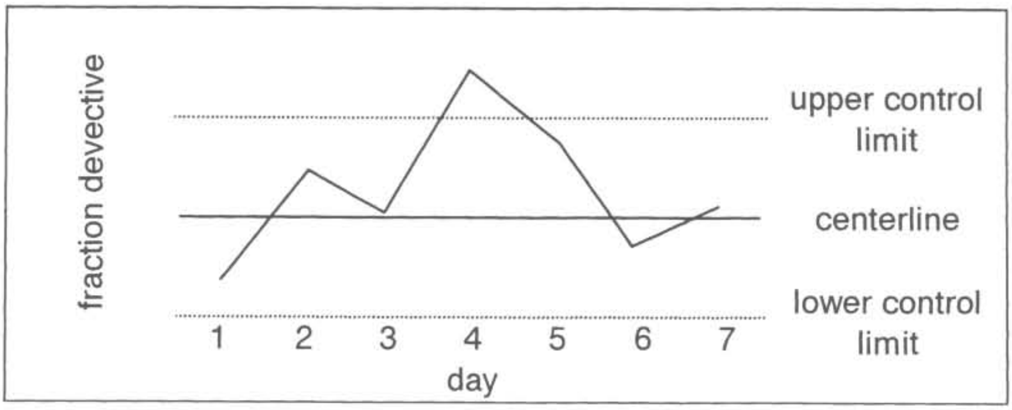


Figure 5: Structure of a control chart (Gitlow et.al., 1989:p167)

A stable process is one from which all special causes of variation have been removed. The process only exhibits variation as a result of inherent system limitations. Once a process is stable, it has a known capability. Only when the process capability is known can the process be compared to similar, or benchmark processes, to determine improvement opportunities. Management can also only manage the deviations that do occur on a daily basis if they have a baseline to work from, as derived from the centerline and upper and lower control limits of a capable process that is statistically in control.

Different types of control charts exist, based on the type of data used as well as the purpose of the chart. Gitlow et.al (1998:p175-176) describe the different types.

Attribute control charts

Attribute data arise from the classification of items into categories, the counts of the number of items in a given category or from counts of the number of occurrences per unit. For example, a result may be good/bad, right/wrong, black/white (categories), or the number of parts per hour that are defected are counted. The following attribute control charts are used:

- p chart : control the fraction of units
- np chart: control the number of units with some characteristic
- c chart : control the number of events in some fixed area of opportunity
- u chart : control the number of events in a changeable are of opportunity
- individual charts : control the count when the assumptions for the other attribute control charts cannot be met

Variable control charts

Variable data arise from the measurement of a characteristic or from the computation of a numerical value from two or more measurements of variable data. Specific attributes of the process, product or service are measured, e.g. length, time or temperature. The values of a variable are measured, in contrast with attribute data where the count of the variable is measured. The following variable control charts are used:

- x-bar chart: control the process average
- R chart: control the process range
- s chart: control the process standard deviation
- median chart: combination of an x-bar and R chart
- individuals chart : control subgroups of size one

To determine if a process is statistically in control a set of simple rules are used, or specific patterns are identified. Gitlow et.al (1989:190) discusses 5 simple rules that indicate a lack of statistical control in a process. To utilise these rules the area between the centerline and a control limit is divided in three zones, each a standard error wide. The zone closest to the centerline is Zone C, and the farthest Zone A.

A process lacks control if:

- Any single value falls outside of the control limits.
- Any two out of three consecutive points fall in one of the A zones or beyond on the same side of the centerline.
- Four out of five consecutive points fall in one of the B zones or beyond on the same side of the centerline.
- Eight or more consecutive points lie on one side of the centerline.
- Eight or more consecutive points move upward in value or downward in value.

Certain control chart patterns exist that is utilized to identify a variation in the process. Table 8 is a summary of these patterns.

Table 8: Summary of control chart patterns (Gitlow et.al, 1989:347)

Pattern	Description	Possible cause
Natural	Does not exhibit any points beyond the control limits, runs, or other non-random patterns. Have most of the points near the centerline.	Stable process
Shift in level	Involves a sudden, or gradual rise or fall in the level of data on a control chart. Also involves trends – gradual shifts in level that do not settle down.	Dramatic change in the process
Cycles	Repeating waves of periodic low and high points	Special disturbances that appear and disappear with some degree of regularity
Wild	Freaks or grouping / bunching – one or more subgroups that are very different from the main body of subgroups	Freaks: Calculation errors, external disturbances Grouping: introduction of a new system of disturbances
Multi-universe	Absence of points near the centerline of too many points near the centerline	Two or more distributions for a quality characteristic changing over time or not changing over time
Instability	Erratic points on a chart exhibiting large swings up and down	Special disturbances that sporadically affect the process
Relationship	Interaction between variables or the tendency of one chart to follow the other	The behaviour of one variable is affecting the other

Management is not only concerned with whether a process is statistical in control or not, but also need to if a process is able to meet specifications (i.e. the specified outer diameter of a shaft). To determine this process capability indices are used (table 9).

Table 9: Process capability indices (Gitlow et.al. 1989:452)

Index	Purpose
C_p	Summarise process potential to meet two-sided specification limits where the process average equals nominal
CPU	Summarise process potential to meet only a one-sided upper specification limit
CPL	Summarise process potential to meet only a one-sided lower specification limit
C_{pk}	Summarise process potential to meet two-sided specification limits where the process is off nominal.

Control charts are a valuable tool in the manager's toolkit for process control and improvement. There is however other techniques that can be used, and these are described in paragraph 5.5.2.

5.5.2 The 7 tools of the 21st century

The 7 tools of the 21st century (third column in table 7) are summarized as follows by Bhote (1997:31-38).

Design of experiments (DOE)

DOE is used to solve those chronic problems that are constantly picked up by statistical process control. It can be used in the design phase of products / processes or in the optimisation of products/ processes. DOE is used to improve quality and therefore to reduce defects in processes and products. DOE separates the important product variables from the unimportant ones. The parameters of these variables are determined and then optimised to establish realistic specifications and tolerances.

The benefits of these simple clue-generating experiments are that it does not interfere with ongoing production, and workers can solve the majority of chronic problems with nothing more than common sense.

Multiple environment over stress tests (MEOST)

MEOST is a reliability improvement tool. MEOST goes further than FMEA (failure mode effect analysis), FTA (fault tree analysis) and ALE (accelerated life tests) to design reliability in the product beyond the needed stress levels. MEOST works because it implies testing the product with combined stresses / environments to simulate actual customer use. It also tests "beyond normal design stress to a maximum practical overstress" situation (Bhote, 1997: 31).

The method of operation of these tests is:

- A profile of all the possible stress levels and environments that the product will be subjected to in the field is obtained. Test chambers are then designed and built to simulate these combined stresses.
- The product is then tested in these chambers, by starting with only a fraction of the stresses that can occur. Gradually the combined stress and time factors are increased until the guaranteed lifetime in the field is reached. If any failures occur failure analysis is done and corrective actions taken.
- The next step is to continue the time-stress increase up to maximum over-design stress levels. Where more than two failures of the same failure mode occur, failure analysis is done and corrective actions taken.
- Steps 2 and 3 are now repeated but for double the time. If the test is successful the product is ready for distribution. If not failure analysis is done and corrective actions taken.
- After six months in the field samples of the product is retrieved for repeat testing as described in steps 2 and 3. With statistical analysis the company can determine if the guaranteed lifetime is / will be met.

The benefit of MEOST is that it virtually eliminates field failures and therefore removes one of the major customer complaints.

Quality function deployment (QFD)

This tool is used to "capture the voice of the customer.... for new products and services" Bhote (1997: 33). The "House of quality" matrix is used to change the "what" (requirements) of the customer into the "how" of design specifications. Similar houses are developed to progress "...from parts to process, process to production, production to test and from test to quality requirements" Bhote (1997: 33). Figure 6 represents a sample House of Quality.

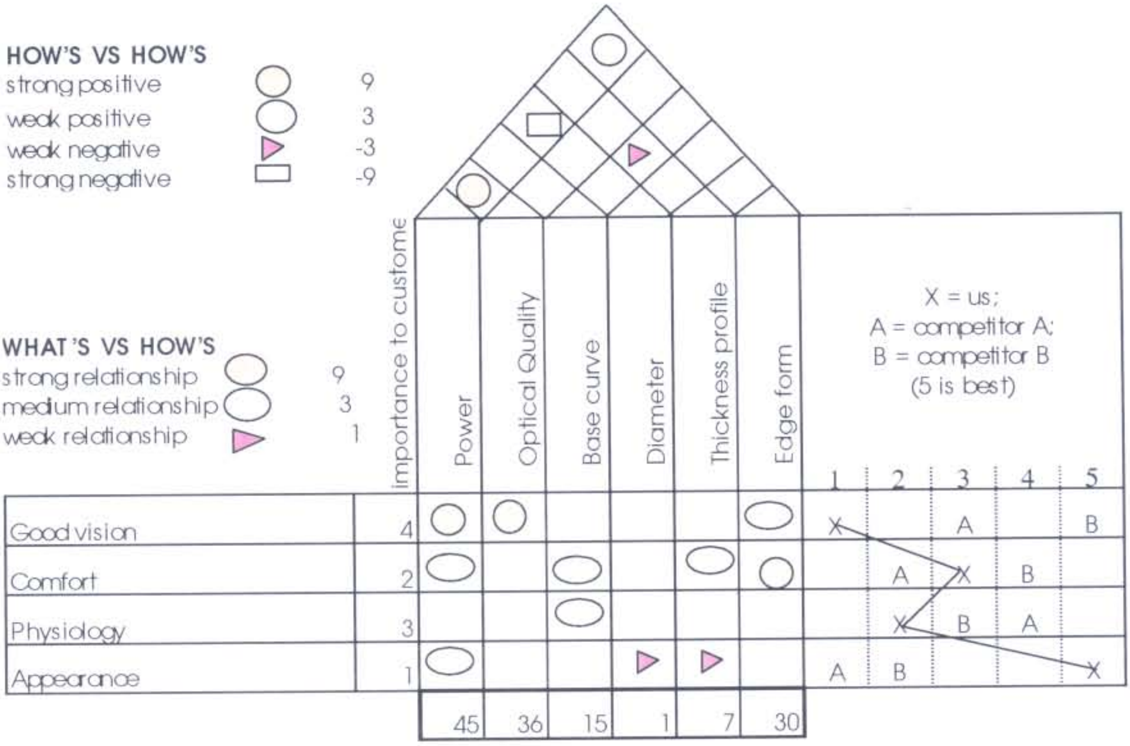


Figure 6: Sample House of Quality (adapted from Bhote (1997: 34))

The customer's most relevant requirements are listed on the far left (the "what"), which are prioritised in terms of importance. On the far right is the rating of the company's performance versus the competition for each requirement. In the middle is a relationship matrix, comparing the link (strong, medium or weak) between each customer requirement (the "what") and each design specification (the "how"). A simple calculation pinpoints the engineering specifications that must be concentrated on to meet customer requirements and therefore ensure competitive strength. On the roof is a correlation matrix to see if each pair of engineering specifications has a reinforcing correlation or a conflicting correlation. In the example above it is clear that the company should focus on the power factor of the contact lenses, as that influences the total quality rating of the product.

Total Productive Maintenance (TPM)

This tool improves equipment productivity and quality in manufacturing processes. It aims to reduce maintenance costs, increase the factory overall efficiency and start preventing errors instead of finding them. It makes use of tools such as DOE (as discussed above), RCM (reliability centered maintenance) and life cycle costing to determine which maintenance strategy to follow for a specific piece of equipment. The maintenance strategy consists of a combination of predictive, preventive, scheduled and repair maintenance. The operators are closely involved in determining the maintenance strategy.

Benchmarking

Benchmarking is the practice of organisations learning and adapting from the best in order to improve their own manufacturing and services processes. The objective is to close the gap with competitors in key function areas within the company. The first step in a benchmarking process is to determine what to benchmark – which key functional areas need improvement. Then it is important to create a baseline of these key areas for comparison with external companies. After the company has decided which external companies are the best in the key areas, they need to visit the companies and gather (as well as share) information that will enable them to compare themselves with the external company. The gap can then be determined and improvement plans put into place to close the gap. A danger of benchmarking is that it is difficult to ensure that apples are compared with apples; therefore the results may be skewed if enough effort was not put into specifying the scope and details of the benchmarking exercise.

Poka-yoke

According to Bhote (1997:36) "This tool eliminates operator – controllable errors…" It is not always possible for the operators to prevent defects if they are working in a labour intensive environment. "The objectives of poka-yoke are to provide sensors (electrical, mechanical or visual) that warn an operator that a mistake has been made or, preferably, is about to be made and can be avoided." Examples of such sensors are thickness guides that deflect items that are either too thick or too thin. Quality teams can then determine the origin of the problem and fix it without letting the faulty parts go through to the next workstation.

Next operations as customer (NOAC)

"NOAC helps improve the quality, cost and cycle time of white-collar jobs" Bhote (1997: 37). It can be applied to service organizations and support services in manufacturing companies. The objectives of NOAC are to break down departmental walls, revolutionise business processes and replace supervisor evaluations with internal customer evaluations. The first step in using the NOAC tool is to establish a steering committee and improvement teams that will oversee the business process re-design. Thereafter the specific problems in the business process are determined and the impact on quality, cost, cycle time and morale is quantified. Next the internal customers are involved to determine what their priority requirements are and then to determine if the internal suppliers can meet those requirements. To be able to develop improvements on the system the total process need to be mapped out in detail, i.e. determine the cycle time for each step in the process. Now the process can be streamlined by removing the non-value adding steps, or the process can be totally re-designed. After implementation of the new process it is important to conduct reviews and to track progress against the targets set.

5.6 IMPLEMENTATION

It is important for organisations to understand what is necessary for a successful implementation of Total Quality Management. If the underlying assumptions and critical success factors are not known and not taken into account it may lead to an unsuccessful Total Quality Management implementation.

5.6.1 Management and employees commitment

Without total support from top management employees will show low participation and enthusiasm for Total Quality Management (Masters, 1996:53). The management team needs to clearly communicate their reason for adopting Total Quality Management by developing a valid case for change and selling it to all employees. The vision and strategic direction of the company that stems from the case for change will not amount to anything if it is not transformed into actions that the total workforce can relate to and support. Total Quality Management uses a technique called policy deployment to transform strategy into action plans.

Management's role has to change from being directive to being coaches for their workforce. (Cox & Wyndrum, 1994:44) This will enable workers to be empowered and supported with proper education, training and decision making responsibilities. In this transformation from followers to partners in the company the workforce will need guidance and coaching from management.

The values and operating mechanisms of the leadership group of a Total Quality Management company is summarized as follows by Nadkarni (1995:92):

- Sharing information on quality problems, future changes, etc. with customers.
- Having respect for people throughout the company, regardless of their position.
- Not compromising integrity at all.
- Making use of quality councils that review quality management
- Developing long range strategic quality plans.
- Personal involvement in the total workforce.
- Sustained commitment with the road taken.

A successful Total Quality Management implementation does not only depend on the commitment and involvement of the managers. The employee also plays an integral role in the process. Employees will need to understand that there is a difference between empowerment and management displacement. (Dresner, 1994:17) Managers will not stop making decisions but will actively involve the employees in the decision making process. Therefore employees must recognise their own value and actively participate in all aspects of Total Quality Management. They must insist on, and engage in, cross training, that will increase the value they can add to the company. Within the Total Quality Management organization a major emphasis is placed on teamwork and employees will need to adapt to this environment and be willing to exchange ideas freely.

5.6.2 Organisational culture

Total Quality Management needs a special company culture in order to survive. Organisations are often impatient and start implementing Total Quality Management without a concentrated effort and strategy for changing the culture (Masters, 1996:53). According to Perry & Wichert (1995:51) the hardest part of changing the culture is getting people to accept the new values and ways of doing things. To institutionalize the new values a culture of sustained communication is needed that will continue before and during the implementation. It is essential that everybody have access to all the information on the new way of doing things, the changes coming their way and any other relevant information they need, when they need it (Woods, 1997:53). This can be a major paradigm shift for companies who believe in only communicating at month-end! Employees in a Total Quality Management environment will constantly be busy searching for better ways of doing their jobs and will therefore require information to assist them in this search. They must be able to specify which information they need, and not just receive monthly reports according to their position in the hierarchy. Employees must at all times be informed of the progress of the quality initiative. It is important that the truth be told, whether good or bad. The new values will only start to become living values when everyone in the organization can relate to the Total Quality Management program, with up-to-date information that can be trusted and is readily available.

There are various ways to communicate the progress made in the implementation of Total Quality Management. Oakland (1989:242) suggests a few:

- Implementing suggestions schemes.
- Having regular departmental workshops.
- Induction and vocational training that addresses aspects of Total Quality Management
- Poster campaigns.
- Specific references to projects and work reminders.
- Quality competitions with prizes and formal presentations.
- Demonstrations and exhibitions to illustrate the workings of Total Quality Management and the progress made with implementation.
- Informative newsletters.
- Opinion surveys.

These are over and above the continuous reporting of statistical analysis on processes where Statistical Process Control has been implemented.

5.6.3 Proper planning

A proper implementation plan for Total Quality Management is of the utmost importance to prevent failure. Masters (1996:53) lists three components of a successful plan:

- Management must obtain company wide commitment for the implementation of the Total Quality Management program.
- The communication must be very precise, clear and frequent. It is of great importance to communicate the vision, mission and goals of the company.
- The last component is to ensure that the plan makes provision for open communication channels to discuss the new focus of the company.

The plan must remain flexible, but a time frame for implementation should be developed and communicated to the whole company.

An implementation plan for Total Quality Management is one aspect of the planning needed, but another important step is to incorporate the Total Quality Management principles into the business planning process. The quality focus must be integrated with the strategic initiatives of a company (Thayer, 1995:16).

5.6.4 Training and education

As Total Quality Management places such a high value on the involvement of the workforce they need to be highly skilled in not only their functional areas but also in all aspects of quality management. This includes knowledge of and ability to use all the tools and techniques described in paragraph 5.5. The emphasis on training will necessitate an increase in expenditure on training. Training can take place via formal training sessions or informal on-the-job training sessions. Masters (1996:54) mentions newsletters and bulletin boards as methods of informal training where 5-minute discussion can be held on current important quality issues and/or topics.

5.6.5 Change management

An ineffective change effort can result in a stalled Total Quality Management program. Trahant & Campbell (1995:38) mentions three setbacks that can occur:

- When change takes too long, the need for change diminishes, leading to a much more difficult implementation.
- Higher costs can occur because of the additional time and attention needed to implement Total Quality Management.
- A sense of failure can paralyse and scare managers and workers alike.

It is therefore of utmost importance that change management is included in the planning stage of a Total Quality Management implementation.

5.7 CONCLUSION

In this chapter Total Quality Management as an operational management philosophy was discussed. Total Quality Management is an operational management philosophy that focuses on processes to improve quality with the intent to obtain total customer satisfaction. This chapter presented the key values of Total Quality Management and explained the impact these values have on the functions within a company. The unique measurement tools and techniques used in a Total Quality Management company were discussed. Finally the pre-requisites for successful implementation of Total Quality Management in a company were determined.

6 JUST IN TIME

6.1 INTRODUCTION

Just-in-Time is an operational management philosophy that is widely used in the manufacturing industry. It has its roots in the Japanese manufacturing industry but has been applied in many other countries since. From its humble beginnings as a system of flow management invented by Taiichi Ohno (Womack & Jones, 1996:37) it has developed into a fully-fledged operational management philosophy. Murphy & Schreffler (1999:68), for example, states that Just-in-Time has been enormously beneficial to automakers and suppliers alike.

Just-in-Time has been hailed as an excellent improvement tool, and therefore a study of the primary principles, tools and techniques thereof is needed to determine what aspects of the philosophy can successfully be used as building blocks for the operational management model in a coal mining environment. The chapter starts by discussing the overall management philosophy – a general description of what Just-in-Time is. The Core principles are listed and discussed and the impact of Just-in-Time on a company is deliberated. Problem solving and measurement tools and techniques are described as well as the prerequisites for implementing Just-in-Time.

6.2 OVERALL MANAGEMENT PHILOSOPHY

In the manufacturing industry Just-in-Time is often mistakenly perceived as an inventory control system, whilst it is actually much more than that. Just-in-Time only comes into its own when it is applied to inventory control as well as to production (Womack, Jones & Ross, 1991:161). This section establishes the nature and extent of Just-in-Time.

According to Wheeler (1986:5) Just-in-Time is "an enterprise wide operating philosophy which has as its basic objective the elimination of waste." Waste is defined as any entity that does not add value to the manufacturing/ development of the product. From this definition it is clear that Just-in-Time does not only have a direct impact on the production line, but also on the logistical chain, the quality management process, the design process and all other functional areas within an organisation. All these processes are necessary to change raw material into final products, but all these processes can have non-value adding activities (waste) included in them. Walter (1986:28) describes Just-in-Time as a philosophy that re-examines every production step with the aim to eliminate every step that is not absolutely necessary and that does not directly add value.

Songini (2000:50) describes Just-in-Time as "...a process where inventory is delivered to the factory by suppliers only when it's needed for assembly". This implies that detail production planning is a prerequisite for Just-in-Time operations, with the throughput determined by the market demand, and the material releases controlled by the production flow pull.

Therefore, Just-in-Time can be described as an operational management philosophy that aims to deliver the required product, within very strict time limitations, to the exact requirements of the customer, without any waste present in the value chain.

6.3 THE KEY VALUES OF THE PHILOSOPHY

6.3.1 Elimination of waste

The basis of Just-in-Time is the elimination of waste. The categories of waste as first defined by Taiichi Ohno are defects in products, overproduction of goods not needed, inventories of goods awaiting further processing, unnecessary movements of people, unnecessary transport of goods and waiting time. Another waste is the design of goods and services that do not meet user's needs (Womack & Jones, 1996:15). The concept of having the right materials at the right time at the right place is an integral part of eliminating waste within a company. There are no unnecessary storage of materials and no excessive stock levels of materials.

(Womack & Jones, 1994:93) argues that it is not enough only to eliminate waste within a company. What is needed is a "lean enterprise". A lean enterprise is where the elimination of waste in internal systems (within companies) as well as the non-value adding activities taking place throughout the whole supply chain (across companies), occurs.

6.3.2 Quality

Deming, Juran and other Just-in-Time practitioners presented the statement "no low cost without high quality" to the manufacturing world (Sandras, 1986:11). Just-in-Time advocates a principle of zero defects in the production process, which will lead to low production costs due to the elimination of waste in the system. To be able to reach the goal of zero defects a highly focused quality management program is needed. Wheeler (1986:6) comments as follows on the quality emphasis needed in a Just-in-Time program:

- Variance in the processes must continuously be reduced if one wishes to improve manufacturability. This can be achieved by using statistical methods to identify and prioritise the opportunities for productivity and quality improvements.
- The operator assumes responsibility for zero defects on his machine. To achieve this management need to provide the appropriate tools, techniques and mechanisms needed to manage the quality process.
- Emphasis must be placed on eliminating the chronic quality problems first, as these disrupt the process flow more significantly than the sporadic problems.
- Pro-active maintenance must be the operators' responsibility.
- With the launch of a new product all functions (design, marketing, production, maintenance) must be involved from the beginning. To ensure a quality product the involvement of these departments throughout the whole product development phase is crucial.
- Extensive training in quality assurance techniques must be given to all operators and inspectors. The long-range goal is to minimise the number of inspectors by achieving zero defects in the process.

Just-in-Time cannot be successful without Total Quality Control (TQC). Using TQC techniques the root cause of a problem is found and eliminated. This solution is then standardised in other related processes to ensure that the problem does not occur again. With the focus on the individual to contribute totally in preventing defects and solving quality problems the function of the quality department changes from quality control to quality audit, and quality is built into the process and product from the beginning. (Sandras, 1986:11)

By eliminating non-value adding activities and reducing work-in-process it becomes critical to control the quality of the production processes very strictly, as there are no buffers to protect the system. Therefore Just-in-Time cannot function properly without a Total Quality Management Program in place.

6.3.3 Continuous process improvement

A key feature of Just-in-Time is that it is an ongoing cycle. No matter how good a company is, or how good they get, they should constantly strive to improve and work more productively. (De Vries, 1987:1). In the management review *The Antidote Issue* (1997:p13) this is referred to as "…the continual hunt for perfection…".

A technique used to achieve continuous improvement is the use of quality circles. Quality circles are discussed in the chapter on Total Quality Management. Teams of people from all levels of the organisation form quality circles where they discuss ideas on how to improve on the current processes.

Performance measurement in a Just-in-Time company is also focused on measuring improvement over the previous performance level and not just the acceptability of the current performance (Hall, 1987:44). Top management need to promote and entrench a culture of continuous improvement among employees.

6.3.4 Total employee involvement

Just-in-Time cannot succeed without the total commitment and involvement of all employees. For example, production line workers must have the confidence to stop a process line when they determine that a problem exists. They are also encouraged to improve their workplaces. The improvement of a workplace starts with basic cleanliness and checks (e.g. for safety measures and first line maintenance) but evolves into active participation in problem solving. Workers are expected to contribute to quality and productivity improvements. Finch & Cox (1986:335) describe an approach to obtain such a culture:

- Managers need to be visible on the shop floor, but not only when they are expediting work. Their focus must be on the workers, determining the morale levels, interacting with the workers etc.
- Reasonably permanent employment is guaranteed.
- Infrequent but steady performance evaluations and promotions as well as generalised career paths for all employees are needed. This will ensure that an employee knows what is expected from him, and how he can progress within the company.
- A culture of collective decision-making and responsibility must exist.
- A holistic concern for employees must be displayed.

The profile of the shop floor worker in a Just-in-Time plant changes from being a production operator only to being a creative value-adding employee. There is respect for fellow human beings, for their aspirations, capabilities and their integrity (Fogarty, Blackstone & Hoffman, 1999:59). Sandras(1986:12) describes the changing role of the shop floor worker in a Just-in-Time environment. In a traditional manufacturing environment only the specialists and management have the responsibility for problem solving. Under a Just-in-Time approach a thinking worker is developed. The worker must have a continuous improvement attitude and a sense of urgency for solving problems. The Just-in-Time worker also knows that producing an item before it is needed does not add value. He/she knows the total production process well and is flexible enough to function within any related production process. Multi-skilling is an essential part of the make-up of the Just-in-Time worker. Therefore the work is done when needed, and there is flexibility in the teams to be able to cover for unforeseen occurrences. If the machine they operate becomes idle, and they do not have any activities that need to be performed on the machine, they can easily move to the next machine within the work center to assist with the operation of first line maintenance.

By creating a culture of total participation a constantly improving process of waste elimination and maximum productivity of all resources can be obtained. This needs to be an ongoing process to prevent stagnation and possible failure of a Just-in-Time program.

6.4 IMPACT ON FUNCTIONS

Just-in-Time impacts the whole organisation. This chapter explores the functional areas where a company that applies Just-in-Time principles differs from one that does not.

6.4.1 Procurement & Supply Management

6.4.1.1 Supplier management

Just-in-Time advocates a reduced supplier base. Sandras (1986: 8) describes the logic residing behind this approach. With fewer suppliers it is much easier to find the cause of incoming material problems. Furthermore, it becomes possible to help the supplier with implementing a quality structure. With more commitment from the manufacturing company better service levels from the supplier can be expected.

Supplier selection is not only based on the basis of price and the bids that they present to supply particular items, but rather on the basis of past relationships and a proven record of performance. Suppliers are also selected to supply whole components not just individual parts. Such a supplier is called a first tier supplier. Womack et al(1991:146) uses the example of a complete motor seat that must be supplied instead of the different parts of a motor seat with the motor manufacturer assembling the parts.

Excellent supplier relations play a crucial part in a Just-in-Time supply chain. As a Just-in-Time system demands consistent and precision delivery, joint commitment and open communication are essential between the suppliers and the Just-in-Time company. To achieve this the purchasing department has to work closely with suppliers and constantly improve their relationship with suppliers. Imai (1986:212) lists some of the actions that need to be taken by the manufacturing company:

- Establish criteria to measure optimum inventory levels
- Improve the quality of the information provided to suppliers
- Establish optimum physical distribution systems
- Understand suppliers' internal requirements better

Just-in-Time companies also assist suppliers in establishing Total Quality Control programs and facilitate Kaizen activities.

One method used to bring the manufacturing company and supplier closer together on an operational basis is defined in the concept of Just-in-Time II (Deierlein, 2000:2). With this concept a supplier employee works full-time in the manufacturing company's purchasing office. The supplier representative is responsible for purchasing the materials or services that his company supplies, utilising the manufacturing company's procurement system and documentation.

An open communication network from the supplier to the manufacturing company is needed. This ensures a quick response to problems. It is necessary that the required schedule for the short as well as the long-term needs is made available to the suppliers, preferably on-line. Any changes to the schedule need to be communicated to the suppliers immediately. The Internet and electronic commerce have made this process very streamlined and efficient. With developments in EDI (electronic data interchange) suppliers and manufacturing companies can communicate instantly, internationally and without the human error that always was a part of the process. Murphy & Schreffler (1999:70) mentions that some transport companies relay information from their trucks to border posts before the trucks arrive there, thus enabling a smooth and fast clearance at customs. Where suppliers and manufacturing companies operate in a Just-in-Time II relationship, restricted access to each other's ERP systems are provided (Atkinson, 2001: 43). This greatly enhances communication.

Walter (1986:28) states "Just-in-Time processes require Just-in-Time information delivery systems". He explains that the actions of reducing lead-times and inventories result in on-line storage of large numbers of active documents. This is due to more frequent orders for supply materials, more receipts of delivered materials, more job runs planned, EDI communication etc. An advanced, integrated ERP (enterprise resource planning) system will support a Just-in-Time company in the daily operations, decision-making, communication with suppliers and strategic planning.

6.4.1.2 Design & development

Just-in-Time companies utilise the knowledge of their suppliers from the beginning of a new product development cycle. The designated supplier of parts will assign design engineers to the development team of the new product. As the blueprint phase is completed the different designs are turned over to the supplier specialists to scrutinize the designs. The first tier suppliers have full responsibility for the design and manufacturing of parts that will perform to the original specifications. The supplier involves design engineers from the manufacturing company during the detail development and design phase. (Atkinson, 2001: 41)

This approach is not applicable to those parts that the manufacturing company deems to be vital to the success of the new product: items that are classified as proprietary technology.

6.4.1.3 Storage

Just-in-Time proposes decentralised storage. The materials needed as input for specific processes should be delivered at the production line, not at a warehouse removed from the area. The ideal is for the materials to be sent directly from the supplier to the point of use. This ensures a simple but flexible storage system. A term used to describe this is DTS (dock to shop). The manufacturing company sends a request for material to the supplier, who will then ship it to the manufacturing company. It is received at the receiving dock on the manufacturing company's system and the material is then directly delivered to the required location in the plant bypassing the warehouse. The benefit of this method of operation can be greatly enhanced if consignment inventory is used. The manufacturing company does not own the material until it is consumed, before then it is still owned by the supplier even if it is sitting on the manufacturing company's shop floor (McBride, Harrison & Clark, 2000: p34). Using the DTS process the supplier keeps a certain amount of material in stock based upon the forecasted requirements provided by the manufacturing company. A danger is that Just-in-Time companies can utilise this method to shift stock holding to the suppliers with the result that the holding cost for the inventory will ultimately make its way back to the manufacturing company. (Murphy & Schreffler, 1999: p67)

6.4.2 Production and scheduling

6.4.2.1 Group technology

Finch & Cox (1986:332) describe the impact that Just-in-Time has on the grouping of machines within a production line. Just-in-Time breaks the traditional pattern of grouping identical machine types together (all the lathes together, all the drills together etc.). With a Just-in-Time production system machines are grouped together not based on their function but on the family of parts that will be routed through them. This ensures shorter queues and more flexibility in the system. It also decreases the work-in-process traveling time. The group of different machines used together is treated as a work centre, and work is planned and allocated to the work centre. High reliability in a work centre is essential as a single breakdown can stop the whole work centre. Therefore the workers in a work centre are skilled in preventative maintenance practices, in identifying maintenance problems and in alerting the correct maintenance teams if problems occur. Workers in a work centre are multi-skilled enabling them to assist their co-workers in the work centre.

6.4.2.2 Model mixes

Traditional production methods favour long runs of the same product: so called fixed model runs. In contrast Just-in-Time stresses the importance of mixed model runs. (Sandras, 1986:10) A mixed model run is a small lot size run of part A, followed by part B in a small lot size run, followed by part C in a small lot size run. The production flow will be A, B, C, A, B, C... With a fixed model run a small change in the schedule (e.g. due to demand) has a large impact on the production capacity and stock levels (i.e. not enough stock, or too much stock). With the smaller lot sizes of a mixed model run it is easier to adapt to the changes.

6.4.2.3 Reduced set-up times

To achieve the small lot size goal, set-up times need to be reduced drastically. The Japanese have revolutionised this concept by showing that set-up times can be reduced dramatically through applying a scientific approach. (Sandras, 1986:8) This is accomplished in two steps: firstly the set-up tasks are separated into internal and external tasks. The external tasks are all those that can be accomplished while the machine is producing. Secondly the internal tasks are analysed and improvements made to reduce the total set-up time. It may be that some tasks are eliminated, or the time required per task is reduced. (Fogarty et al., 1991:584) In their aim to reduce set-up time they initially sought SMED (single minute exchange of dies i.e. set-up of machines under 10 minutes). Next they aimed for OTED (one touch exchange of dies, i.e. set-ups under one minute) and the ultimate goal is NTED (no touch exchange) where either no set-up is needed or the set-up can be accomplished in the time it takes to transfer a completed part out of and another into the machine (Sandras, 1986:9).

6.4.2.4 Scheduling

Production scheduling in a Just-in-Time environment is based on the actual need and not planned need. This implies that production is driven by market demand (pull system) versus the push system (produce to make stock). A push system assumes the next workstation will be ready to process the material, where-as in a pull system the material is not sent to the next workstation until it is requested. Toyota's pull system is called the Kanban system due to the Kanban cards and containers originally used. Toyota also utilises an electronic form of Kanban within their distribution and logistical network. (Murphy & Schreffler, 1999: 72)

Kanban cards and/or containers are used to indicate when a workstation can start with the fabrication of a new batch of items. De Vries (1987:5) describes the process as follows: "As a container is emptied of parts at the second work centre, the container and kanban are returned to the preceding, or first, work centre, where the kanban authorises production of another container of parts".

The secret of the Kanban system lies in the number of Kanban cards that are circulating in the system at any one time. The number of cards controls the number of parts produced per time period. Fogarty et al (1991:591) presents a formula to derive the number of Kanban cards to use in a sequential flow process.

$$N \geq \frac{D\,(M + P)(1.0 + S)}{Q}$$

Where

N = the integer number of cards/containers required

D = the demand rate per hour

M = the average wait and move time required for the card/container

P = the average set-up, run and inspection time required to manufacture the parts in the card/container

S = a safety factor, expressed as an percentage

Q = the quantity of parts held by each container

To implement Just-in-Time scheduling is therefore "...to move towards producing a set of products across the range, with quantities in proportion to the current sales mix, in shorter time buckets." (Bicheno, 1986:22). However, Bicheno emphasises that it is dangerous to move towards Just-in-Time scheduling unless good inventory control have been achieved. Just-in-Time scheduling (pull system) assumes that the material for a specific work centre will be available when that work centre needs it. If the inventory control system is not working satisfactorily, work centres may be stopped due to a lack of feed material. This can lead to late deliveries of final products.

6.4.2.5 Uniform work loads

Just-in-Time demands smooth and stable production rates due to the nature of the Just-in-Time deliveries of feed materials from suppliers and the lack of large work-in-process buffers. The daily production schedules determine the production rates – make daily what you want to sell daily. A uniform workload is defined as the cycle time required to meet, but not exceed demand. It is a production rate for all components and assemblies that is synchronous to the demand rate (Wheeller, 1986:7). It is not possible to keep the production rate the same for all machines, but the bottlenecks should be occupied fully and the non-bottlenecks can be allowed some idle time. (Bicheno, 1986: 22)

6.4.2.6 Engineering

With the demand for a stable plant the reliability and availability of the production line is very important. Engineering problems can affect the total production line and bring production to a standstill. As there are no excess buffers in the production line a breakdown can shut the whole line down. Therefore preventive maintenance management is a crucial element in a Just-in-Time environment. The focus of the preventive maintenance program is on process control: to eliminate the production of defective units. The operators also have a big responsibility in understanding and identifying maintenance problems. The operator needs to be responsible for first line maintenance. The engineering department also needs to focus on the automation of equipment. The more tasks that the equipment can perform itself (health checks etc.) the more flexible the operator becomes.

The maintenance and production departments must be aligned to understand each other's needs. Engineering problems that arise must be discussed between the two departments, prioritised and given attention to as planned. The traditional communication methods and barriers between production and maintenance do not allow for quick response time. In a Just-in-Time environment people from production and maintenance will be part of the same quality circles (Sandras, 1986: 14).

6.5 PROBLEM SOLVING AND MEASUREMENT TOOLS & TECHNIQUES

A Just-in-Time company focuses on continuous improvement in the process of eliminating waste. Therefore the problem solving and measurement tools used within a Just-in-Time company are focused on these two aspects. It is important to note that the problems that are focused on are firstly the chronic problems, then the sporadic problems (Hutchins, 1988:52). The sporadic problems are normally dramatic and sudden, but their solution would present no change from past performance. It would just normalise the situation. Chronic problems on the other hand are those problems that have always been there. They go unchallenged and people have become accustomed to them. These are the problems that the Just-in-Time problem solving and measurement tools aim to isolated and solve. This chapter explores these tools.

6.5.1 Problem solving sequence

Hutchins (1998:54) describes a universal problem solving sequence as presented by Dr Juran.

- Firstly the symptom is clearly defined:
    - A set of theories on the causes of the symptom is defined. This is done by utilising typical TQM techniques such as brainstorming, Pareto analysis and the fishbone diagram.
    - Next these theories are tested in an effort to identify the true cause of the symptom.
- Secondly a remedy for the cause is developed:
    - All possible remedies are listed.
    - The optimum remedy is selected.
    - The remedy is tested for validity and implemented.
- Thirdly the remedy needs to be sustained:
    - The ever-present RTC factor (resistance to change) must be addressed.

- The remedy must be transformed into a solution that will last without constant supervision. If this is not possible regular process audits need to be conducted.

An example of this process in practice can be observed at the Toyota SA plant in Durban (as observed by the author on a visit in May 2003). The different teams make use of process flows describing the part of the process they are responsible for. Any deviations picked up within the process are captured on a problem identification sheet, referring to detail such as the process step, time and date. These deviations range from a part falling from a specially designed bracket to a product deviation. As the teams rotate (work in shifts) the information is clearly visible for all teams working in that work centre, and all contribute to the problem solution process. The team then discusses all the problems during their daily meeting. Possible reasons for the deviation are listed and explored. When the team has identified the root cause of the problem this is captured on the problem identification sheet. This illustrates step 1 in the above sequence. The decision on what action to take to fix the problem is handled in the same way.

6.5.2 Specific measurements

Just-in-Time requires an appropriate measurement system that will focus on the key values of the philosophy. Fogarty et.al. (1991:600) list the following key criteria to be measured:

- *Raw materials*: inventory dollar days, raw material stock outs, setup reduction, vendor delivery performance, vendor quality performance
- *Equipment*: machine breakdowns, setup reduction
- *Facility*: space requirements (utilisation)
- *Employee*: morale, education and training acquired, labour effectiveness
- *Final product*: cycle efficiency, process improvement, lot-size reduction, material stock-outs, WIP reduction
- *Transformation process*: cycle efficiency, process improvements

They also describe a KPI to measure manufacturing efficiency (ME) that differs from those used in non-Just-in-Time companies. Traditionally ME is calculated by dividing the total of setup time and operation time by the total manufacturing lead-time. However this will provide a misleading result, as the queuing or waiting time is included in the calculation of the total setup and operations time. A more accurate measure of ME is VAE (value added efficiency). VAE is calculated by dividing the processing time by the total manufacturing lead-time of the part. This result is an accurate measure of the percentage of time a part is being processed and therefore having its value increased.

6.5.3 Process improvement

Identifying deviations can be by observation (refer to the Toyota SA example) or by statistically analysing the process. As quality management is a key value of Just-in-Time, process capability and improvement studies are used extensively in a Just-in-Time company. The aim of these studies in a Just-in-Time company is to eliminate variability, and therefore increasing predictability. Hutchins (1988:120) describes it as being the essence of Just-in-Time: parts leaving a machine can be assembled without the need for any checking, and they will always be defect free (no waste in the system). Just-in-Time utilises control charts and Statistical Process Control to determine process capability and then improve the process. These methods are discussed in detail in the chapter on Total Quality Management, paragraph 5.5.1.

6.6 IMPLEMENTATION

It is important to realise what is needed for a successful implementation of Just-in-Time as it can have disastrous effects if handled wrongly. Womack & Jones (1996: 140) state two reasons why lean production efforts do not deliver on the promised results. One is that many companies understand and utilise the underlying concepts (as discussed in paragraph 6.3) but they cannot integrate the concepts into a coherent business approach. In essence they grasp the power of the individual concepts (i.e. Kanban, pull scheduling, work centers) but are not able to implement the different concepts together in a balanced system. Secondly, it is very difficult to introduce the concepts into mature organisations (organisations that are not in the start up phase any more, that have entrenched systems and processes), as these organisations are usually not susceptible to change. Specific areas to focus on before introducing Just-in-Time in a company are described in the following paragraphs.

6.6.1 Suppliers

Just-in-Time production schedules can play havoc with suppliers. They may experience uneven demand for labour and equipment that can result in excessive set-up and production control cost. This is due to the demand for smaller lot sizes to be delivered more frequently. The suppliers need to change the way that they manage the transport of the items. De Vries (1987: 13) mentions the term "contract shipping" as a mechanism for suppliers to manage their logistical cost. It is essentially a transport plan developed between the supplier and the manufacturing company with the aim to keep trucks moving with as full as load as possible – thereby reducing the handling cost per unit and increasing the time between deliveries. With contract shipping components are off-loaded at a plant and finished products loaded for delivery at another point.

6.6.2 Employee commitment

The role of employees in the success of Just-in-Time has been mentioned before. Therefore it is a vital pre-requisite that the employees are totally committed to the new method of operations to be followed. Keys (1991:22) describes the management style that is needed within a Just-in-Time company to create the new culture. Employees should be managed according to Theory Z (a theory of behaviour). According to this theory everyone in the organisation:

- Trusts everybody else
- Has an in-depth understanding of their fellow employees
- Has a common heritage and cultural background.

In a diverse country aspect number three cannot easily be achieved, but nevertheless the company needs to develop a culture and shared values that will bind the employees together regardless of heritage and cultural background.

Keys (1991:22) also underlines the value of the Just-in-Time elements trust, subtlety and intimacy. These must be in place to enable everyone in the organisation to co-operate fully in achieving the Just-in-Time goals of the organisation. These elements support the Theory Z principle to achieve fully motivated people.

Also, the demands that Just-in-Time places on the workers imply that they need to be well educated. To be successful with Just-in-Time a company may have to retrain a major part of the organisation.

6.6.3 Capacity production

During the process of implementing Just-in-Time many disruptions may occur as waste is identified and eliminated. To curb the impact of these disruptions Keys (1991:24) advises that Just-in-Time companies should attempt to operate at less than full capacity. The spare capacity is needed otherwise disruptions are magnified. Where possible the production rate should also be stabilised. By not having to solve problems caused by erratic production scheduling the company can focus on process control, waste eliminations and the successful implementation of all Just-in-Time elements.

6.6.4 Long term emphasis

Just-in-Time is inherently a long-term approach to doing business (Keys, 1991:24). It is questionable if a company will see any results with implementation of Just-in-Time when the reason for the change is to get a quick fix. If middle management is under short-term pressure to increase profits any hope of a successful Just-in-Time implementation are doomed.

6.7 CONCLUSION

In this chapter the management philosophy Just-in-Time was discussed. Just-in-Time can be described as an operational management philosophy that aims to deliver the required product, within very strict time limitations, to the exact requirements of the demand. It is a philosophy that embraces the production chain from the designing phase through to the client receiving the final product.

This chapter presented the key values of Just-in-Time and explained the impact these values have on the functions within a company. The unique measurement tools and techniques used in a Just-in-Time company were discussed. Finally the pre-requisites for successful implementation of Just-in-Time in a company were determined.

7 THEORY OF CONSTRAINTS

7.1 INTRODUCTION

Eli Goldratt developed the Theory of Constraints in the mid 1980's. It evolved from the production scheduling software called OPT (Optimised Production Timetables), developed and marketed by the company that Goldratt was the chairperson of (Rahman, 1998:p336) & (Goldratt, 1998:p1). The concepts of OPT was illustrated in a novel, The Goal. The formulation of Theory of Constraints as an operational management philosophy evolved over the years too not only encompasses shop floor activities but all aspects of business. This chapter will explore the different aspects of the Theory of Constraints.

7.2 OVERALL MANAGEMENT PHILOSOPHY

A comprehensive definition of the Theory of Constraints is provided by Geyser (1995:1): "The Theory of Constraints is an overall management approach which enables management to focus on the identification and elimination of the organisation's constraints and to implement a process of ongoing improvement in order to achieve the organisation's goal". Normally the objective of an organization, or its goal, would be to make profit, in the short term as well as the long term. Therefore the Theory of Constraints ensures profit maximisation by focusing on the constraint/s within the organization.

Bushong, Talbott & Burke (1999:p53) refer to Theory of Constraints as "...a systems approach based on the assumption that every organization has at least one factor that inhibits the organization's ability to meet its objectives. Simatupang, Hurley & Evans (1997:748) elaborates on this idea by stating that Theory of Constraints is "...a series of interdependent elements joined together like a chain for a common purpose. The weakest link serves as a constraint that prevents the system from achieving its goal". It is clear that the constraint in any system restricts the performance of the system in relation to its goal (Siha, 1999:p255).

Rahman (1998:p337) builds on the concept of constraint management by stating that there must be at least one constraint within every system, and that this is not necessarily a bad thing as it presents opportunities for improvement.

The Theory of Constraints can therefore be described as an operational management philosophy that manages the organisation as a chain and focuses on the weak links within the chain, with the aim to make profit now and in the future.

7.3 THE KEY VALUES OF THE PHILOSOPHY

7.3.1 Causality vs. Necessity

One of the basic building blocks of Theory of Constraints is the issue of causality and necessity (Houle, 1998:p1). Causality is the logical thought process of "if…then". When you want to undertake an action, you ask yourself: "if I do this, then something specific will happen to me". Necessity is looking at a situation from the future backwards. The statement would be: " to have a certain result, I must do something specific, or obtain something". By not only looking at a "if...then" phrasing but at "if…then…because" it is possible to clarify the reasons why things will happen, and that can lead to the surfacing of certain assumptions. The current reality (as it is perceived) can be altered by asking these questions together. That will provide solutions that can prevent negative results, or it can enhance positive results.

These two concepts are used to provoke the thinking processes regarding the perceived reality. It challenges the perception of current reality and in doing so surfaces the assumptions that may exist and also assists in creating an understanding of the environment that the reality exists in. A thorough understanding of the problem is created leading to solutions that are clearly thought out and projected into the future.

7.3.2 Constraints

A company can be viewed as a chain where the links represent the different processes that exist in the company. All the different processes in the value chain, e.g. procurement, manufacturing, distribution, sales and marketing, are essential in turning raw material into final products delivered to the client. These individual processes are integrated and as in a chain, there is always one weak link that limits the strength of the whole chain. That weak link is defined as the constraint of the system. A constraint can be physical (a resource, raw material etc) or managerial in nature (a policy on overtime, marketing focus area).

A constraint is anything that limits a system from achieving its targets and/or a higher level of performance than the baseline. The importance to know where the constraint in a system is located cannot be underestimated. Goldratt (1986: 179) states that "An hour lost at a bottleneck is an hour lost for the total system" and "bottlenecks govern both throughput and inventories". Also, as the constraints determine the performance of the system, any improvement in the performance of the constraint will improve the performance of the system (Rahman, 1998:p337).

According to Burkhard (1999:p2) there exist four types of constraints: physical constraints, supply constraints, market constraints and policy constraints. There are rarely more than two constraints in a system. The challenge for the business owner is to identify the constraint/s and to manage them. This is achieved by using the five focusing steps of the Theory of Constraints.

7.3.3 Five focusing steps for continuous improvement

A practical approach to identify and manage the constraints is defined in five steps (Goldratt & Cox, 1992: p303). It is important not to skip a step as that can lead to a process breakdown, which in turn may lead to wrong decision-making regarding the identification and management of the constraints.

1. *Identify the constraint(s)*

   There are various ways to do this. The most obvious method to determine where a physical constraint is located is to find the pile-up of work-in-process before a workstation. More analytical methods would be to determine the tempos of workstations (the unit with the slowest tempo could be the constraint), determine where the workers are always working (no idle-time) etc. To determine a managerial or policy constraint it is necessary to make use of the Theory of Constraints thinking processes (specifically the Current Reality Tree), as described in paragraph 7.5.

2. Exploit the constraint(s)

When the constraint has been identified, it must become the focus area of operational planning and management. This unit must not be allowed to stop because of other system inefficiencies. Everything needs to be done to ensure constant production at this workstation. This can be done by scheduling the priority entities being processed by the constraint to have preference, placing a buffer before the constraint to ensure constant feed, ensuring that only feed products of the right quality is processed by the constraint (to prevent unnecessary rework) and installing good quality control for the products moving downstream from the constraint (as a unit that has been processed by the constraint and that is scrapped later is lost for ever as a final product – there are no spare units). A managerial constraint should not be exploited but eliminated. (Rahman, 1998:p337) The managerial constraint should be replaced by a policy that will support increased throughput.

3. Subordinate everything else to the constraint(s)

This implies that every other component (non-constraints) in the system must be adjusted to support the effectiveness of the constraint. The constraint should determine the production schedule of the manufacturing chain. The non-constraints will need to work according to the tempo of the constraint. Non-constraints by definition have extra production capacity. This extra capacity must not be used to produce more units than the constraint is capable of at 100% utilisation. Non-constraints are therefore allowed to have idle time.

4. Elevate the constraint(s)

In this step the constraint is broken. It is essential that the order of these steps is followed, and managers must restrain from jumping to this step. The logical order of these steps will ensure that the optimal solution is found within a shorter time period. There are many ways of elevating a constraint, e.g. adding additional resources, work can be outsourced or the product can be re-designed to send it through another unit.

5. *Do not let inertia set in: refocus on the next constraint(s)*

When the constraint has been broken the performance of the system will rise, but soon another constraint will emerge. As soon as this happens the cycle needs to be repeated. The policies and rules made when exploiting a constraint, needs to be re-examined. It may be that those rules and policies have become constraints in themselves.

Rahman (1998:p336) illustrates the concept graphically in figure 7.

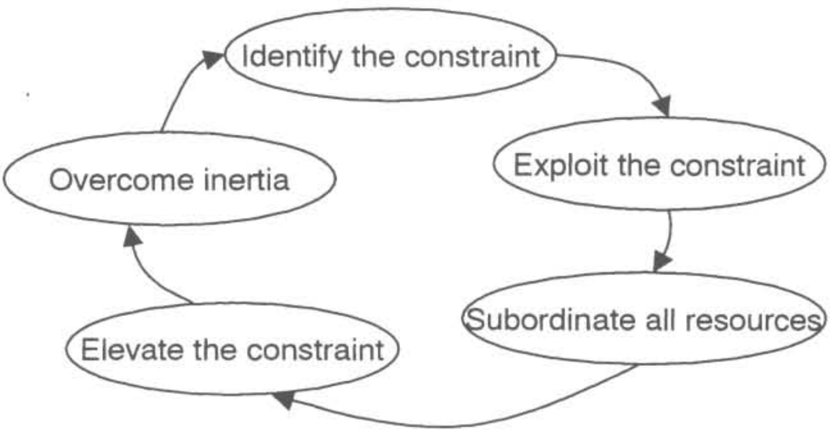


Figure 7: Theory of Constraints five focusing steps

7.3.4 Constraint based measurements

Traditionally companies use financial measurements (ROI, NPV etc.) when evaluating and making business decisions. These companies operate in the "cost world". In this world the focus is on cost cutting, not increasing sales. But there is a limit to cutting costs: a point is soon reached where further cost cutting results in the loss of operational efficiency. When looking at the fundamental measurements of the Theory of Constraints cost is captured in categories but not allocated to products. The three fundamental measurements are:

- Throughput: the rate at which the system generates money through sales
- Inventory: all the money the system invests in purchasing things the system intends to sell
- Operating expense: all the money the system spends in turning inventory into throughput

These fundamental measurements are described in more detail in paragraph 7.5.

When using throughput as the main driver for making business decisions there is no limit to the performance increases that can be realized in a company. Such companies concentrate on increasing and expanding their market demand (increasing their throughput). Donlin (1993:p52) states, "Where throughput is the focus, every action is geared to moving the company forward". When the three fundamental measurements are used in business decision-making, the bottom line measurements are impacted, moving the company towards greater profitability. The following table shows the link between the Theory of Constraints measurements and the traditional bottom line measurements.

Table 10 : Theory of Constraints impact on bottom line(Goldratt, 1986, p31)

FUNDAMENTAL MEASUREMENTS	BOTTOM LINE MEASUREMENTS		
	Net profit increase	Return on investment increase	Cash flow increase
Throughput ↑	√	√	√
Inventory ↓		√	√
Operating expense↓	√	√	√

7.4 IMPACT ON FUNCTIONS

The Theory of Constraints has a profound impact on the way a business is run. It requires a total mind shift, as the traditional methods and thinking within a business are no longer valid.

7.4.1 Finance

Many companies have elaborate financial and non-financial measurements that are not necessarily contributing to the goal of an organisation. Rexford, Lockamy III & Cox III (2002:p197) conducted an experiment to determine the performance of a company using traditional cost accounting versus constraint based accounting. They came to the conclusion that the performance of a company will dramatically improve when making use of the fundamental measurements of the Theory of Constraints and focusing on constraint management. One reason lies in the fact that the concept of "product cost" does not exist within the Theory of Constraints. In constraint-based accounting all indirect and direct labour cost is treated as fixed operational costs, and cost is not allocated to a product. Business decisions are made by evaluating the constraint, and calculating the impact on the business based on the throughput - and operating cost per constraint minute (Geyser, 1995:p1). Rexford et.al (2002:p191) explains that traditional cost accounting methods assume independence between events; therefore the sum of the individual improvements in the system is equal to the improvement of the system. Constraint-based accounting recognizes the constraint as the limiting factor with regards to the system's ability to perform.

7.4.2 Marketing and sales

In a throughput world the organisation's ability to achieve vast sale increases is not limited by policy constraints, as would be the case in a cost world organisation. By using the five focusing steps the focus is placed on those issues that prevent sales; those issues that are making customers unwilling to buy more of the company's products (Geyser, 1995:p3). More innovative approaches to new product development, market niche creation, product range etc. can be developed. The emphasis of the marketing department changes to develop an offer that the client cannot refuse. Houle (1998:p6) refers to this approach as the "Implementable Unrefusable Offer".

Marketing and sales also have a role to play in the identification and management of the company's constraints. Their marketing strategies must revolve around the performance of the constraints, as the constraints dictate the product throughput, and therefore the sales (Geyser, 1995:p3). If a sales team base their strategy on profitability ranking derived from traditional cost-absorption accounting, it may be that the products that use the constraint most efficiently are not highly ranked. This can lead to the wrong marketing strategy, in that the constraint is not being utilized to the fullest (Burkhard, 1999:p5).

7.4.3 Scheduling

The Theory of Constraints uses a scheduling technique known as DBR (drum-buffer-rope) scheduling (Goldratt & Fox, 1986, p98). This technique consolidates all scheduling around the tempo of the constraint. The drum is the rate of production of the constraint. The whole plant produces according to this beat. The reason is that the constraint's production rate is the slowest, thus non-constraints are limited in their production to ensure a low inventory level. If for some reason non-constraints fall behind, they have excess capacity to catch-up. The rate of raw material releases is synchronised with the drum, thus the concept of a rope between the first workstation and the constraint. Provision is made for disruptions in the production that can cause the constraint to stop, by building a buffer in front of the constraint. This buffer is referred to as a time-buffer, as it is linked to the average time it will take to restore any disruptions in the stations preceding the constraint.

A buffer is also placed before all assembly stations where parts moving through a constraint are combined with other non-constraint parts. This is to ensure that products are finished and shipped on time.

The advantages of this approach are: (Goldratt & Fox, 1986:p96)

- Current throughput is protected.
- Future throughput is enhanced.
- Operating expense is not increased (no extra equipment or operators needed to cover for inefficiencies in system)
- Inventory is reduced

Goldratt & Fox (1986:p100) describe the steps for implementing the drum-buffer-rope scheduling technique:

- Determine the constraint (market demand could be one).
- Determine the schedule of the constraint by taking into account its limited capacity and the market demand that it must satisfy.
- Schedule the succeeding operations normally from the constraint's schedule. When a part leaves the constraint the next operation can start, and so forth.

- The preceding operations are scheduled to include the production of the time-buffer just in front of the constraint.
- Build in a time-buffer before any assembly where a constraint feed and non-constraint feed is combined. Now backtrack from this time buffer to schedule when the non-constraints should start producing.

As this is a constantly changing environment where constraints are constantly elevated and broken the schedule must constantly be refined to fit the new constraints.

Rahman (1998:p339) lists nine rules to be followed when following Theory of Constraints scheduling:

- Balance flow rather than capacity. This requires a different approach to releasing raw materials into the system, materials handling etc.
- The level of utilization of a non-constraint is not determined by its own potential but by a constraint in the system.
- Utilisation and activation of a resource are not synonymous.
- An hour lost at a bottleneck is an hour lost for the total system.
- An hour saved at a non-constraint is just a mirage.
- Constraints govern both throughput and inventories.
- The transfer batch may not (and many times should not), be equal to the process batch.
- The process batch should be variable and not fixed.
- Schedules should be established by looking at all the constraints simultaneously, knowing that lead times are the result of a schedule and cannot be predetermined.

7.4.4 Project management

Traditionally when a project plan is developed people tend to combat the uncertainty of predicting estimated task durations by including safety time. Safety time is therefore built into all tasks, leading to a very conservative project duration estimate. Project managers know this, and usually cut the estimated task duration times. As the task owner knows that he built in safety, he will wait until the last moment to start with the task, usually too late (as other critical tasks also stake a claim to his time). This is one of the factors that lead to projects rarely being completed on time.

The Theory of Constraints has a different approach to project management called Critical Chain Scheduling. The critical chain is defined as the longest chain of dependant steps within the project (Rand, 2000:p176). Patrick (1998,p1) defines critical chain management as: " it identifies and protects what's critical from inevitable uncertainty, and as a result, avoids major impact of Parkinson's law at the task level while accounting for Murphy's law at the project level". He describes the paradigm shift that is needed, in that project managers must shift their focus from ensuring that milestones are achieved to the only date that matters, the final due date of the project.

The Critical Chain method differs dramatically from normal project management thinking in the following ways:(Patrick, 1998:p1-7) & (Jacob & McClelland, 2001:p1-12)

- Tasks' estimated durations are only based on the time needed to do the work without any safety time built in.
- Aggregated safety factors are built in by utilising buffers of time. Feeding buffers are built in where a non-critical task feeds a critical chain task. The feeding buffers protect the critical chain from execution variability along the paths that feed it. A project buffer is built in at the end of the chain, with the aim to protect the project from the effects of execution variability along the critical chain.
- Non-critical resources working on a task that will be passed on to a critical resource, will warn the critical resource in advance that they (non-critical resources) are nearing the end of their task. This will enable the critical resource to prepare for the task and immediately work on it when it is passed on.
- A work ethic called "relay runner work ethic" calls for people to begin work as soon as they have been assigned to a task, to work continuously until completion of the task, and to provide immediate notification of the completion of the task. This is in contrast with traditional project management where resources often wait until the last moment to start with a task, and rarely inform anyone if the task is finished ahead of time.
- Project control is accomplished not through tracking due dates, but through a concept called "Buffer management". It is a process of managing the aggregated safety in the feeding and project buffers.

- The progress of a project is not measured in terms of the progress already made (% completed), but by determining the amount of work left, the status of the project and the size of critical tasks buffers.

7.5 PROBLEM SOLVING AND MEASUREMENT TOOLS & TECHNIQUES

7.5.1 Thinking processes

Many operational and system problems (e.g. under production, not meeting sales targets, high production costs) are manifested in inappropriate policies and behavioral patterns. To solve these types of problems / constraints three questions must be answered: what to change, what to change to, and how to cause the change (Houle, 2001p3). The "what to change" question could be very difficult to answer as a problem may have many undesirable effects (UDE's) that cloud the real problem. Usually the effort in problem solving is directed at solving the UDE's but the core problem is not identified and solved. Therefore a UDE may be eliminated but many more will surface until the core problem has been identified and rectified. Cooper & Loe (2002:p137) state, "An accurate identification of the core problem provides a platform to analyse the roots, rather than the symptoms of success and failure". The Theory of Constraints' thinking processes are a set of logical tools that assist people in answering the questions of "what to change, what to change to and how to cause the change". Goldratt (1998b:p5) developed the thinking processes with the aim to:

- Enable people to rapidly identify the core erroneous policy.
- Enable the construction of new policies without bringing on new problems.
- Enable the construction of a feasible implementation plan that would not be hampered by resistance to change.

There are five thinking processes that are used (Rahman, 1998:p341):

What to change?

- The Current Reality Tree (CRT) determines the root causes and core problems.

What to change to?

- The Evaporating Cloud (EC) reveals underlying assumptions.

- The Future Reality Tree (FRT) transforms innovative ideas and interventions into powerful solutions.

How to cause the change?

- The Pre-Requisite Tree (PRT) removes possible obstacles form blocking the solutions.
- The Transition Tree (TT) formulates a detailed implementation plan.

The different thinking processes are discussed in the following paragraphs, (SAPICS, 1994:p1-11).

CURRENT REALITY TREE (CRT)

The CRT focuses your thinking to identify the core problem (s) of a situation. Undesirable effects are usually attacked in an effort to solve problems. This does not have a lasting effect. The CRT is used to determine the causality between the undesirable effects and then arrive at the core problem(s). The process starts off by listing all the different UDE's that exist. The different UDE's are connected to each other, by asking the questions to determine the causality and necessity between them. These questions are continuously asked until the one or two core problems are identified – those problems that lead to all the UDE's. Figure 8 is a graphical representation of the basic outline of a CRT.

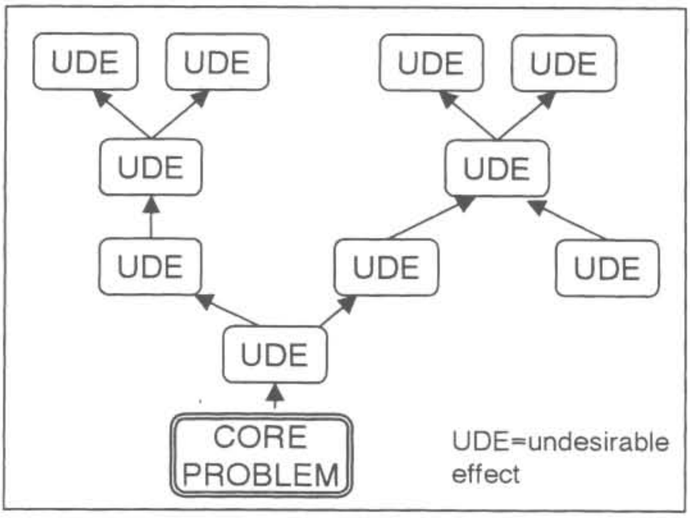


Figure 8: A basic outline of a current reality tree (Sapics, 1994)

A company that is battling financially will be used as an example to illustrate the different trees. The company's sales are down, customer complaints are pouring in, and the share price is taking a tumble. Figure 9 shows the CRT constructed for this company. The core problem of the company is identified as the fact that cost is higher than sales volume.

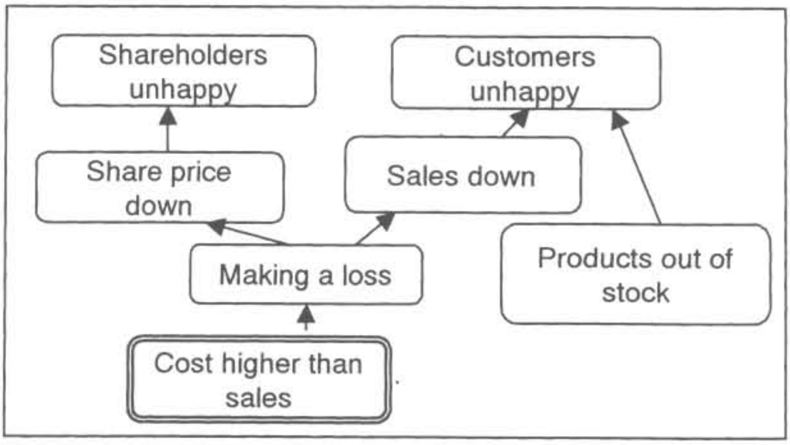


Figure 9: Example of a CRT

THE EVAPORATING CLOUD (EC)

When the core problem(s) have been identified by die current reality tree, the question " what has prevented us from eliminating the root cause in the past?" invariably arises. The answer usually lies in the conflict between opposing forces. An example can be *laying off people vs. not laying off people*, both requirements to achieve a goal. Once these opposing forces have been identified evaporating clouds can be built. The challenge now is to be very innovative in challenging the assumptions underlying these opposing forces. This is a crucial step to ensure the successful elimination of the core problem(s). In challenging the assumptions creative ideas for the solution are generated. Figure 10 provides the conceptual outline of an EC.

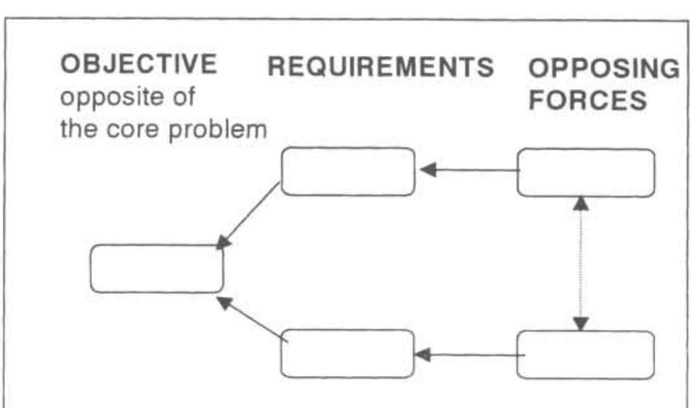


Figure 10: A conceptual outline of an evaporating cloud (Sapics, 1994)

Building on the example provided, an EC for the company in trouble could be as shown in figure 11. The objective of the company is to obtain the opposite of the core problem, in this case to make a profit (sales being more than the cost). To enable this they need to produce more products, and as the company is working on a two-shift system they need to work overtime to achieve the extra output.

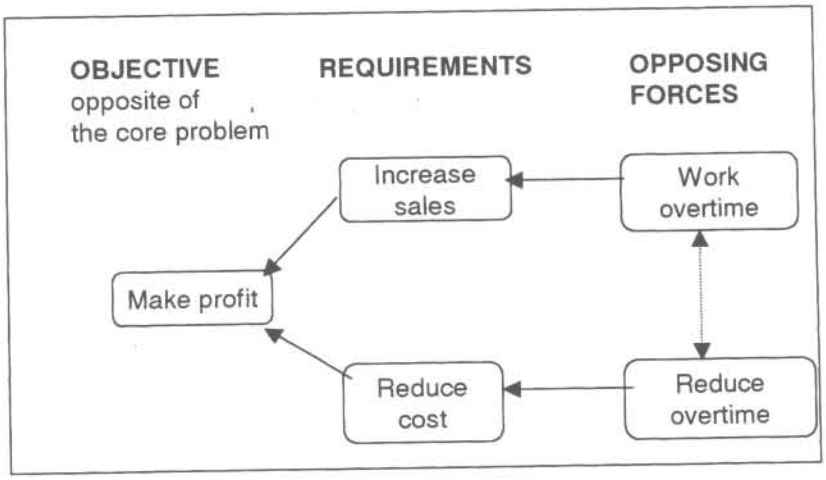


Figure 11: Example of an EC

The underlying assumption is that the only method to increase production is to work overtime. When management discussed the dilemma with the unions, they decided to bring in another shift that will be manning the constraint resource. This will be far cheaper for the company than paying extra overtime over a long period (while also staying within the overtime restrictions of the labour law and therefore not paying penalties) and more work opportunities are created with the additional shift.

THE FUTURE REALITY TREE (FRT)

The ideas generated from the EC need to be changed into a solution. All the interventions needed to create the solution must be determined. The future reality tree should be a mirror image of the current reality tree. All the UDE's are transformed into desirable effects (DE's). A well-constructed future reality tree will reflect all the positive effects that will stem from the interventions as well as the actions needed to eliminate the root causes. It may be that negative branches are identified. A negative branch is a concern that stems from the proposed change. Specific injections are needed to trim the negative branch, i.e. eliminate the concern. Figure 12 illustrates the conceptual outline of a FRT.

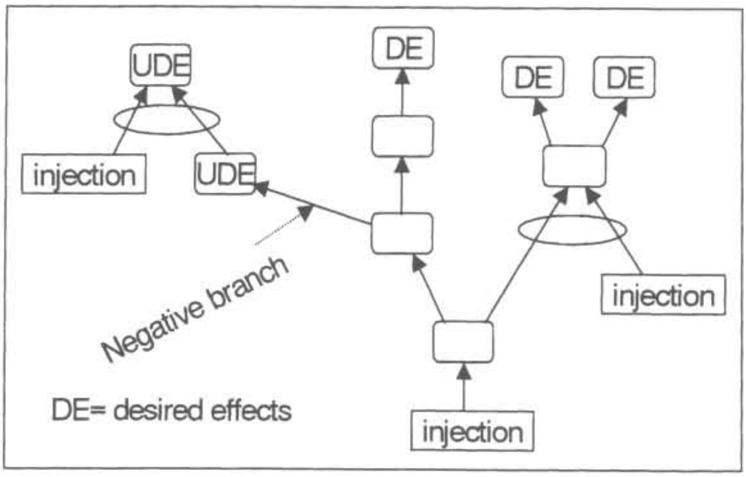


Figure 12: A conceptual outline of a FRT (Sapics, 1994)

In the example the solution decided upon was to add an additional shift. The result of this is depicted in the FRT in figure 13. The injections needed to insure that the solution works, are "HR handles change management effectively", "sales force can sell additional volume in negative market", and "competent people are available". These are the critical factors that must be in place to achieve the DE's.

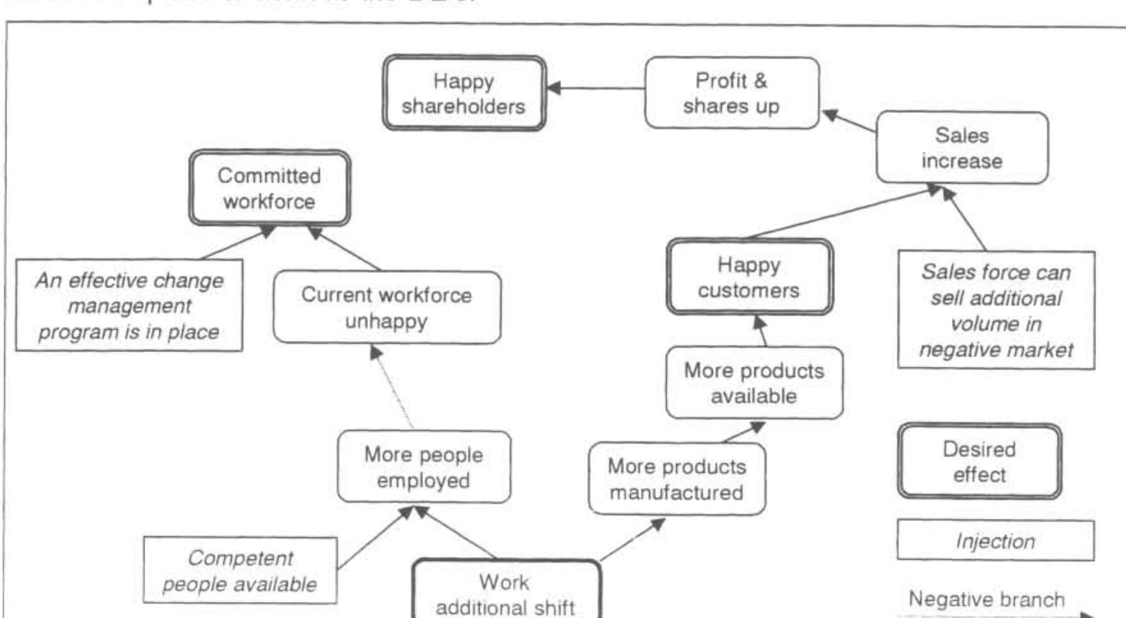


Figure 13: Example of a FRT

THE PREREQUISITE TREE (PRT)

The FRT is the outline of the solution. The injections needed to achieve the solution are not described in detail, and the assumption is that they are achievable. However, there may be certain obstacles that can prevent these injections from happening. The PRT is used to determine these obstacles and to develop ideas to overcome them. These ideas are known as "intermediate objectives". Every obstacle must have intermediate objectives developed that will overcome the obstacle. Refer to figure 14.

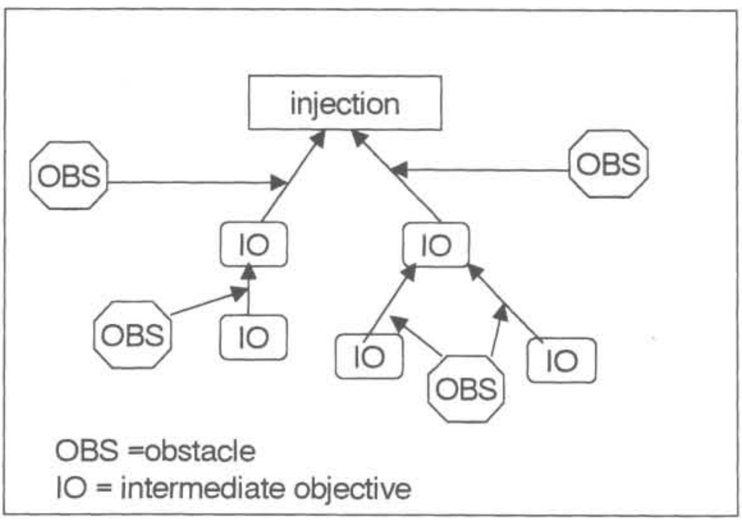


Figure 14: A conceptual outline of a PRT (Sapics, 1994)

Referring to the example, a PRT was developed for the injection "an effective management program is in place" (figure 15). This enables the company to understand clearly what must be done to ensure that all the injections are in place, leading to a successful implementation of the third shift solution.

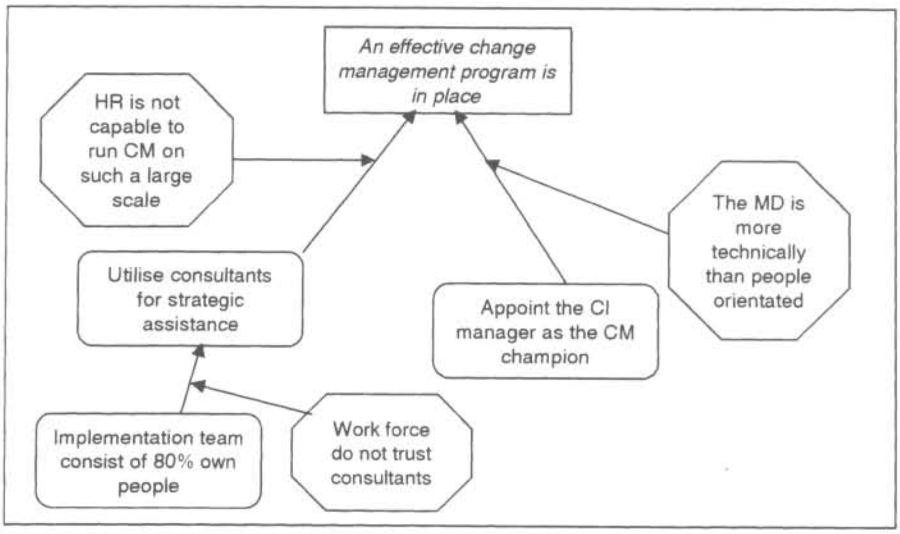


Figure 15: Example of a PRT

THE TRANSITION TREE (TT)

The TT is used in conjunction with the FRT to arrive at a detailed implementation plan. It transforms the strategic outline reflected in the FRT into a tactical outline. The steps that need to be taken by specified persons to reach the intermediate objectives as shown in the PRT are plotted in a time sequence. An example of the design of a FRT is depicted in figure 16.

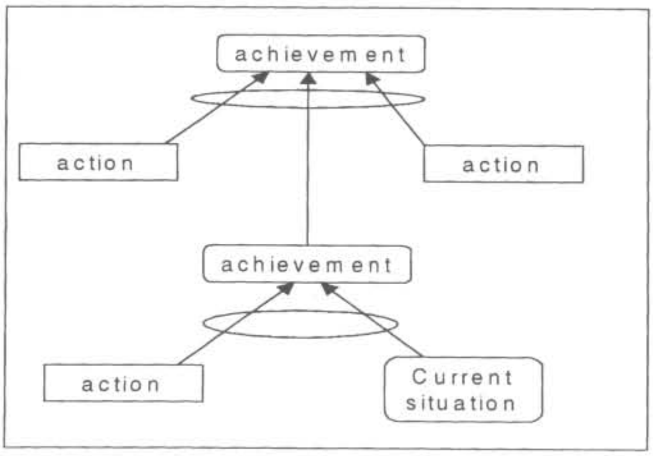


Figure 16: An outline of a TT (Sapics, 1994)

The one Intermediate Objective identified in the example was to utilise consultants to assist with the change management needed. The detail action plan to appoint the consultants is shown in the TT in figure 17.

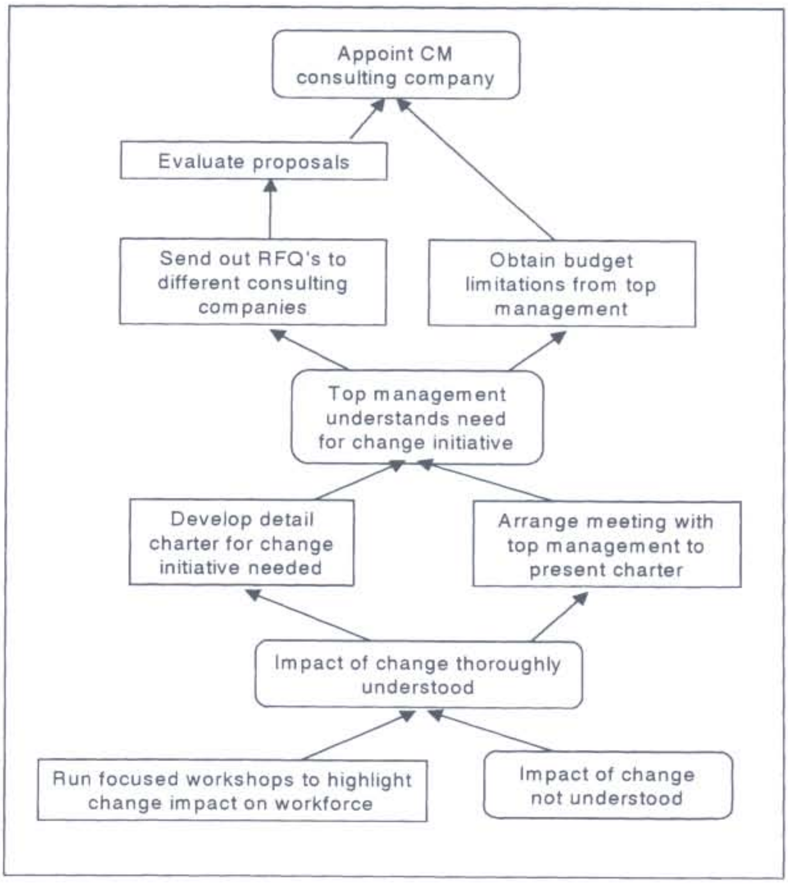


Figure 17: Example of a TT

SUMMARY OF THE THINKING PROCESSES

To summarise the use of the five thinking processes, the transition tree was used. It shows the process that starts of with UDE's, through the development of solutions and the final implementation plan. Refer to figure 18.

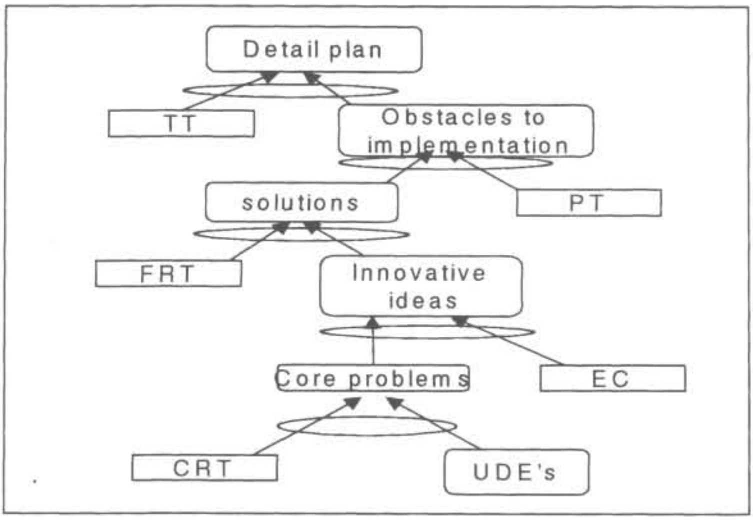


Figure 18: Graphic outline of use of tree's

7.5.2 Fundamental measurements for the entire system

To measure the entire system, the three fundamental measurements of throughput, operating expense and inventory, as well as the traditional measurements of net profit and return on investment are used.

Throughput, operating expense and inventory were briefly touched on in paragraph 7.2.4. In the following paragraphs these measurements are discussed in more detail (Goldratt, 1987:p4-13).

Throughput

The rate at which the system generates money through sales

The words "through sales" is very important, as it stresses the fact that increasing the finished goods stock without selling it does not contribute positively to the net profit of the company. Furthermore, throughput cannot be achieved from internal money transfers, because no money enters the system. A sale only takes place at the point where money exchanges hands and it is an irreversible transaction.

The unit for throughput is an average rate at a convenient time period, e.g., R/month. The Rand value equals the sales made in the period minus the purchased materials that went into these sales. More clearly, " throughput is ... sales minus all the money paid per item to entities which are external to the system" (Goldratt, 1987:p6).

Inventory

All the money the system invests in purchasing things the system intends to sell.

Normal financial methods determine "cost of goods sold" as "purchase price of raw material" + "value added" (labour, overhead). The "net profit" is then calculated as "sales" minus "cost of goods sold". To be able to show a high profit per financial period the "value added" items are moved around between periods. This can lead to a situation where a reduction of inventory (good practice) reflects as poor performance on the financial statement. Most companies are forced by external parties to report inventory as an asset. The Theory of Constraints does allow for this, but an internal reporting system that differs from this approach is used to base business decisions on. In this approach value added to inventory is disregarded. Finished goods are valued according to the price paid for the materials used in it, without any allocated cost.

Items used in operating the plant (e.g. hydraulic oil) are added to inventory when purchased. As it is consumed it is transferred from Inventory to Operating Expense. This also applies to other assets like buildings and machinery. Depreciation is allocated to operating expense. All capital investment forms part of inventory.

Operating expense

All the money the system spends in turning inventory into throughput

Operating expense is the money used to change raw material into saleable product. All maintenance and operational material, labour, utilities and sundries will be classified as operating expense the moment it is used. All the costs that can be linked to the conversion of inventory into throughout are included. There is no difference made between fixed, variable, direct or indirect cost. The salary of the managing director is handled in the same way as that of the shop floor worker.

It is now very easy to define waste. Any expense that does not contribute to converting inventory into throughput is waste and should be avoided.

Traditional bottom line measurements

Using only throughput, inventory and operating expense as measurements, management is capable of measuring the performance of the company. As the traditional measurements of return on investment and net profit are so entrenched it would be unwise to totally disregard them. Goldratt (1988a:p14) describes the link between the fundamental measurements and the bottom line measurements as follows:

Net Profit = Throughput minus Operating Expense:

(NP = T – OE)

Return on investment = Throughput minus Operating Expense divided by Inventory:

(ROI = (T –OE)/I)

Non-financial measurements, for example productivity and inventory turns, can also be expressed using a combination of throughput, inventory and operating expense.

Inventory turns = Throughput divided by Inventory

(Inventory turns = T / I)

Productivity = Throughput divided by Operating Expense

(Productivity = T/OE)

7.5.3 Control measurements

Goldratt (1988a:p15) describes a set of measurements called "control measurements". These are supportive of the fundamental measurements in that they can be utilised to measure the total system but also sub-systems. The three measurements, Throughput-Rand-Days, Inventory-Rand-Days and Local-Operating-Expense are discussed below.

Throughput-Rand-Days

This measurement deals with quantifying the magnitude of the deviation of the plant from its promised commitments to clients. It measures things that were supposed to be done and were not done. Many plants measure this in either number of shipments missed or number of units not sent. When the size of the orders and the selling prices of the units do not differ these measurements are sufficient. As soon as these differ it is necessary to introduce a different measurement. Throughput -Rand-Days are the value each order has when assigning a value equal to its selling price multiplied by the number of days the shipment is late.

The target of Throughput-Rand-Days is zero.

Inventory-Rand-Days

Inventory-Rand-Days measures things that we should not do but were done anyway, for example building a high finished goods inventory to increase the efficiencies of certain equipment.

Companies measure finished goods inventories in Rand value and time value. To calculate Inventory-Rand-Days these metrics are multiplied. For example a R2 million inventory with a 5-day period until it is sold (finished inventory) equals an Inventory-Rand-Days value of 10. By calculating the Inventory-Rand-Days the focus is placed on inventory reduction. To decide how much inventory to reduce, the concepts of Customer-Tolerance-Time and Product-Lead-Time are used. Customer-Tolerance-Time is the time from when a customer places an order until he expects delivery. Product-Lead-Time is the elapsed time to produce the product without giving it any special priority versus other products. If the Customer-Tolerance-Time is more than the Product-Lead-Time it is not necessary to hold any finished goods inventory. For the opposite scenario finished goods inventory should be held to cover the expected demand in the interval equal to Product-Lead-Time minus Customer-Tolerance-Time.

Local Operating Expense

Local-Operating-Expense is the expense the local area (department) has full control over. This refers to the direct expenses that the area has control over, without any allocated costs. These allocations must not be included in the expense account used for this measurement, but captured where it actually occurs. An example is the allocation of overhead Information Management (IM) cost. The local area may be a user of IM facilities but do not incur any cost – therefore the cost should not be allocated. If the local area did expend IM cost (i.e. buying a new computer) that cost will be included in the Local Operating Expense account.

7.6 IMPLEMENTATION

The prerequisites for a successful and sustainable implementation of Theory of Constraints are discussed next.

7.6.1 Change management

The Theory of Constraints implies a dramatic change from the traditional way of doing things. It is therefore important for management to have a formal change management program in place. This program must allow for a gradual change in the processes, but all the while keep the momentum of the implementation. Jacob & McClelland (2001:p11) describe an implementation process that is specifically designed to obtain the support and collaboration of all parties.

- Senior management needs to determine what changes are required, and what their specific roles will be in facilitating these changes.
- The organisation needs to be informed on what will change, why it is necessary, what the benefits are and when and how they (the people) will participate in the changed process.
- Previously trained experts analyse the business to map the generic Theory of Constraints solution to the business and identify areas for customisation.
- The whole organisation is involved in the new process; they are trained and their new roles are assigned.

- A specific date is assigned to the "go-live" of the new system.
- The process of continuous improvement starts.

When implementing the Theory of Constraints effective, fast and constant communication is essential. People and processes will be evaluated differently and that may cause some uncertainty in the workforce. People may be moved around due to constraint management activities, and they may perceive these changes negatively. Management needs to constantly reassure employees and involve them in the process from the beginning (Miller, 2000, 50).

7.6.2 Stagnation

Goldratt (1998b:p5) discusses the danger of stagnation within a company that operates according to Theory of Constraints principles. Stagnation can occur in three different ways. Firstly, a company can ignore step five of the five focusing steps. Step five forces one to revisit all the assumptions made when elevating a constraint. If the company does not re-evaluate the process constantly and check if the constraint identified is still valid, erroneous decisions are made that will lead to a loss. Secondly, a company may have used the five focusing steps to manage their physical constraints and have achieved dramatic results in a very short time. But as soon as the constraint becomes an external one, such as the market, the company often does not identify it and therefore cannot improve further. Thirdly, Goldratt (1987:p40) discusses the danger of being satisfied with your current position. When a company has gone through a major change and achieved substantial results, the danger is that they can become complacent and not embark on a continuous improvement program.

6. CONCLUSION

In this chapter the management philosophy Theory of Constraints was discussed. Theory of Constraints is an operational management philosophy that manages the organisation as a chain and focuses on the weak links within the chain, with the aim to make profit now and in the future. The key values of Theory of Constraints and the impact these values have on the functions within a company, as well as the unique measurement tools and techniques used were discussed. Finally the pre-requisites for successful implementation of the Theory of Constraints in a company were detailed.

8 HIGH LEVEL COMPARISON BETWEEN MINING AND MANUFACTURING

8.1 INTRODUCTION

In chapters 5-7 the content and characteristics of Total Quality Management, Just-in-Time and Theory of Constraints are discussed. Most of the theory, examples and case studies of these operational management philosophies are based on the manufacturing sector, whilst some refer to the services sector. It is therefore necessary to determine the differences between a mining and manufacturing environment before an operational management model for a mining production unit can be developed. The following paragraphs highlight the main differences.

8.2 PHYSICAL ENVIRONMENT

8.2.1 Static versus. Dynamic physical environment

A manufacturing company has a static physical environment. Usually it consists of physical structures (workshops, warehouses, plants etc) and outside yards. Fluctuations in the weather (rain, heat, wind) can influence outside operations, but normally inside operations will continue as before.

The situation in an underground coal mining unit is vastly different. There are physical structures above-ground (administrative buildings, workshops etc.) but the "manufacturing" of the product takes place underground where the environment is constantly changing. Because of the production process new ground is opened every day, changing the physical environment. Outside weather variations has an impact on the conditions underground, as it directly impacts temperature, gas build up etc. The physical environment is taken into account in the planning process in a mining company.

8.2.2 Safety hazards

In a manufacturing environment the production equipment and /or the products, assert a safety or health risk. This differs from the mining environment where not only the production equipment and product, but also the environment poses a hazard. Gas and / or coal dust explosions, roof falls and flooding are constant factors that need to be addressed, managed and planned for.

8.2.3 Expanding versus fixed physical environment

In a manufacturing company the size of the work area stay fixed. It only changes with new expansions or changed layouts. In an underground coal mining operation a section can advance an average of 30 m per shift. Taking into account that there can be 5-10 sections per mine, this constitutes a rapidly expanding mine. Some sections do pillar extraction [1], in effect reducing the mine area. Very accurate and up to date mine planning is needed to cope with this constant changing environment.

8.3 INVENTORY

8.3.1 Raw material

In a manufacturing company raw material is normally acquired from an outside supplier. Large procurement departments, warehouses and internal logistic systems are needed to manage the inventory. The stock levels of inventory and release strategy play an important role in the total production process.

In the mining production unit the raw material is already there. It does not need to be bought or transported to the beginning of the work stream. It does not have a price, except for the purchase price of the initial mineral rights. The stock levels are high enough to never have a problem with delivery. Releasing the material only depends on production planning. A

[1] During the normal pillar & board coal extraction process blocks of coal are left over while advancing, for roof support purposes. At the end of a viable block of coal, the section retreats, using pillar extraction as a method of reclaiming the blocks of coal left over. This causes the roof to fall behind the section, closing that part of the mine totally.

problem that can only partly be managed is that of the quality of coal. The inherent quality (inorganic content etc.) and other factors influencing the quality (dolerite intrusions, burnt coal) of coal can be predicted with different geological explorations. However, it is very difficult to achieve a high accuracy and is costly. The production team does have an influence on the quality of coal. Not cutting into the roof or floor and not loading metal and other scrap onto the belts can reduce the contamination. There are also various actions they can take to reduce the fine coal percentage.

An interesting observation is that in a manufacturing environment the raw material moves through the (fixed) first work station, and further along the production line. In a coal mine the raw material is fixed and the first workstation (continuous miner) moves through it.

8.3.2 Work-in-process

Work–in–process (WIP) in a manufacturing plant consists of the raw material going through different workstations and constantly changing form or characteristics. A combination of different raw materials is assembled and the final product looks different from the input materials. Buffers are used between workstations for various reasons, e.g. to protect the bottleneck, to hide inefficiencies, etc.

WIP in a coal mine is in essence the feedstock coal, mined from the coal face, crushed to smaller pieces, which are transported from the production section to the bunker. Underground it does not have as much value as when it lies on a stockpile, screened and blended. Value is also added by beneficiating it to differentiate between different grades of coal. Buffers underground and on surface are in the form of bunkers, and they are there to protect the output of the mine (a serie system of conveyors) as well as to achieve a smooth flow of coal. For export coal stockpiles have the added advantage of reducing the total moisture content of the coal.

8.4 STRATEGIC PLACING

Detail planning and research is needed to determine the best location for a specific plant. Market research, accessibility to transportation, distribution networks etc. play a role in determining where to base the plant. A mine is totally dependent on where the resources are located. If it is 60 km into a desert or near a big city, that is where the mine will be placed. This places a strain, logistically and cost wise, on the mine to ensure that workers, spare parts, equipment, the final product etc. are transported to the different locations efficiently.

8.5 SUSTAINABILITY OF RESERVES

A manufacturing company normally has more than one product line. The types of products and product mix can be changed according to market specifications and / or availability and accessibility of raw materials. A mining company is dependent on the reserves it has acquired. These reserves are not all of the same quality, and usually deteriorate the older the mine becomes (the main shaft is normally sunk at the spot with the best reserves). With increased productivity (necessary to stay competitive) the mine life decreases. New reserves need to be acquired for the company to stay in business. This can be difficult, as the resource pool is finite.

8.6 CONCLUSION

A mining production environment differs substantially from a manufacturing or services environment. These differences will determine to what extent different operational management philosophies can be applied in a mining production unit.

9 EVALUATING THE OPERATIONAL MANAGEMENT PHILOSOPHIES

9.1 INTRODUCTION

The three operational management philosophies Total Quality Management (TQM), Just-in-Time (JIT) and the Theory of Constraints (TOC) were discussed in chapters 5 to 7. The key values, specific problem solving and measurement tools and techniques as well as their impact on functional areas were described. From these elements those that are most applicable in an underground coal mining production unit must be selected. In this selection the main differences between a mining and manufacturing unit, as discussed in chapter 8, needs to be taken into account

Table 11 provides a summary of the elements of the three philosophies.

Table 11: Summary of the elements of JIT, TOC & TQM

KEY VALUES		
JIT	**TQM**	**TOC**
▪ Elimination of waste ▪ Quality ▪ Continuous process improvement ▪ Total employee involvement	▪ Total customer satisfaction ▪ Continuous improvement ▪ Fact based decision making ▪ Total employee involvement	▪ Causality & necessity ▪ Constraints ▪ Five focusing steps for continuous improvement ▪ Constraint based measurements

Table 11 continues

IMPACT ON FUNCTIONS		
JIT	**TQM**	**TOC**
• Procurement & Supply Management ○ Supplier management ○ Design & development ○ Storage • Production & scheduling ○ Group technology ○ Model mixes ○ Reduced set-up times ○ Scheduling ○ Uniform work loads ○ Engineering	• Safety • Marketing • Product design • Procurement • In-bound & out-bound logistics • Quality assurance • Organisational structure	• Finance • Marketing & sales • Scheduling • Project Management

Table 11 continues

PROBLEM SOLVING TOOLS AND TECHNIQUES		
JIT	**TQM**	**TOC**
• Universal problem solving sequence • Specific measurements ○ Value added efficiency • Process improvement through Statistical Process Control	• 14 Quality control tools • 7 Quality management tools	• Thinking processes ○ Current reality tree ○ Evaporating cloud ○ Future reality tree ○ Pre-requisite tree ○ Transition tree • Fundamental measurements ○ Throughput, inventory and operating expense • Control measurements ○ Througput-rand-days, inventory-rand-days, operating expense

9.2 RATING THE ELEMENTS

In chapter 4 the three functions that are critical for the mining operational management model were determined to be "streamline processes, manage bottlenecks and identify root causes". These functions are therefore the criteria against which the elements in table 11 are evaluated. The tool that is used for the evaluation is a perspective-modelling matrix (VM Services (v4), 1992).

In paragraph 4.4 the functions were scored, indicating the level of importance of the function. Utilising the score the functions are weighted proportionally on a scale of 1 to 10 (10 being the highest). The function "streamline processes" achieved the highest score, and therefore carries a weight of 10. "Manage bottlenecks" came second with a score of 10, and is weighed proportionally against the score of 13 of "streamline processes", thereby having a weight of 8 allocated. Similarly "identify root causes" is weighted as 7. The weighting of the functions is illustrated in table 12.

Table 12: Weighing the functions

FUNCTION	SCORE (as per par. 4.4)	% BASED ON HIGHEST SCORE	ALLOCATED WEIGHT
Streamline processes	13	100	10
Manage bottlenecks	10	76	8
Identify root causes	9	69	7

The weight per function is used in the perspective matrix to ensure that the importance of a function (with relation to the mining operational management model) is taken into account when evaluating the elements. The function plus its allocated weight is inserted at the top of the perspective matrix (refer to tables 13, 14 & 15).

The different elements are listed per category (key values, impact on functions and problem solving tools and techniques). The elements are evaluated per category, i.e. all the key values of each of the three management philosophies are compared against each other. Tables 13, 14 & 15 illustrate the evaluation of the elements per category, and following the tables the evaluation process is explained.

Table 13: Scoring of key values

Key to score
1 : poor
2: fair
3 : good
4 : very good
5 : excellent

ELEMENT OF PHILOSOPHY *Key values*	Function	Streamline processes	Manage bottlenecks	identify root causes	Total	Ranking
	Score	13	10	9		
	Weight	10	8	7		
JIT						
Elimination of waste	weighed score	50	32	7	**89**	**3**
	score	5	4	1		
Quality	weighed score	30	16	7	**53**	**8**
	score	3	2	1		
Continuous process improvement	weighed score	20	16	14	**50**	**9**
	score	2	2	2		
Total employee involvement	weighed score	30	24	21	**75**	**5**
	score	3	3	3		
TQM						
Total customer satisfaction	weighed score	10	8	14	**32**	**10**
	score	1	1	2		
Continuous improvement	weighed score	40	24	28	**92**	**2**
	score	4	3	4		
Fact based decision making	weighed score	20	16	28	**64**	**4**
	score	2	2	4		
Total employee involvement	weighed score	30	24	21	**75**	**5**
	score	3	3	3		
TOC						
Causality & necessity	weighed score	10	8	7	**25**	**11**
	score	1	1	1		
Constraints	weighed score	30	40	7	**77**	**4**
	score	3	5	1		
Five focusing steps for continuous improvement	weighed score	40	24	35	**99**	**1**
	score	4	3	5		
Constraint based measurements	weighed score	30	24	14	**68**	**6**
	score	3	3	2		

Table 14: Scoring of impact on functions

Key to score
1 : poor
2: fair
3 : good
4 : very good
5 : excellent

ELEMENT OF PHILOSOPHY	Function	Streamline processes	Manage bottlenecks	identify root causes	Total	Ranking
Impact on functions	**Score**	13	10	9		
	Weight	10	8	7		
JIT						
Supplier management	weighed score	10	8	7	**25**	**5**
	score	1	1	1		
Design & development	weighed score	10	8	7	**25**	**5**
	score	1	1	1		
Storage	weighed score	10	8	7	**25**	**5**
	score	1	1	1		
Group technology	weighed score	10	8	7	**25**	**5**
	score	1	1	1		
Model mixes	weighed score	10	8	7	**25**	**5**
	score	1	1	1		
Scheduling	weighed score	10	8	7	**25**	**5**
	score	1	1	1		
Uniform work loads	weighed score	10	8	7	**25**	**5**
	score	1	1	1		
Engineering	weighed score	30	16	7	**53**	**4**
	score	3	2	1		
TQM						
Safety	weighed score	10	8	7	**25**	**5**
	score	1	1	1		
Marketing	weighed score	10	8	7	**25**	**5**
	score	1	1	1		
Product design	weighed score	10	8	7	**25**	**5**
	score	1	1	1		
Procurement	weighed score	10	8	7	**25**	**5**
	score	1	1	1		
In-bound & out-bound logistics	weighed score	10	8	7	**25**	**5**
	score	1	1	1		
Quality assurance	weighed score	10	24	21	**55**	**3**
	score	1	3	3		
Organisational structure	weighed score	30	24	21	**75**	**1**
	score	3	3	3		
TOC						
Finance	weighed score	10	8	7	**25**	**4**
	score	1	1	1		
Marketing & sales	weighed score	10	8	7	**25**	**4**
	score	1	1	1		
Scheduling	weighed score	30	32	7	**69**	**2**
	score	3	4	1		
Project Management	weighed score	10	8	7	**25**	**4**
	score	1	1	1		

Table 15: Scoring of Problem solving tools & techniques

Key to score
1 : poor
2: fair
3 : good
4 : very good
5 : excellent

ELEMENT OF PHILOSOPHY	Function	Streamline processes	Manage bottlenecks	identify root causes	Total	Ranking
	Score	13	10	9		
Problem solving tools & techniques	Weight	10	8	7		
JIT						
Universal problem solving sequence	weighed score	40	16	28	**84**	**2**
	score	4	2	4		
Value added efficiency	weighed score	10	8	7	**25**	**6**
	score	1	1	1		
Process improvement through SPC	weighed score	30	24	21	**75**	**3**
	score	3	3	3		
TQM						
14 Quality control tools	weighed score	30	24	21	**75**	**3**
	score	3	3	3		
7 quality management tools	weighed score	20	16	7	**43**	**4**
	score	2	2	1		
TOC						
Five trees	weighed score	30	24	35	**89**	**1**
	score	3	3	5		
Fundamental measurements	weighed score	20	8	7	**35**	**5**
	score	2	1	1		
Control measurements	weighed score	20	8	7	**35**	**5**
	score	2	1	1		

Each element is evaluated against each function, with the purpose to determine the extent of the impact that the element has on the function. In effect it measures the level of influence the element has on achieving the function. For example, in table 15, the first element of Just in Time is "universal problem solving sequence". The evaluation process is to consider the details of the element (for this element provided in paragraph 6.5.1), and based on that knowledge, determine if the "universal problem solving sequence" will streamline processes in the mining unit, will assist in managing bottlenecks, and will assist in identifying the root causes of problems. Depending on the answer, a score is given on a scale of 1-5 (1=poor; 5=excellent), and entered in the bottom row against the element in the perspective matrix (named score). In the example, the "universal problem solving sequence" is deemed to influence the streamlining of processes very good, but will only assist moderately with managing bottlenecks.

To account for the importance of the relevant function, the weight of that function is multiplied with the score of that element relative to the function. Again referring to the example, the score of 4 given to the element "universal problem solving sequence" for the function "streamline processes" is multiplied with the weight of the function (10) and the result (40) is entered in the top row of the element (named weighed score)

When all the elements have been evaluated the weighed scores per element are summed and entered in the column named "Total". Relating to the example, the total weighed score for the element "universal problem solving sequence" equals "streamline processes weight + manage bottlenecks weight + identify root causes weight" (40+16+28) equalling the total score of 84.

In the column "Ranking" the elements are ranked from highest total weighed score (1) to lowest total weighed score.

9.3 ANALISING THE RESULTS

To analyse the results, and determine the elements that will be the building blocks for the mining operational management model, different mathematical and statistical analysis are performed. The results from these are used to make the final decision regarding the inclusion or exclusion of the different elements.

9.3.1 Mathematical and statistical analysis

All the elements with their respective scores are combined, sorted and ranked from highest to lowest weighed score (table 16).

Table 16: Summary of scores

NR	ELEMENT	PHILOSOPHY	CATEGORY	TOTAL	RANKING
1	Five focusing steps for continuous improvement	TOC	Key values	99	1
2	Continuous improvement	TQM	Key values	92	2
3	Elimination of waste	JIT	Key values	89	3
4	Five trees	TOC	Problem solving	89	3
5	Universal problem solving sequence	JIT	Problem solving	84	4
6	Constraints	TOC	Key values	77	5
7	Total employee involvement	JIT	Key values	75	6
8	Total employee involvement	TQM	Key values	75	6
9	Organisational structure	TQM	Impact on functions	75	6
10	Process improvement through SPC	JIT	Problem solving	75	6
11	14 Quality control tools	TQM	Problem solving	75	6
12	Scheduling	TOC	Impact on functions	69	7
13	Constraint based measurements	TOC	Key values	68	8
14	Fact based decision making	TQM	Key values	64	9
15	Quality assurance	TQM	Impact on functions	55	10
16	Quality	JIT	Key values	53	11
17	Engineering	JIT	Impact on functions	53	11
18	Continuous process improvement	JIT	Key values	50	12
19	7 quality management tools	TQM	Problem solving	43	13
20	Fundamental measurements	TOC	Problem solving	35	14
21	Control measurements	TOC	Problem solving	35	14
22	Total customer satisfaction	TQM	Key values	32	15
23	Causality & necessity	TOC	Key values	25	16
24	Supplier management	JIT	Impact on functions	25	16
25	Design & development	JIT	Impact on functions	25	16
26	Storage	JIT	Impact on functions	25	16
27	Group technology	JIT	Impact on functions	25	16

28	Model mixes	JIT	Impact on functions	25	16
29	Scheduling	JIT	Impact on functions	25	16
30	Uniform work loads	JIT	Impact on functions	25	16
31	Safety	TQM	Impact on functions	25	16
32	Marketing	TQM	Impact on functions	25	16
33	Product design	TQM	Impact on functions	25	16
34	Procurement	TQM	Impact on functions	25	16
35	In-bound & out-bound logistics	TQM	Impact on functions	25	16
36	Finance	TOC	Impact on functions	25	16
37	Marketing & sales	TOC	Impact on functions	25	16
38	Project Management	TOC	Impact on functions	25	16
39	Value added efficiency	JIT	Problem solving	25	16

These results are plotted on a line graph as shown in figure 19. On the horizontal axis the elements are represented (with reference to the number in table 16), and the vertical axis represents the score.

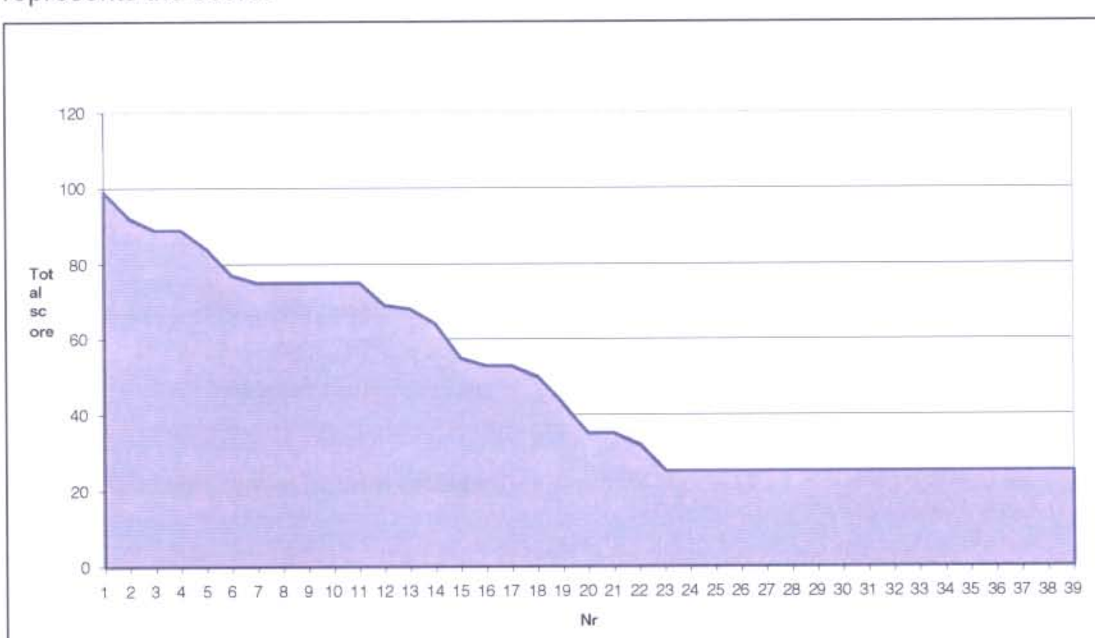


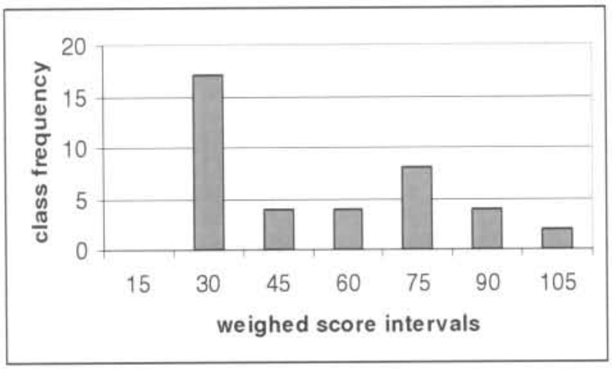
Figure 19: Graphical representation of score values

Basic statistical measures of the dataset containing the scoring results are performed (refer to table 17).

Table 17: Statistical analysis of data set

Measure	Value	Explanation
Mean	48.38	Average (arithmetic mean) of the score ratings
Median	35.00	Tthe number in the middle of the set of score ratings
Mode	25.00	Most frequently occurring, or repetitive, value in the set of score ratings
Standard Deviation	25.39	Measure of how widely values are dispersed from the average value (the mean).
Kurtosis	-1.32	Relatively flat distribution if compared with the normal distribution
Skewness	0.51	Indicates a distribution with an asymmetric tail extending toward more positive values.
Range	74.00	Maximum minus minimum values
Minimum	25.00	Minimum value in set of score ratings
Maximum	99.00	Maximum value in set of score ratings
Sum	1887.00	Sum of score ratings
Count	39.00	Number of elements in set of score ratings

Lastly a histogram based on the dataset is constructed. The aim is to determine if any pattern exists with reference to groupings of weighed score values. Refer to figure 20.



Bin	Frequency	Cumulative %	Indiv %
15	0	.00%	
30	17	43.59%	43.59%
45	4	53.85%	10.26%
60	4	64.10%	10.26%
75	8	84.62%	20.51%
90	4	94.87%	10.26%
105	2	100.00%	5.13%

Figure 20: Histogram of scored ratings

9.3.2 Discussion of analysis

From the line graph (figure 19) a separation between two sets of elements, at element 11 and 12 is observed. In the first set (1-11) the elements exhibit a natural closeness in the value of the scores, with stability in the ratings from element 7 – 11. In the second set (12-39) the elements depict a constant, linear drop in the scored ratings.

From table 16 it follows that elements 1-11(28% of total number of elements) represent 48% of the total score. If a Pareto ranking is performed on the dataset it does not provide any insight, as the 80% mark (based on the cumulative score) is only reached at element 24 (62% of the number of elements). The 80/20 rule is therefore not applicable as a method of determining which elements to include.

The statistical analysis in table 17 indicates a fairly flat distribution, with a large standard deviation. The large standard deviation between weighed scores is expected as the scoring process followed is fairly robust, and a difference of 1 on the score given can be amplified greatly due to the multiplication with the weight.

An interesting pattern is found in figure 20, the histogram. The bin range 0 – 60 contains 25 elements that contribute to 64% of the total score. This equates to an average of 2.6% per element. The bin range 60-105 contains 14 elements that contribute to 36% of the total score. This also equates to an average of 2.6% per element. Therefore elements 1-14 carry an equal weight compared to elements 15-25, and can be seen as a natural grouping.

To summarise, from the line graph elements 1-11 stand out as a possible cluster of elements, and from the histogram (and supporting data table) elements 1-14 stand out. As elements 12-14 support elements 1-11 and are not in disparity with any of the underlying assumptions of these elements, elements 1-14 are chosen as building blocks for the mining operational model.

9.4 CONCLUSION

In this chapter a set of 14 elements were identified as being the most suitable and applicable as building blocks for the mining operational management model. These elements all support the functions of the mining model as defined in chapter 4.

10 THE MINING OPERATIONAL MANAGEMENT MODEL

10.1 INTRODUCTION

The purpose of the mining operational management model was defined as:

"The operational management model needs to provide a first line supervisor with a proactive management tool that will assist him/her in quickly and easily adjusting the operations of the unit as well as to plan for the future in order to achieve the short and long term goals of the unit."

In the previous chapter the building blocks for the operational management model were chosen. From these building blocks the operational management model for a mining production unit is constructed. The model need to accomplish the purpose as stated above.

In the first part of this chapter the model is described. In the second part the roadmap to implement and institutionalise the model in a mining company is explained. In chapter 11 an illustration of the use of the model is provided.

10.2 OVERVIEW

For any production unit to succeed it must define what its purpose in the company is. This point of departure drives all further decision-making. This also applies to the mining operational management model. The production unit needs to define its vision and core values. Only then can the management of the unit be executed through the operational management model (from here-on referred to as the mining model). The mining model consists of two levels: a strategic and an operational level. On the strategic level a process focus exists, and continuous improvement of activities are driven. On the operational level the focus is on the day-to-day running of the unit. There is however a constant interchange of information between the two levels, and an integrated management approach is followed. The outline of the mining model is illustrated in figure 21.

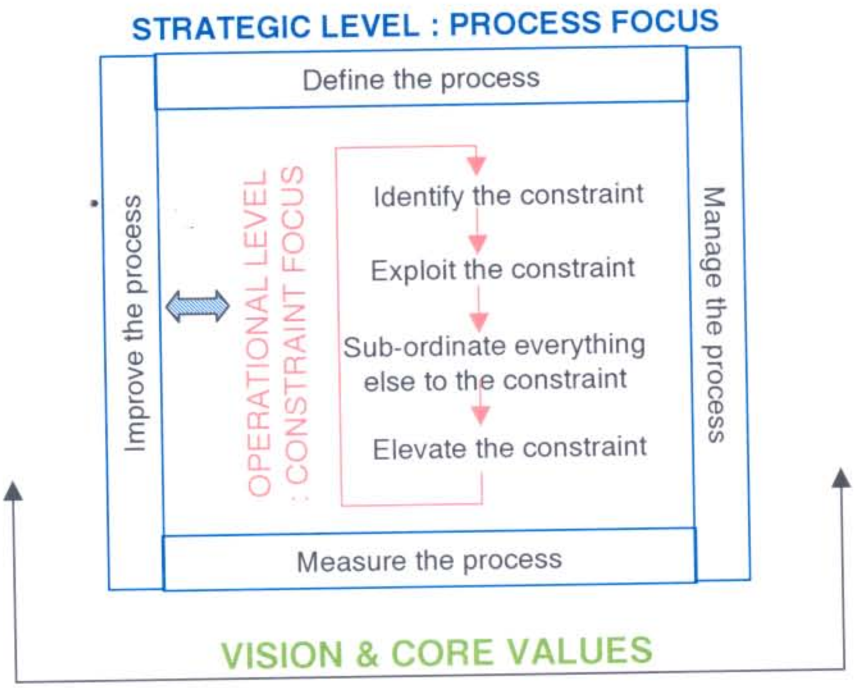


Figure 21: Overview of mining model

The different aspects of the model are discussed in the following paragraphs. To indicate how different elements are utilised as building blocks, the element number (referring to table 12, chapter 9, paragraph 9.3) is indicated in square brackets, i.e. *[element x]*.

10.3 TEAM FOCUS

The first step for any production unit is to understand what its purpose in the company is. Therefore the team needs to develop their vision and core values. The following are guidelines on the attributes of a vision and mission for the team:

<u>Vision</u>

A vision must:

- be aligned with the company's vision
- refer to the quality of the product (coal)
- refer to the achievement of the throughput targets

Core values

The core values must as a minimum refer to the following:

- The company's core values
- Waste elimination being a passion *[element 3]*
- Constraints dictating all decisions *[element 6]*
- Decision making based on facts not emotions *[element 14]*
- The accountability and responsibility of all team members *[elements 7 and 8]*

10.4 STRATEGIC LEVEL

After the team has defined their vision and core values, the steps of the strategic cycle take effect. At this level the mining model focuses on the processes within the production unit, as well as the processes that the unit interface with. It provides an ordered sequence of events that addresses process definition, process management and finally process improvement *[element 2]*. Steps 1 and 2 are a yearly activity whereas steps 3 and 4 are activities that take place continuously. Step 4 integrates with the operational cycle, as improvement opportunities that arrive from the constraint management activities within the operational cycle utilise the same process improvement steps as described in step 4 of the strategic cycle.

Step 1 - Define the process

The first activity within step 1 is to ensure that the organisational structure of the unit is conducive to team work *[element 9]*. Organisational barriers (such as a split in reporting between engineering and production) may not exist. It is advisable that a team building exercise with the assistance of a facilitator is held. As the team composition changes this step needs to be repeated periodically.

The next activity is to define the activities of the production unit, as well as the interfaces with activities outside of the production unit *[element 2]*. Mapping the processes, and indicating the boundaries, achieves this.

After the mining process has been mapped accountabilities for every step in the process is determined. This ensures that every team member understands his or her specific role and responsibilities.

Step 2 – Manage the process

This step identifies the process management rules for the production unit. These rules need to be in place to ensure that decisions are taken based on facts, and according to the strategy of the mine *[element 14]*. As these rules are based on customer satisfaction the first action is to determine what the customer's requirements are. This can be achieved by answering the following questions:

- What are the required production targets?
- What is the production schedule? (When must what quantity be produced)
- What is the allowable cost expenditure for the unit to achieve the targets?
- What are the required quality targets?
- What is the planning for the unit in terms of mine layout for the next year?
- What major initiatives are planned for the mine for the coming year?

After the questions have been answered it is necessary to establish measures that quantify the performance of the production unit regarding the requirements of the customers with relation to quality, production and cost.

Quality

The measurements for quality are related to the quality of the coal sent to the client. These may include the following:

- Coal size - the size distribution of the coal produced
- Contamination – the percentage non-carbon material in the coal.
- Calorific value – the energy value of the coal

Production

The main production target for a production unit is that of tons of coal mined. This is defined per year, month, week, day and shift, and the targets depend on the mine production plan.

Supporting the tonnage target are production time targets, so called time buckets (grouping together similar actions and measuring the time used per period-mining term) that can be tracked on a "minutes per shift" basis. Some time bucket categories are:

- Cutting minutes
- Maintenance minutes
- Breakdown minutes
- Operational delay minutes
- Geographical delay minutes

<u>*Cost*</u>

The budget for the unit is determined based on the production target. The budget is developed according to the Theory of Constraints' definitions of inventory and local-operating-cost *[element 13]*.

Step 3 – Measure the process

In step 2 of the strategic cycle the items that must be measured (KPIs) were determined. These KPIs need to be measured regularly (daily for the production and quality KPIs, monthly for the cost KPIs), and any deviations acted upon immediately. The specific tools used to measure the KPIs are:

<u>*Quality*</u>

- Use control charts to track quality measurements *[element 11]*. Firstly determine the capability of the mining process to produce coal according to the quality requirements within the boundaries of the geological circumstances. This will enable the first line supervisor to act immediately when deviations against not only the target, but also the capability of the mining process, occur *[element 10]*. It is important that the first line supervisor is thoroughly trained in the basis statistical measurements, in order for him to understand the control charts and use the information from them. He must also be able to explain the control charts to his team. The quality control department will perform the analysis of the data. The results of the analysis are provided to the first line supervisor, and he will plot it on the control chart in the unit.

- Where possible on-line analysers should be used to provide instant readings of the coal quality, but should still be backed up with the analysis from the laboratory.

The template for the control charts is shown in figure 22.

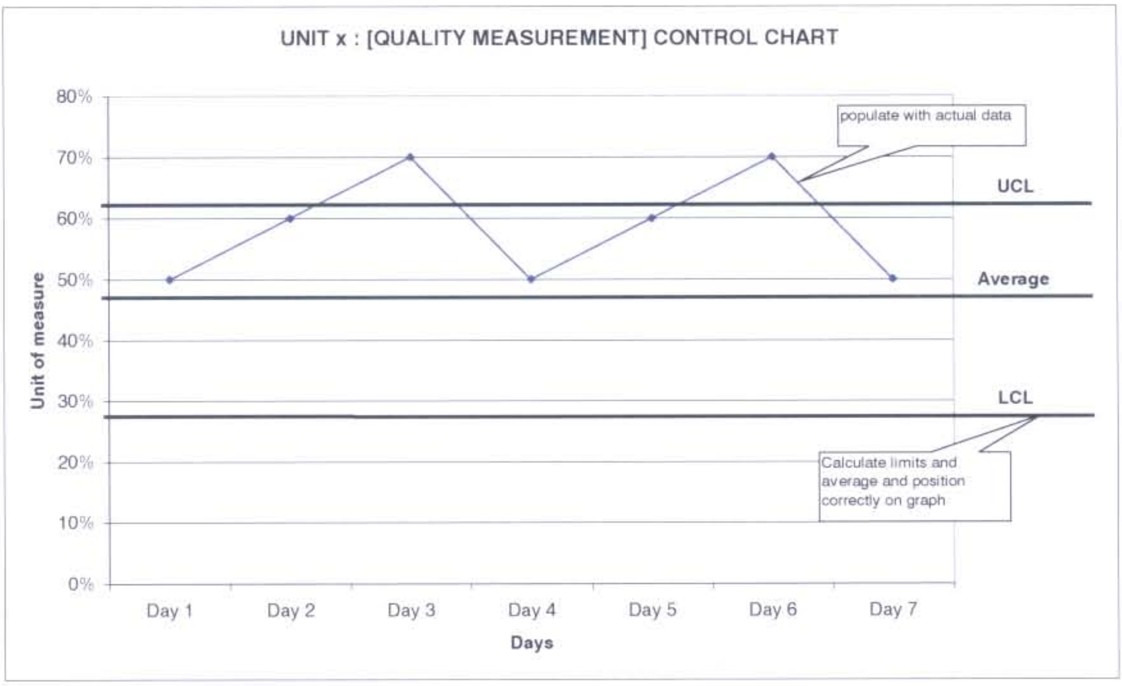


Figure 22: Template for quality control charts

Production

- To keep track of the tonnages line charts should be used, which the team can plot themselves to show the cumulative tons for the month, and year. The actual tons per shift produced are based on the scale readings (scales are installed on all section conveyor belts) and is provided daily to the first line supervisor. He then plots it on the graphs in the section. Refer to figure 23 for the template.
- Targets for the production time buckets should be determined for the production unit based on the tonnage that must be mined per shift. The ratio between the different categories of shift time can be pre-determined based on history. A scatter diagram per shift time category can be constructed, with on one axis the minutes and on the other the tonnages mined per shift *[element11]*. The time per bucket is determined

from the production report compiled during each shift. All non-production times are captured manually, and the cutting time of the continuous miner is captured via the hour meter on the continuous miner (also entered on the production report). These times are entered into the ERP (enterprise resource planning) system from where detailed reports can be extracted. The first line supervisor either pulls the information himself, or he receives it daily from his planner. He then plots it on the scatter diagrams in the section. Refer to figure 24 for the template.

Figure 23: Cumulative tons template

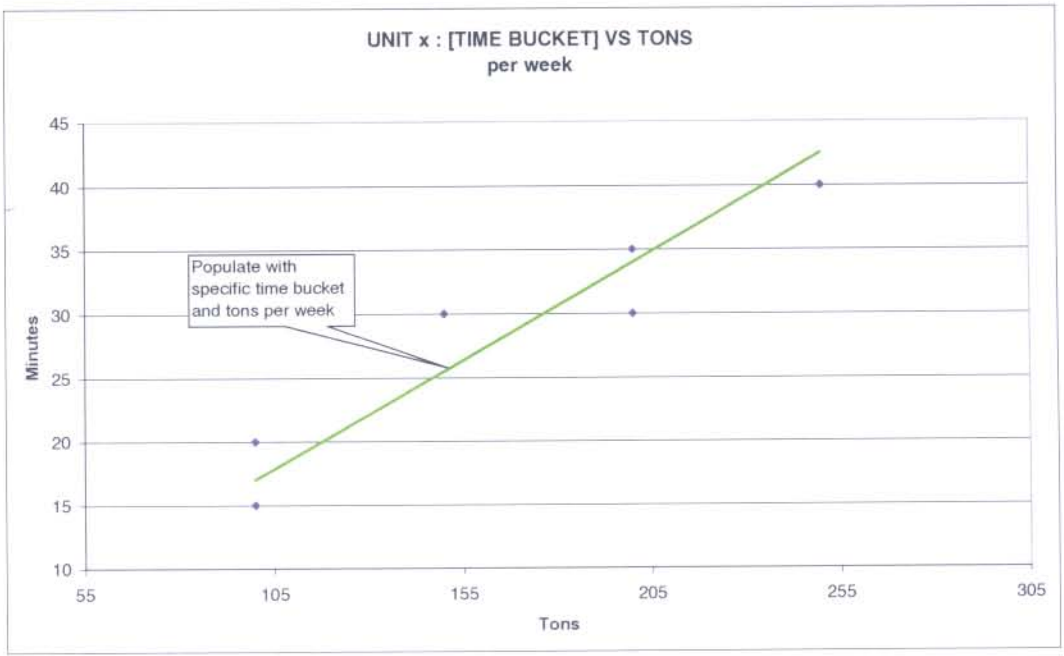


Figure 24: Tons versus time bucket template

Local-Operating-Cost and Inventory

- The cost expenditure needs to be broken down into main categories, i.e. overtime, maintenance, production material.
- These cost categories are measured on a weekly basis utilising a bar chart, plotting the actual against the budget *[element11]*. The first line supervisor extracts this information from the ERP, or the financial department provides it to him. Refer to figure 25 for the template.
- The inventory figures for the unit are managed on a unit of issue basis. Each mining section has a small store where day-to-day consumables and spares are kept. It is important that the levels of inventory are kept as low as possible. To track this all the different items kept in inventory must be counted weekly, the incoming stock added and the resulting final stock levels calculated. This can be tracked manually in a book, or where a computer is available on a spreadsheet. The first line supervisor determines minimum and maximum stock levels for the section based on the consumption history, lead time for delivery and risk profile of the item. These levels are determined in consultation with the stock optimisation department utilising the relevant formula for the mine.

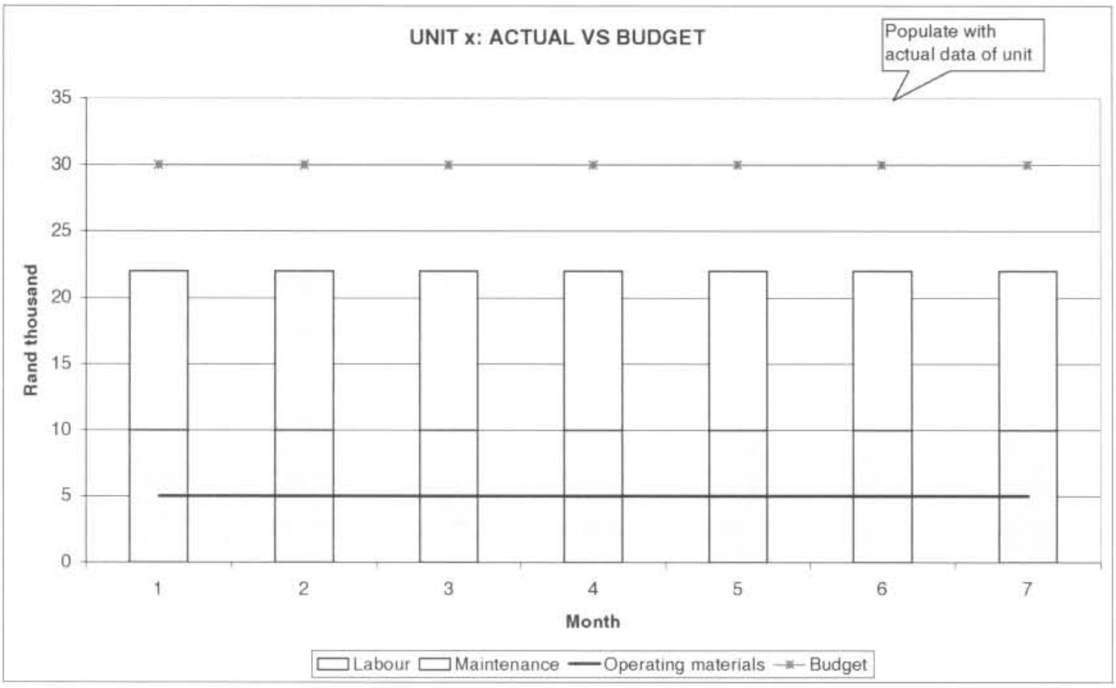


Figure 25: Actual versus budget template

Step 4 – Improve the process

The nature of the model implies that improvement opportunities will arise due to the measurement of the KPIs, as well as due to the constraint management activities. Therefore a constant interaction between the strategic and operational cycles takes place within this step. To address these improvement opportunities the following process must be followed: *[element 5]*

- Clearly define the deviation. To do this the following questions need to be answered:
  - When did the deviation occur?
  - Was it a once off, or did it occur more than once?
  - If frequently, is there a pattern in the occurrences?
  - Where did the deviation occur? What resources were involved?
  - What were the symptoms?
- Develop different possible reasons for the deviation. To do this various tools can be utilised:
  - Current Reality Tree *[element 4]*
  - Brainstorming, Fishbone Diagram, Pareto analysis *[element 11]*

- Each of these possible reasons are tested to determine if the occurrence of the reason would lead to the experienced symptoms as defined in step 1. From this analysis the core reason for the deviation will be identified.
- Develop a solution to prevent the deviation from occurring again. To be able to do this the following tools can be used:
  - Evaporating Cloud
  - Future Reality Tree
  - Brainstorming
  - Benchmarking
- An implementation plan for the solution needs to be developed. It is important that all interfaces with peripheral processes are analysed to ensure no negative effects due to the solution being implemented occur. For example a solution may require a section conveyor belt's speed to be increased, but where it feeds on the main conveyor belt the chute cannot handle the increased volume of coal. Depending on the complexity of the solution a full project plan may be needed. Before any project plan can be developed Prerequisite and Transition trees need to be constructed, to understand the impact of the solution fully and to determine all the interventions needed for the solution to be successfully implemented.

After the improvement plans have been developed, it must be implemented. It is the first line supervisor's responsibility to keep track of the progress of the improvement plans. This can be achieved by holding 2-weekly project meetings with the core team that is responsible for the implementation of the project.

It is important to close the loop of the strategic cycle by again revisiting step one to three whenever any major process change has taken place due to the process improvement process.

10.5 OPERATIONAL LEVEL

Through performing all the steps as per the strategic cycle the first line supervisor will have a clear understanding of the process and performance of the production unit. Continuous improvement activities take place that could alter the production capacity of the unit. It is therefore important that the day-to-day operations are managed taking into consideration what volume and quality coal the unit can produce and comparing that to what is expected from the unit.

The first line supervisor will make use of the five focusing steps of constraint management to manage the operations of the unit on a day-to-day basis *[element 1 and 6]*. At any point in this cycle the process improvement steps (paragraph 10.4.4) can be utilised to assist with developing solutions to identify and manage the constraint.

Step 1 – identify the constraint

The ideal situation in the coal-mining environment would be for the constraint to be the continuous miner, as that is the first operation in the production chain. This is however not always the situation. The constraint can either be within the unit itself, or the demand for coal. Where the constraint is within the unit it will be the operation where the tons/hour that can be processed is equal to, or less than, the demand for coal.

To identify the constraint one or more of the following steps are taken:

- Analyse the production tempos of the equipment in the section and compare that with the demand rate.
- Analyse the downtime information to determine where the major waiting time occurs.
- Execute time studies in the section.
- Ask the team members which piece of equipment or part of the process is keeping them from achieving their target.
- Utilise simulation software to identify the constraint.

The constraint can be one of the following:

- The coal (feedstock): it may be very difficult to mine due to the geological conditions.
- The production (continuous miner, roofbolter etc) or auxiliary (switch gear, water pumps etc.) equipment.
- The conveyor system transporting the coal from the production unit.
- A management policy.
- The production plan – the demand may be too low – the unit has capacity to produce much more than it is required to.

Step 2 – exploit the constraint

After the constraint is identified, it must be utilised to the fullest. The golden rule is that every minute lost at the constraint is a minute lost to the system. Every ton of coal lost due to the constraint is a ton lost forever.

There are different options available to exploit the constraint. The following are guidelines.

- Reduce set-up times. This is applicable where a machine needs to be set-up after maintenance or where items need to be changed during on-line maintenance (such as changing picks and spray-water heads on the continuous miner, changing drill-bits on the roofbolter etc.) *[element 3]*
- Utilise the constraint as fully as possible– investigate hot-seat change over, doing maintenance in the off-shifts etc.
- Improve the availability of the constraint. Make sure that the maintenance strategy that is followed on the constraint is the right one. Analyse the downtimes on the constraint in-depth to determine what the major problem areas are. Involve the supplier extensively to increase the lifetime of the constraint.
- Make sure the quality of the coal being processed by the constraint is correct. If the constraint is used to process sandstone, scrap or low quality coal, the time lost will not be gained later.
- The quality of the product as it is processed must be controlled very rigidly from the beginning of the mining process. In the mining process coal that is too finely cut, or contains too much stone, cannot be reworked. It implies that the time the constraint was kept busy handling the coal, is wasted. It is therefore important that the quality of the coal must be maintained from the first time it is cut. For example, the continuous miner need to have roof-and-floor control systems in place (to prevent it from cutting roof and floor), the picks must be sharp to prevent fine coal generation etc.

Step 3 – subordinate everything else to the constraint

The production rate of the constraint dictates the production tempo of the whole unit. The drum-buffer-rope scheduling technique needs to be utilised to schedule the production rate of all the processes in the unit *[element 12]*.

If the continuous miner is the constraint the scheduling is easy as the rest of the equipment can only work as fast as the feedstock tempo. If downstream equipment is the constraint, then the continuous miner's cutting tempo, for instance, need to be adjusted accordingly. If the demand rate is the constraint the coal feeder tempo must be adjusted to the required rate. That will have the effect of controlling the production rate of the whole unit.

Step 4 – elevate the constraint

Only when the constraint is being used to full capacity, and the scheduling has been adapted to follow the tempo of the constraint, must any attempt be made to increase the capacity of the constraint. This can be achieved by:

- Having a standby piece of equipment available to use when the constraint is down, or to use concurrently with the constraint.
- In a mining section it may be difficult to add production equipment, but redesigning some features of the equipment, or using a different model can also increase capacity.
- It is very important that the right equipment is used for the different mining conditions. Exchanging equipment with other sections to ensure a right fit with the environment is an option.
- Changing mining methods and/or procedures.

Step 5 - re-evaluate the system

When changes are made in the section, it sets in place a whole new set of rules, with the possibility of a new constraint that has emerged. Inertia must not be allowed to set in, and the first line supervisor needs to start again at step 1 of the operational cycle, "identify the constraint". This must happen every time step 4 of the constraint management cycle has been completed.

10.6 IMPLEMENTATION

To implement the mining model the following aspects have to be taken into account:

- the implementation pre-requisites for Just-in-Time, Theory of Constraints and Total Quality Management as described in chapters 5-7
- the method of institutionalising it in the mining company.

As the building blocks of the mining model have their roots in the three operational management philosophies (JIT, TOC & TQM) all the prerequisites for implementation of these philosophies need to be taken into account. The following list is a summary of all the prerequisites.

- Management and employee commitment
- Organisational culture of sustained communication.
- Proper planning of the implementation project.
- Training and education of the employees in the new initiative.
- Proper change management.
- Supply of parts logistics changed.
- Operate at less than full capacity.
- Long-term emphasis.
- Prevent stagnation.

The approach to capture these prerequisites in the implementation of the model, is as follows:

- A project sponsor from the management group must be appointed. The role of the sponsor is to support and guide the production units in the process of implementing the mining model.
- A road show where the following three topics are discussed must be held:
    - Why do we need to change?
        - High expectations from the customers regarding quality, cost and throughput of coal

        - Highly skilled technical people exist but without the necessary operational management skills
        - Shareholders expect world class business results
    - What must we change to?
        - Production units run as business units, according to world class business principles
        - Ownership of these units lies with the unit members
        - Integration across functions
        - Continuous improvement culture
    - How will we get there?
        - Implementation of the mining operational management model
- The mining model is first implemented with three pilot units, and rolled out to three more after a six-month period.
- Formal classroom based training takes place before and during the implementation period. The training is broken down into different modules, of which the first line supervisor and deputy attends all, and the total team attends some. Refer to table 18 for the training module details. On the implementation plan (table 19) the training intervals are indicated. The training is scattered over the implementation period to increase the learning process, and decrease the production loss at any one time due to training.
- Facilitators from the continuous improvement department also partake in the training, and they are allocated to a unit for support and guidance during the first six months of implementation.
- Formal reviews by mine management take place during the implementation period according to the implementation schedule depicted in table 19.
- Every six months the mining model is introduced to 3 more units. For a small mine (4-5 production units) the implementation period will be one year, and for a large mine (8-10 production units) approximately two years. This process can be accelerated if the number of units introduced to the mining model per six-month period is increased. It all depends on the resources available to act as facilitators and trainers.

Table 18: Training modules detail

Nr.	Module title	Content	Participants
1	Change management	Change management principles Team building exercises Team roles	FLS, TM, F[2]
2	Mining model	Methodology of mining model Illustration of mining model	FLS, TM, F
3	Basic statistical techniques	Control charts Basic statistical measurements (st.dev etc)	FLS, F
4	Basic finances	Definitions of inventory, local-operating-expense Determining a budget and controlling it	FLS, F
5	Constraint management principles	Five focusing steps of constraint management DBR technique	FLS, TM, F
6	Waste management	Different types of waste Ideas on eliminating waste	FLS, TM, F
7	Process improvement process	Steps for process improvement Quality circles principles	FLS, F
8	Basic problem solving techniques	Brainstorming Pareto Fish bone diagram	FLS, F
9	Advanced problem solving techniques	Five trees (TOC) Evaporating cloud	FLS, F

[2] FLS = first line supervisor; TM = team members; F = facilitator

Table 19: Implementation plan for mining model

	MONTH 1					MONTH 2			
	Initial stage	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
MINING MODEL ACTIVITIES	Road show	Define team vision, core values	Step 2 of strategic cycle:	Populate graphs & tables with unit actual data	Identify constraint	Constraint management steps	Constraint management steps	Constraint management steps	Constraint management steps
		Define the process according to step 1 of strategic cycle	-determine customer requirements		Measure against targets	Measure against targets	Measure against targets	Measure against targets	Measure against targets
			-establish measurements				Identify improvement opportunities from measurements	Identify improvement opportunities from measurements	Identify improvement opportunities from measurements
								Process improvement steps	Process improvement steps
TOP MANAGEMENT SUPPORT ACTIVITIES									Mine manager visits unit; discusses measurements and improvement opportunites
TRAINING	Modules 1 & 2		Modules 3 & 4	Module 5		Module 6	Modules 7 & 8		

	MONTH 3	MONTH 4	MONTH 5	MONTH 6	MONTH 7	MONTH 8	MONTH 9	MONTH 10-11	MONTH 12
MINING MODEL ACTIVITIES	Constraint management steps	Constraint management steps	Constraint management steps	Constraint management steps	Constraint management steps	Constraint management steps	Constraint management steps	Constraint management steps	Constraint management steps
	Measure against targets	Measure against targets	Measure against targets	Measure against targets	Measure against targets	Measure against targets	Measure against targets	Measure against targets	Measure against targets
	Identify improvement opportunities from measurements	Identify improvement opportunities from measurements	Identify improvement opportunities from measurements	Identify improvement opportunities from measurements	Identify improvement opportunities from measurements	Identify improvement opportunities from measurements	Identify improvement opportunities from measurements	Identify improvement opportunities from measurements	Identify improvement opportunities from measurements
	Process improvement steps	Process improvement steps	Process improvement steps	Process improvement steps	Process improvement steps	Process improvement steps	Process improvement steps	Process improvement steps	Process improvement steps
TOP MANAGEMENT SUPPORT ACTIVITIES	Mine manager visits unit; discusses measurements and improvement opportunites	Mine manager visits unit; discusses measurements and improvement opportunites	Mine manager visits unit; discusses measurements and improvement opportunites	Presentation to Executive Group: targets and results, improvement initiatives			Mine manager visits unit; discusses measurements and improvement opportunites		Relook vision & values; process definitions; customer requirements; measurements
									Presentation to Executive Group: targets and results, improvement initiatives
NEXT ROLLOUT PLANNING ACTIVITIES		Mine management determines 3 new units			3 new units start their cycle (month 1, week 1)				
TRAINING	Module 9			3 new units receive training on Modules 1 & 2					

10.7 SUMMARY

Utilising the identified elements from the operational management philosophies Just-in-Time, Total Quality Management and Theory of Constraints a model for use in the mining production unit is constructed. The model is simplistic enough for the first line supervisor to utilise but powerful enough to assist him in achieving, and exceeding, his targets. All the necessary prerequisites for a successful implementation are captured in the implementation plan.

11 MINING MODEL – APPLICATION

11.1 INTRODUCTION

In this chapter actual data from a coal mining section is used to provide an example of how the mining model is be applied. The actual data is used as a basis to identify deviations, and the techniques as prescribed by the mining model are demonstrated with fictitious examples.

11.2 UNIT INFORMATION

The production unit (Unit 1) is a single continuous miner development section (pillar-and-board) mining in an area with normal geological conditions. The equipment used in the unit is:

- 1x continuous miner (CM)
- 2 x roof bolters (RB)
- 1x in-section crusher and feeder
- 3x shuttle cars (SC)
- 1x in-section conveyor
- 1x switchgear and transformer
- 1x maintenance service unit
- pumps and other portable equipment

The seam height is approximately 3.5 meters, with some minor dolerite intrusions. The floor is soft sandstone and the roof is stable.

The section operates on a 2-shift system, working 6 days a week.

The organisational structure of the unit is shown in table 20.

Table 20 : Section organisational structure

PRODUCTION		MAINTENANCE	
Shift Boss	3	Foreman (over 2 sections)	4
Miner: production	2	Artisan	6
Miner: general	1	Helpers	5
Continuous miner operator	5		
Roofbolter operator	5		
Shuttle car operator	7		
Crusher & feeder (tip) operator	2		
Belt operator	2		
General worker	4		
TOTAL	**32**		**16**

The first line supervisor of this section is one of the shift bosses, and his deputy is one of the foremen.

The financial year of the mining company stretches from July to June, and all production and cost planning are done accordingly.

The company's vision is "To be a respected mining enterprise, harnessing our talents in applying competitive technologies to excel in selected coal markets"

The company has five core values, namely:

- Integrity
- Winning with people
- Excellence in all we do
- Continuous improvement
- Customer focus

11.3 TEAM FOCUS

In July of every year the first line supervisor holds an Indaba where the whole team gets together to work through the vision, values, and process definition steps of the mining model. Following that the first line supervisor with his deputy and his line manager discusses the process management aspects.

The vision of Unit 1 is: "We achieve excellence in all we do through participation and continuous improvement."

The unit has decided that they embrace the company's five values as their foundation values, and added the following defining statements:

We as Unit 1 believe that:

- All waste is evil
- Constraints govern our decisions
- Decisions are based on facts
- We all own the unit

11.4 STRATEGIC LEVEL

Step 1 – define the process

After all the team members have affirmed their commitment to achieve the team's vision and values they have a small team building exercise. This is to ensure that no barriers exist between individuals and between operations and engineering. During this session it emerges that the one roofbolter operator have a passion for the engineering field. The first line supervisor takes a next step to discuss this with the HR department, but provisionally assigns the one foreman as the roofbolter operator's mentor.

The first line supervisor and the team have previously mapped out the activities of the unit and allocated responsibilities to it. During the Indaba they re-visit the process map to ensure that it is still valid (refer to figure 26).

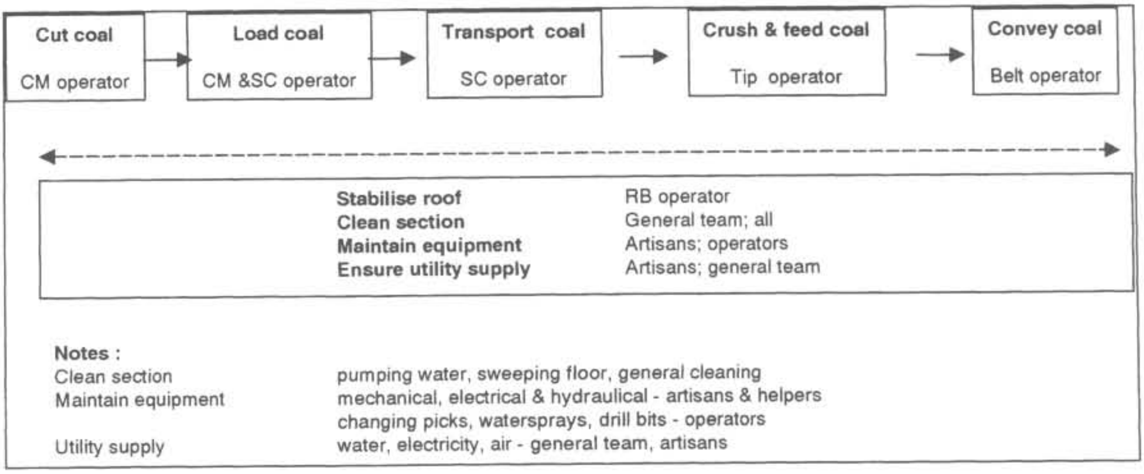


Figure 26 : Process map Unit 1

Step 2 – manage the process

After the Indaba the first line supervisor, his deputy and his line manager plan for the next year, by clearly all the process management rules for the unit as depicted in A and B below.

<u>*A: Customer requirements*</u>

- Production target — 930 000 tonnes/annum
- Production schedule — Equal tonnes per shift
  Tonnes per month according to tonnes per shift
  Increase in production before Easter and Christmas period
- Cost — R14/ton
- Quality — Reducing fine coal generation and contamination
- Unit layout and movements — According to the geological mine planning the section will experience a dyke (major dolerite intrusion) of 3 meters thick in month 7.
- Major initiatives — Implementation of an EMIS (enterprise wide management information system)
  Investigation into the implementation of an on-board roof bolting system (roofbolter and continuous miner combined)

B: Measurements

Based on the customer requirements specific measurements need to be defined. These are in the categories of quality, production and cost.

Quality KPIs

• Fine coal	<28%
• Contamination	<2%

Production KPIs

• Cutting minutes	253 minutes per shift
• Cutting tempo	7.3 tonnes/minute
• Production	Avg. 77 500 tonnes/month
	Avg. 18023 tonnes/week
	Avg. 1638 tonnes/shift

Also track the following:

• Maintenance delays	minutes per shift
• Breakdown delays	minutes per shift
• Operational delays	minutes per shift
• Geographical delays	minutes per shift

Cost KPIs

➢ CM major overhaul	R1.80/tonne
➢ SC major overhaul	R0.68/tonne
➢ Inventory	R20.05 million
	Capital cost of section (R20 million) + cost of in-section stock (R50 000)

A budget for the year for Unit 1 is drawn up, of which the summary is shown in table 21

Table 21: Budget for Unit 1 for the financial year

CATEGORY	RAND MILLION
Labour	4.48
Sundries	0.07
Operating materials	0.71
Maintenance	5.56
TOTAL	*10.82*

Step 3 – measure the process

The team will continuously measure the KPIs utilising the different tools as prescribed in the mining model. Some examples are shown in figures 27-29.

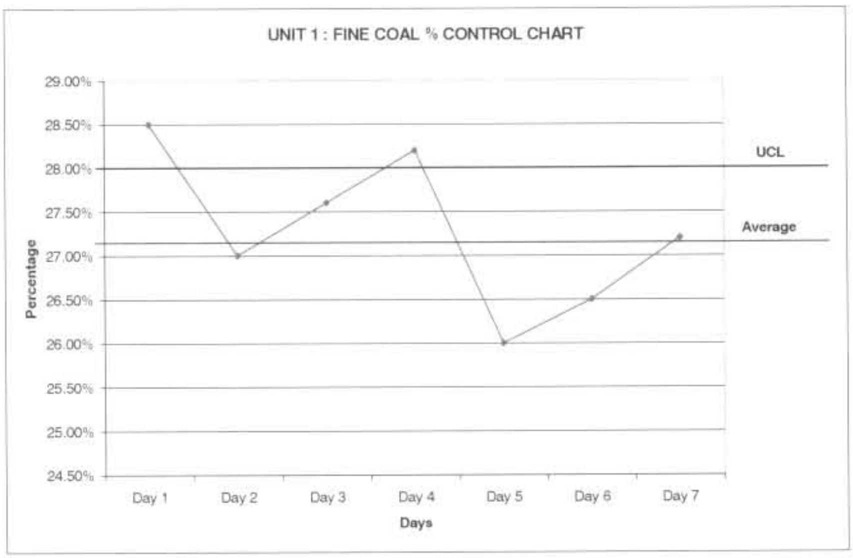


Figure 27: Fine coal % control chart

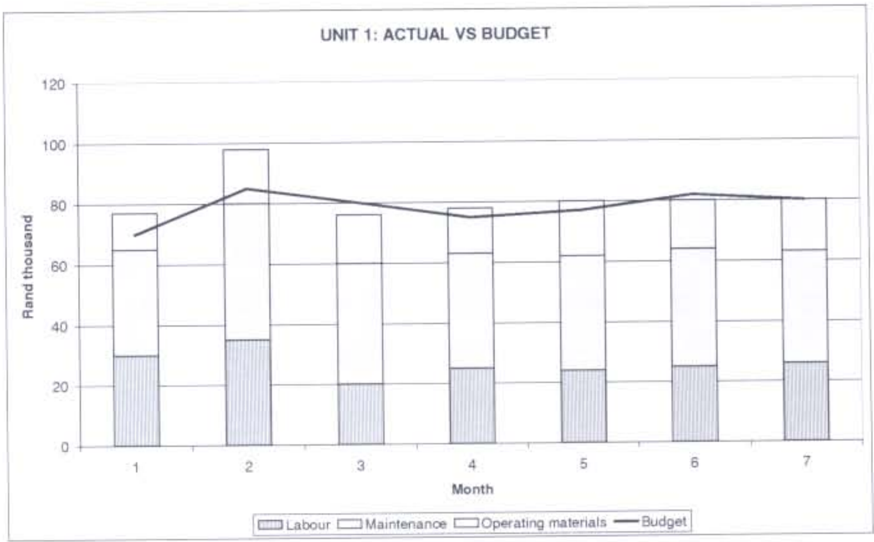


Figure 28: Actual versus budget figures

Figure 29: Production figures

Step 4 – improve the process

From the regular measurement of the KPIs deviations from target are identified. These deviations need to be corrected. To do this the step-by-step improvement process can be followed. Deviations can also be detected during the operational cycle, and the same improvement process utilised. To illustrate the improvement process a problem that is identified by to the constraint management activities will be used. Refer to step two in paragraph 11.5.

11.5 OPERATIONAL CYCLE

Due to a previous improvement project a shuttle car with a small capacity was exchanged for one with a bigger capacity. The shuttle cars were identified as being the constraints and by introducing the bigger shuttle car the total constraint capacity was increased. The first line supervisor knows that this major change could cause the constraint to shift, and therefore decides to go through the whole cycle again.

Step 1 – identify the constraint

The first line supervisor pulls various reports from the management system to determine if the introduction of the bigger shuttle car did improve throughput. Figure 30 shows the average tons per shift per machine for the production unit.

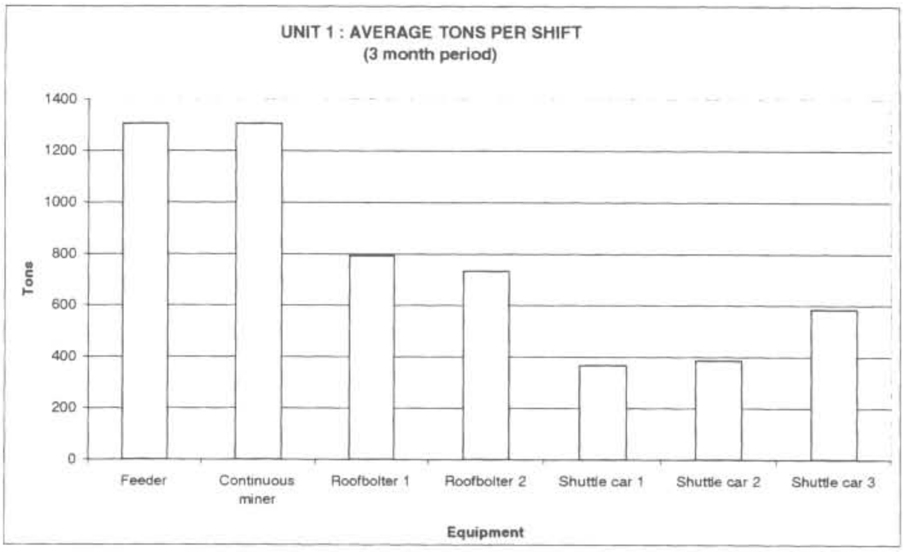


Figure 30: Average tons per shift per equipment

It is clear that shuttle car 3, the new shuttle car, is carrying more tons per shift that the other shuttle cars. The combined average tons per shift of the shuttle cars are 1336 tons, in comparison to the continuous miner's 1306 tons. Therefore the shuttle cars are no longer the constraint.

The customer requirement averages 1638 tons per shift; therefore the market demand is not the constraint. The feeder is currently operating to 65% of design capacity (avg. 2000 tons per shift) and can accommodate the shift to avg. 1638 per shift throughput without any problems. The roof bolters may be the constraint, but after careful analysis of the downtimes of the last three months (table 22) it is agreed that the 31 occurrences of waiting time for a roofbolter is not a cause for concern, or the reason for the throughput target not being met.

By method of elimination it is determined that the continuous miner is the new constraint of the unit.

Table 22: Top 15 downtimes recorded over three months

Downtime description	Occurrences	Total Duration (minutes)
Normal traveling time	144	3822
Tramming between faces	179	3807
Change picks /sleeves	190	2601
Trailing cable faulty	16	1965
Maintenance	10	1914
Wheel unit LH rear	4	1850
Inspections start of shift	96	1774
Waiting for roof support	31	1685
Crew station talks	115	1146
Tail end full of coal	8	1089
Structure	2	1065
Extension / shortening conveyor belt	12	1052
Hydraulic pipe / fitting	14	960
Water valve closed or faulty	8	925
Wheel unit RH faulty	3	904

Step 2 – exploit the constraint

The first line supervisor decides to use the process improvement cycle (paragraph 10.4.4) as a tool to generate solutions on exploiting the continuous miner. He nominates members from the team to form a quality circle with the instruction to improve the production output of the continuous miner. The next paragraphs illustrate the process improvement cycle.

<u>Clearly define the deviation.</u>

To answer the questions in this step of the improvement process the quality circle team members analyses the scatter chart of the production figures versus the cutting minutes, as well as the production over time line chart. Refer to figure 31.

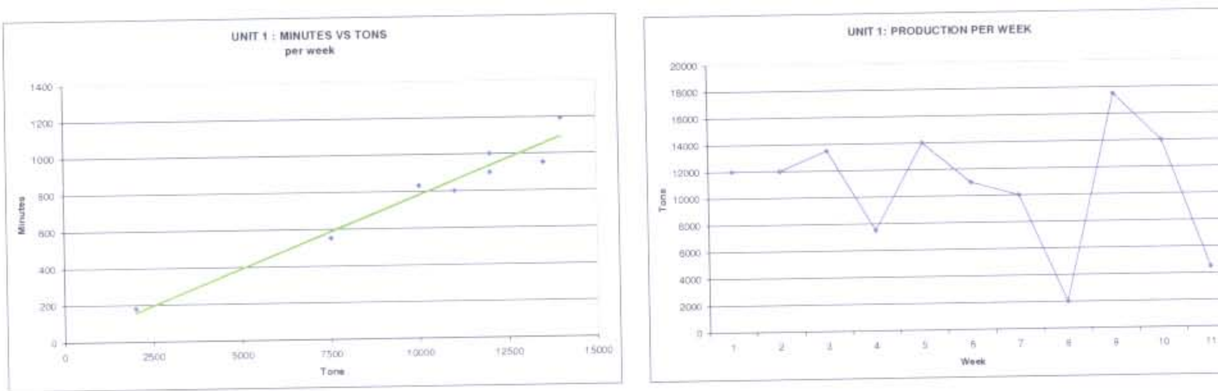


Figure 31: Analysis of production data

From the analysis the quality circle team members deduce that as soon as more than 12500 tons per week is mined the cutting minutes start to vary indicating instability in the process, and a dip in production follows soon after. To fully clarify the deviation the quality circle answers the questions as depicted in table 23:

Table 23: Summary of deviation

QUESTION	ANSWER
When did the deviation occur?	When production per week exceeds 12500 tons
Was it a once-off, or did it occur more than once?	It occurred twice in a 11-week cycle
Is there a pattern in the occurrences?	Yes, see question 1
Where did the deviation occur? What resources were involved?	At the CM. Resources are the CM operator, artisans, helpers
What were the symptoms?	Production decreased

Possible reasons for the deviation

The quality circle team members decide to utilise a fishbone diagram to determine possible causes for the deviation. Refer to figure 32.

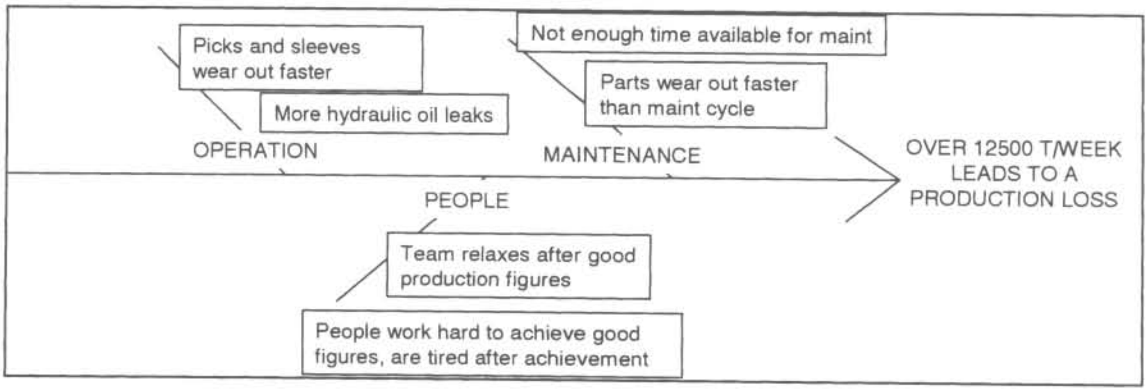


Figure 32: Fishbone diagram of possible reasons for the deviation

Test each possible reason to identify the core reason.

To determine if a possible reason is the core reason the quality team studies the downtimes of the last three months (table 22). Starting with the operational reasons they determine that the downtime for changing picks and sleeves are disproportionate to the rest of the downtime reasons. This supports the possible reason of "picks and sleeves wear out faster" as the core reason. The downtime "hydraulic /pipe fitting" do not constitute to a major downtime, and is rejected by the quality team as the possible core reason for the deviation. Next they examine the maintenance related possible reasons. To determine if the maintenance cycle is too long (parts wear out faster than the maintenance cycle) they consult with the mine engineer. He informs them that the maintenance cycle was determined together with the original manufacturer and that it conforms to the design specifications. Therefore it is not a possible cause for the deviation. The last possible reasons are all people related issues. The quality circle discusses the possible reasons with the Human Resources officer of the mine, as well as with the unit members during the regular crew station talks. Based on the feedback of these discussions they all agree that the people related issues couldn't be the reason for the deviation, as the whole unit is fully committed and motivated to achieve the production targets.

As a result of the analysis the quality circle to comes to the conclusion that with high production figures being achieved per week (more that 12500), the picks and sleeves on the cutting drum wear out considerably faster than if the production per week were less. This is due to the wear pattern on the picks and sleeves that are not linear in relation with the production output. The increase in worn out picks and sleeves led to an increase in downtime to change them, to such an extent that almost all the picks and sleeves had to be replace simultaneously. This explained the drop in production shortly after the 12500 tons/week level was reached.

Develop a solution to prevent the deviation from occurring again

The quality team knows that three alternatives exist to prevent the deviation from occurring again:

- Redesign the picks and sleeves to extend their lifetime
- Change the picks and sleeves in a shorter time
- Extend the lifetime of the picks and sleeves as currently designed.

As alternative one is a long-term activity outside their scope of expertise the quality team requests the in-house design specialists to register a project to increase the lifetime of the picks and sleeves. To find a solution for alternative two and three the quality circle decides to benchmark with other production units in their mine. From this benchmarking exercise they develop two solutions:

- Change sleeves on a preventative basis in the off-shift.
    - Picks that are in new sleeves do not wear out as easily.
    - It takes very long to change a sleeve. By changing the sleeves on a scheduled basis in non-production time it will prevent production time loss.
- Utilise a pick tray to have new picks available at the continuous miner.
    - When changing picks the pick container is fetched from the in-section storeroom, which is not close to the coal front. By having a pick tray with a certain amount of picks in it close by, the picks can be changed as soon as the continuous miner stops. The added benefit is that the helper can quickly see when the tray must be filled up (principle of poka-yoke)

Develop an implementation plan for the solution/s

To ensure that the solutions are implemented successfully the quality circle develops basic project plans to implement both the solutions. Neither of the solutions require major changes, and the solutions can be implemented within the next few shifts.

Step 3 – sub-ordinate everything else to the constraint

From the training on constraint management the first line supervisor knows that the scheduling of the whole section should be according to the drumbeat of the constraint. As the continuous miner is the first workstation in the production process, this is easy enough to manage. The first line supervisor ensures that the feeder speed is adjusted to the new throughput quantity, and also that the speed of the section conveyor belt is increased. As a lot of time is wasted when the continuous miner trams (moves) from one coal cutting area to another it is necessary that the whole team assists during this operation. The first line supervisor for that reason assigns each available team member with a specific task during the tramming process. This allows the continuous miner to start cutting again at the new cutting area with minimal time delay.

Step 4 – elevate the constraint

It is not possible to add another continuous miner to the section, as the return on capital expenditure is not high enough. It is however possible to increase the output of the continuous miner by upgrading some of the parts on it. To do this the first line supervisor together with the engineering team implements the following:

- Limit switches is installed on the continuous miner to prevent the cutting drum from cutting into the floor or roof, which would result in time going to waste by cutting stone. It also improves the quality of the product.
- More robust cutting drum gearboxes is installed on the continuous miner, to increase the turning speed of the cutting drum, thereby cutting more coal per minute.

Step 5 – re-evaluate the system

During and after all the changes have been made the supervisor constantly measures the performance of the unit to check if any other deviations occur. He also re-evaluates the system to check if the continuous miner is still the constraint, by returning to step one of the constraint management cycle.

11.6 CONCLUSION

In this chapter an actual production unit with actual results were taken and the use of the mining model illustrated. The whole process starting with the strategic cycle setting the targets for the year, and the operational cycle for the day-to-day management of the unit is demonstrated. Some of the problem solving techniques as well as the process improvement steps are shown. It is clear that the logical, easy to follow steps of the mining model enable the first line supervisor to continuously improve the performance of the unit.

12 REVIEW

The coal mining industry faces many challenges. There is increased pressure from the market for higher quality coal at lower cost and increased volume. To satisfy these requirements the mining company needs technically skilled first line supervisors who have the operational managerial skills necessary to cope with these demands. The problem is that first line supervisors possess the technical skills, but not the necessary operational management skills. Various operational management philosophies exist that provide world-class practices on how to manage in a production environment. It is unfortunately not possible to implement these philosophies as-is in a mining company due to the various differences between manufacturing and mining. The solution is to provide an operational management model adapted from these philosophies to the first line supervisor. The design of the mining operational management model is based on selected building blocks borrowed from the operational management philosophies. Implementation of the easy to use mining model is illustrated by means of real data from a coal mining production unit.

REFERENCES

ATKINSON, W. 2001. Does JIT II still work in the Internet age?. Purchasing, June 2001, vol. 130, nr. 17, p41-43.

BELLEFEUILLE, J. 1993. Total Quality Management. IEEE Spectrum, September 1993, p47-50.

BHOTE, K.R. 1997. A powerful new tool kit for the 21st century. National Productivity Review, Autumn, p29-38.

BICHENO, J. 1986. The journey. Productivity SA, October 1986, vol. 2, nr. 5, p18-23.

BLOCH, H.P. 1992. Beyond Total Quality Management. Hydrocarbon Processing, May 1992, p25.

BUSHONG, J.G., TALBOTT, J.C.,BURKE, J.F. 1999.. An application of the Theory of Constraints. CPA Journal, April 1999, vol. 69, nr. 4, p53-56.

BURKHARD. 1999. You can't spot serious shareholder value? Checkyour paradigms!. www.goldratt.com/burkhard.htm. (15/09/2003).

COOKE, F.L. 2000. Implementing TPM in plant maintenance: some organizational barriers. International journal of quality and reliability management, vol. 17, nr. 9, p1003-1016.

COOPER, M.J., LOE, T.W. 2000. Using the Theroy of Constraints' thinking processes to improve problem-solving skills in Marketing. Journal of Marketing Education, August 2000, vol. 22, nr. 2, p137-147.

COX, J., WYNDRUM, R.W.JR. 1994. IEEE Total Quality Management. IEEE Communications Magazine, October 1994, p42-45.

DE VRIES, M.E. 1987. Just-in-time. CSIR Technical Digest, no. 17, p1-27.

DEIERLEIN, B. 2000. JIT, zero tolerance for late deliveries. Fleet equipment, January 2000, vol. 26, nr. 1, p36-39.

DINESH, D & PALMER, E. 1998. Management by objectives and the balanced scorecard: will Rome fall again?. Management Decision, vo. 36, nr. 6, p363-369.

DONLIN, G.E., August 1993. In the name of throughput, Furniture Design and Manufacturing. p42-52.

DRAMAN, R.H., LOCKAMY III, A., COX III, J.F. 2002. Constraint based accounting and its impact on organisational performance : a simulation of four common business strategies. Integrated Manufacturing Systems, 2002, vol. 13, nr. 4, p190-200.

DRESNER, M. 1994. TQM : not just for manufacturing anymore. Chemtech, August 1994, p14-17

FINCH, B.J., COX, J.F. 1986. An examination of Just-in-time management for the small manufacturer: with an illustration. Int. J. Prod. Ress, vol. 24, nr. 2, p329-342.

FOGARTY, D.W., BLACKSTONE, J.H. & HOFFMAN, T.R. 1991.Production & Inventory Management, 2nd ed. Cincinnati : South-Western Publishing Co.

GEYSER, G.J. 1995. Theory of Constraints. Course material..

GITLOW, H., GITLOW, S., OPPENHEIM, A., OPPENHEIM, R. 1989. Tools and Methods for the Improvement of Quality. Illinois : Irwin.

GOLDRATT, E.M., Fox, R.E., 1986. The Race. North River Press, New York.

Goldratt, E.M., 1987. The theory of constraints journal. vol. 1, nr. 1 , Avraham Y Goldratt Institute, New Haven.

Goldratt, E.M., 1988. The theory of constraints journal. vol. 1, nr. 3 , Avraham Y Goldratt Institute, New Haven.

GOLDRATT, E.M., 1998. My saga to improve production. www.goldratt.com/saga.htm. (24/06/2000).

GOLDRATT, E.M., Cox, J., 1992. The Goal. NPI, Pretoria

HALL, R.W. 1987. Attaining Manufacturing Excellence. Illinois :DowJones-Irwin.

HOULE, D. 1998. Introduction to the Theory of Constraints. www.goldratt.com/juk4t.htm. (24/06/2000).

HUTCHINS, D. 1988. Just-in-Time. England: Gower Technical Press Ltd.

IMAI, M. 1986. Kaizen. New York : McGraw Hill Publishing Company.

JACOB, D.B. & MCCLELLAND JR., W.T. 2001. Theory of Constraints Project management. www.goldratt.com. (10/09/2003).

KEYS, D.E. 1991. Five critical barriers to successful implementation of JIT and Total Quality Control. I.E, January 1991, p22-24,61

KOBAYASHI, I. 1994. Keys to workplace improvement. USA: Productivity Press.

LINDBECK, A, & SNOWER, D,J. 2000. Multitask learning and the reorganization of work: from tayloristic to holistic organisations. Journal of Labour Economics, July 2000, vo. 18, nr. 3, p353-367.

MASTERS, R.J. 1996. Overcoming the barriers to TQM's success. Quality Progress, May 1996, vol. 29, nr. 5, p53-55.

MCBRIDE, M., HARRISON, S. & CLARK, B. 2000. Dock-to-shop is Just-in-Time. IIE Solutions, September 2000, vol.32, nr. 9, p34-38.

MCMANUS, K. 1995. Acquiring knowledge and skills for twenty-first century supervision. Management development review, vo. 8, nr. 5, p18-24.

MURPHY, T. & SHREFFLER, R. 1999. When ASAP isn't good enough. Ward's Auto World, May 1999, vol. 35, nr. 5, p67-72.

NADKARNI, R.A., 1995. Not-so-secret recipe for successful TQM. Quality Progress, vol. 28, nr. 11, p91-96.

OAKLAND, J.S., 1992. Total Quality Management. Oxford : Butterworth-Heineman Ltd.

PATRICK, F.S.. 1997. Critical scheduling and buffer mangaement. Getting out form between Parkinson's rock and Murphy's hard place. Project Management Network, April 1999,p1-8.

PERRY, B.A., WICHERT, A. 1995. Implementing Total Quality Management in an engineering environment. CIM Bulletin, February 1995, vol. 88, nr. 987, p50-53.

PRETORIUS, P.J. 2001. Personal interview. Pretoria.

RAHMAN, S. 1988. Theory of Constraints. A review of the philosophy and its applications. International Journal of Operations & Production Management,1998 , vol. 18, nr. 4, p336-355.

RAND, G.K. 2000. Critical chain : the theory of constraints applied to project management. International Journal of Project Management, 2000, vol. 18, p173-177.

SAPICS, 1994. Theory of Constraints : challenging, innovating, achieving!. Paper presented at conference.

SANDRAS, B. 1986. About face to JIT. Productivity SA, October 1986, vol. 2, nr. 5, p8-17.

SIHA, S. 1999. A classified model for applying the theory of constraints to service organisations. Managing service quality, 1999, vol. 9, nr. 4 p255-264.

SIMMONS, A. 1994. Interfacing numbers with people : lessons in quality measurement techniques. IEEE Communications Magazine, October 1994, p36-39.

SONGINI, M.L.. 2000. Just-in-Time manufacturing. Computer World, November 2000, vol34, nr. 47, p50-53.

The Antidote Issue, 1997, vol. 8, p11-14

THAYER, M. 1995. Chemical companies extend Total Quality Management boundaries. C & EN, February 1995, p15-23.

TRAHANT, W. & CAMPBELL, J. 1995. Managing change and implementing total quality in the mining industry. CIM Bulletin, January 1995. vol. 88, nr 986, p36-39.

VM SERVICES. 1992. Innovative decision thinking through value management.

WALTER, G. 1986. Just -in-time methodology: Applied to document and information processing. Journal of information and image management, July 1986, p26-29.

WHEELER III, W.A. 1986. Just in time: strategy for survival. Promat, September 1986, p5-7

WOODS, J.A. 1997 The six values of a quality culture. National Productivity Review, Spring 1997, vol. 16, nr. 2, p49-55

WOMACK, J.P., JONES, D.T. & ROOS, D. 1991. The machine that changed the world : the story of lean production, New York : First HarperPerennial.

WOMACK, J.P. & JONES, D.T. 1994. From lean production to lean enterprise. Harvard Business Review, March / April 1994, vol. 72, nr. 2, p93-104.

WOMACK, J.P. & JONES, D.T. 1996. Beyond Toyota : how to root out waste and pursue perfection. Harvard Business Review, September / October 1996, vol. 74, nr. 5, p140-151.

ZHANG, Q & CAO, M. 2002. Business process reengineering for flexibility and innovation in manufacturing. Industrial management & data systems, vo. 102, nr. 3, p146-152.

ZINELDIN, M. 1999. Exploring the common ground of total relationship management (TRM) and total quality management (TQM). Management Decision, vol. 37, nr. 9, p719-728.

ZULTNER, R.E. 1993. TQM for technical teams. Communications of the ACM, October 1993, vol. 36, nr. 10, p79-91.